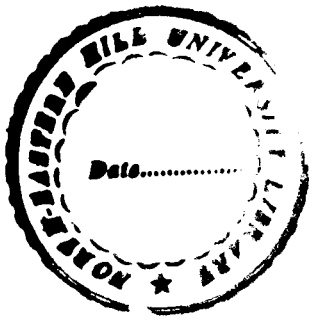
STUDIES ON SOIL MICROBIOLOGY OF GROUNDNUT (*Arachis hypogaea* L.) UNDER DIFFERENT FERTILIZER TREATMENTS

By

R. LALFAKZUALA



SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN BOTANY OF NORTH EASTERN HILL UNIVERSITY

SHILLONG

2004

Thesis

NORTH EASTERN HILL UNIVERSITY
SHILLONG

18th March, 2004

I, ***R. Lalfakzuala***, hereby, declare that the subject matter of this thesis entitled "Studies on soil microbiology of groundnut (*Arachis hypogaea* L.) under different fertilizer treatments" 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.

(R. LALFAKZUALA)

Prof. A.K. MISRA
Head
Dept. Of Botany

Dr. H. KAYANG
Supervisor

Dr. M.S. DKHAR
Joint Supervisor

Head
Department of Botany
School of Life Sciences
N.E.H.U., Shillong

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Dr. H. Kayang and Dr. (Miss) M. S. Dkhar for their untiring guidance, valuable suggestions and encouragement during the entire course of investigation.

I most sincerely express my thanks to Prof. A. K. Misra, Head, Department of Botany and other faculty members for their valuable suggestion and cooperation.

I would like to acknowledge my thanks to Dr. G. C. Munda (Principal Scientist), Dr. U. K. Hazarika (Senior Scientist), Dr. D.P. Patel (Senior Scientist), Dr. A. N. Panwar (Senior Scientist) and Mr. Fukawn, Division of Agronomy, Indian Council of Agricultural Research for NEH Region, Barapani, Shillong for their valuable cooperation and support during my field experiment.

I am also thankful to Prof. R. R. Mishra, Prof. G. D. Sharma and Prof. B. Kharbuli for their help and encouragement.

My thanks are also due to my colleagues Mr. M. Khongsai, Mr. John Zothanzama, Miss. M. Dkhar, Miss. A. P. Sooting and Miss. B. Gashnga for their help and encouragement.

I am also grateful to my friends Mr. H. Lalruatsanga (Morphology & Embryology Lab.), Mr. Lalliansanga Pachuau (Plant Physiology Lab.), Miss. Vanlalhruaii Ralte (Ecology Lab.), Mr. G. Rosangkima (Tumour Biol. Lab. Deptt. of Zoology), Mr. Lalngura (Protein Chemistry Lab. Deptt. of Biochemistry), Mr. Lalhmachhuana (Documentation Officer, NEHU), Mr. D. R. M. Buam (NEBRC) and Miss Monalisa Kharmudai (NEBRC) for their help during my research work.

My thanks are also due to the office staffs of the Department and to the library staffs, School of Life Sciences.

I would like to express my indebtedness to my beloved parents, sisters, nieces, nephews, in laws and local guardian whose best wishes, prayers and constant inspiration conferred me this distinction.

The financial assistance from North Eastern Biodiversity Research Cell (NEBRC), NEHU, Shillong, in the form of research fellowship is gratefully acknowledged.

Last, but not the least, I am very much grateful to the Almighty God for giving me strength and opportunity that enable me to complete this work.

16/3/09

(R.LALFAKZUALA)

Dedicated to

My beloved

Parents

CONTENTS

List of Figures

List of tables

List of plates

General introduction

Groundnut (*Arachis hypogaea* L.) has been accepted and considered as a vegetable oil seed crop in India during mid to late 19th century and since then occupied the first place among the oil seeds grown in the country. In the oil seed scenario of India, groundnut is the largest component, which occupies 45% of the total oil seeds area and 55% of the country's total oil seed production. In Meghalaya, groundnut was introduced during the middle of 1980's and the experimental results on production potential revealed that the crop was highly potential for its cultivation in this region (Munda *et al.*, 1997). Groundnut is grown in the region as a kharif crop and also predominantly grown as a sole crop at ICAR, Barapani, which significantly increases the total productivity. It can also be grown as intercrop in rice and maize based cropping systems under upland situations. Groundnut is usually sown in the month of May to middle of June and completes its life cycle from 115 to 120 days. Seed germination, flowering and pod formation start after 7, 30 and 60 days of sowing respectively.

Since groundnut is a leguminous crop, it can easily fix atmospheric nitrogen through its nodule present in the root system. The host legumes can enrich their immediate soil environment with rhizobia through rhizosphere effects. The extent to which this enrichment occurs, the specificity of the process and its interaction with soil management factors remain poorly described (Thies *et al.*, 1995). Several microbes present in the soil are believed to be beneficial for plant growth. Intensification of agriculture in the tropics has resulted from a shortage of farmland and insufficient food production to satisfy the needs of an expanding

population. Many tropical farmers are challenged by the prospect of intensifying their production while sustaining or improving the fertility and productivity of soils with only locally available natural resources (Beare *et al.*, 1997).

It has been now recognized that productivity of agriculture cannot be maintained solely by input of energy and fertilizer but biological components that maintain productivity also cannot be ignored any longer. Natural productivity of soil depends upon many known and unknown interactions of these components. Looking to the prospect and potential of groundnut cultivation in the region, it would be of great interest to study the microbial status from the agricultural soil with a view to know their distribution, density, ecology and their ability to colonise in the soil. Increased insight into these relationships will without doubt, contribute a better appraisal of microbial species essential component of various agro-ecosystems.

The diversity of plant communities in forests and agro-ecosystem has received a great deal of scientific attention but the microbial diversity is often ignored. Dick (1992, 1994) described that soil is a fundamental component of agro-ecosystem; it acts as a biological entity with complex biochemical reaction. Little is known of the importance of the functional diversity of soil microbial communities for the sustained functioning of terrestrial ecosystems (Beare *et al.*, 1995; Moore *et al.*, 1995; Pankhurst *et al.*, 1996). Limited information is available in the North-Eastern Region regarding the importance of microbial diversity in the functioning of soil (Pankhurst *et al.*, 1996; Giller *et al.*, 1997). However, meagre information is available on distribution of soil organic matter, nitrogen,

phosphorus, microbial populations and enzyme activities under hilly region in general (Nayak and Srivastava, 1995), while no significance attempt has been made so far to study the microbiology of agricultural soil system of the region in particular.

It is important to determine optimum diversities of soil microbial populations of both natural and agricultural systems for their sustainable management. The management of soil fertility through the manipulation of soil biological processes is central to the sustainability of both natural and managed ecosystems (Swift, 1987). Sustainability focuses on the quality of soil resources, and the relationship between its uses, management and the environment (Larson and Pierce, 1994). An understanding of soil microbial processes and community structure is essential for developing sustainable management systems (Swift, 1987; Miller, 1990). In order to maximize the beneficial effects of microbial activity, we need a greater understanding of the factors influencing microbial diversity and activity. The abundance and activities of soil microorganisms are influenced by various environmental (e.g. soil type, nutrient status, pH, moisture) as well as plant factors (e.g. species, age). Microbial growth in soil is carbon limited and therefore, the presence of organic matter has the greatest influence on microbial populations (Lynch and Whipps, 1990; Wardle, 1992).

Microbial diversity indices can function as bio-indicator to show community stability and describing the ecological dynamic of community (Atlas, 1984) and analysis of soil microbial diversity is important to evaluate the importance of perturbations on soil systems (Turco *et al.*, 1994). Microbial population can also

provide an early indication of changes in soil long before it can be measured by changes in organic matter (Powlson *et al.*, 1987). It has been generally hypothesized that reduction in soil microbial diversity will result in reduction in the functional capability of soil (Giller *et al.*, 1997). However decline in soil microbial diversity does not consistently result in reductions in the functional diversity of microbial communities (Klein *et al.*, 1986).

The knowledge of complex relationship between plant and microorganisms and also among different microorganisms is an important aspect to understand plant behavior. The diversity of soil fauna and microorganisms is influenced by vegetation, soil factors, climate and management practices (Gupta and Malik, 1996). Microorganisms perform a vital role in the soil as they are responsible for the decomposition of the organic matter and they play an important role in the transformation of various nutrients from non-available to available form. Soil microorganisms play a very important role in soil fertility not only because of their ability to carry out biochemical transformation but also due to their importance as a source and sink of mineral nutrients (Jenkinson and Ladd, 1981). 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, and decomposition of organic residues and detoxification of soil contaminants (Swift *et al.*, 1979; Miller, 1990; Hendrix *et al.*, 1990; Lavelle *et al.,* 1994). There have been studies on the distribution of microbial diversity in various environmental niches (Stolp, 1988), extremely limited work has been carried out on microbial diversity of various management practices (Wardle, 1995; Bhatti and Mulia, 1995).

A number study is available in the literature on temporal and depth wise distribution of microorganisms and their activities in forest, grassland and abandoned land soil (Tiwari and Mishra, 1995). It has been recognised that there is a wide scope of study regarding the occurrence and distribution of microbes in the rhizosphere of different crops as well as in the agriculture soil, as this may lead to better understanding of the organisms and their role in maintaining sustainability of agriculture. Moreover, their population study with respect to their ecological preference may help in employing them suitably as potent biofertilizer.

Recognition of the importance of soil microorganisms has led to increased interest in measuring the nutrients held in their biomass (Martikainen and Palojarvi, 1990). With increased study, more precise information has been gained on the influence of the microbial biomass on carbon and nutrient cycling, controlling turnover and mineralization of organic substrates (Sparling, 1985) and influencing crop productivity (McGill *et al.*, 1986). 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). Study of microbial communities and biomass in agriculture soil may give insight into the role of microbes in restoring soil fertility.

Soil life is highly diverse and consists of interacting population of microorganisms and soil fauna, whose activities influence physical, chemical and biological properties of the soil. Doran and Parkin (1994) defined soil quality as, "The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and

animal health." Determination of the optimum diversities of soil microbial populations of both natural and agricultural systems for their sustainable management is very important.

The main function of soil organism is to restore the nutrients in a form that can be used by the plants (Gupta and Malik, 1996). Cycling of elements in soils and thus, ecosystem functioning is governed largely by microbial activity, the effects of cropping systems and fertilization on the soil biota are ecological important (Kennedy and Smith, 1995). Disturbing the biological equilibria with changes in the composition and the activity in the microflora can damage soil fertility both in the short and long-term (Brookes, 1995).

Recent interest in agro ecosystem research has been focused on the introduction of sustainable management practices in agriculture, including crop rotations and fertilization systems to maintain soil quality and productivity and to minimize the negative effects of agriculture production on the environment. Agriculture is an important sector of the global economy and since it is most sensitive to and highly dependent on weather conditions, climate changes could have important repercussions on the world food supply (Rensenzweig and Parry, 1994). Agricultural soils receive nutrients in the form of organic matter, manure, chemical fertilizers and through weathering of parent rocks. Physico-chemical characteristics of agricultural soil are also determined by the type of crop and agricultural practices (Fujisaka, 1990; Lewis *et al.*, 1991). Agricultural practices particularly input of manure and cover crops could have large impacts on the size and activity of soil microbial communities (Kirchner *et al.*, 1993; Powlson *et al.*,

1987). Land used activities particularly related to agricultural and forestry can have considerable impact on the biological health of soils (Parinkina and Klyueva, 1995). Changes in soil microorganisms may have an important effect on the productivity of soil, since they influence the crop production by acting as catalyst for bio-transformations (Roder *et al.*, 1988).

Nitrogen fertilizer has indeed caused a significant increase in crop yield; it has also brought about some unfavorable result. Besides the impairment of environmental quality, this practice also caused a decline in soil productivity through excessive soil erosion, nutrient runoff and deteriorated soil chemical properties (Moldenhauer *et al.*, 1967; Kang, 1993). The addition of certain organic fertilizers causes a net immobilization of soil nitrogen (Murwira and Kirchmann, 1993). Inorganic N fertilization can have significant effect on soil microorganisms and enzymes through higher plant yields and thus, crop residues, and through its impact on soil pH depending on the amount and type of fertilizers (Tabatabai *et al.,* 1992).

An understanding of microbial processes is important for the management of farming systems, particularly those that rely on organic inputs of nutrients (Smith and Paul, 1990). It was observed that larger microbial biomass in soils receiving cover crops and manures than in the same soils receiving only mineral fertilizers (Nannipieri *et al.,* 1990; Kirchner *et al.,* 1993). Soils are inhabited by microorganisms and are responsible for breaking down of organic matter and mobilization of nutrients. In order to understand the fertility of soil, it is very important to analyse the soil microorganisms both quantitatively and qualitatively.

Field studies on different soil enzymes have been made on soils under monoculture (Das and Mishra, 1986; Dkhar and Mishra, 1987). The analysis of soil enzymes is important indicator to know the fertility levels of soils. Since enzymes carry out most of the biological processes, knowledge about enzyme activity and their variation in soil has considerable biological significance. Investigation on a limited number of enzymes shows that agriculture management practices affect their activities (Dick, 1994). Soil enzyme activity is often used as an index of microbial activity in soil as well as their fertility. Urease and phosphatase have been the most commonly studied soil enzymes along with dehydrogenase activity, which provides an index of total biological activity (Macfadyen, 1970). Enzymes catalyse all biochemical reactions and are an integral part of nutrient cycling in the soil.

Soil enzymes are believed to be primarily of microbial origin (Ladd, 1978) but also originate from plants and animals (Tabatabai, 1994). Soil enzymes have been suggested as potential indicators of soil quality because of their relationship to soil biology, ease of measurement and rapid response to changes in soil management (Dick, 1994; Dick *et al.,* 1996). Such an index would integrate chemical, physical and biological characteristics and be used to monitor the effects of soil management on long-term productivity (Doran and Parkin, 1994). The activity of soil microorganisms is strongly linked to the activity of enzymes, and soil management (including crop rotations, fertilization, tillage and crop residue placement) strongly influences the activity of soil enzymes (Miller and Dick, 1995; Deng and Tabatabai, 1996a, b, 1997; Klose *et al.*, 1999). Most of the

enzymes are added to soils by decaying microbial tissues, plant residues and animal remains.

The physico-chemical properties of soils can directly influence the structure, spatial distribution and activity of microbial population and enzymes in soils, which are potential early indicators of soil health and quality (Schnurer *et al.*, 1985; Dick, 1994). Each of the organic and microbial fractions in soil has special influence on enzyme activity (McLaren, 1975; Skujins, 1976). Soil microbial activity contributes to the regulation of soil carbon storage, soil respiration and ecosystem productivity (Bauhus *et al.,* 1998). Urease activity can suppress by long term N fertilizer application (Dick *et al.*, 1998; McCarty *et al.*, 1992). Few reports are available on the activity of enzymes in agricultural soils (Nannipieri, 1984).

Carbon storage in agricultural and forest soils has attracted attention recently due to its potential as a substantial carbon sink (Hu *et al.*, 1997). The microbial biomass is a sensitive indicator of changes resulting from agronomic practices and other perturbations of the soil ecosystem (Doran, 1987; Smith and Paul, 1990). Management practices significantly affected organic carbon C, carbohydrate contents, microbial biomass C and organic C turnover rates in agricultural soils (Hu *et al.*, 1997). Although small in mass, the microbial biomass is among the most labile pools of organic matter and thus serves as an important reservoir of plant nutrients, such as N and P (Jenkinson and Ladd, 1981; Marumoto, *et al.* 1982). The role of soil microbial biomass as a relatively labile

nutrient pool in the cycling of C, N and P is well established (Marumoto *et al.*, 1982; Van Veen *et al.*, 1987; Duxbury *et al.*, 1989; Jenkinson and Parry, 1989).

The soil microbial biomass is of importance in most ecosystems because it forms the base of the detritus food web and serves as a sink and source for most plant-available nutrients (Anderson and Domsch, 1980; Jenkinson and Ladd, 1981). This biomass thus has the potential to influence plant growth (Okano *et al.*, 1987). Studies have documented an increase in microbial biomass and activity (Mahmood, *et al.*, 1997) as well as decrease of these parameters (Burket and Dick, 1998) with increasing N fertilizer application. 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). Study of microbial communities and biomass in agriculture soil may give insight into the role of microbes in restoring soil fertility.

The microbial communities are influenced by soil moisture and temperature (Cambell and Biederbeck, 1976), physical disturbance of soil (Doran, 1987) and interaction with soil fauna (Beare *et al.,* 1992). Soil microbial activity contributes to the regulation of soil carbon storage, soil respiration and ecosystem productivity. Soil respiration provides insights into the rates of organic matter breakdown and mineralization (Dalal, 1975). Long-term cropping systems and N fertilization can influence important soil properties such as soil structure and density, soil pH, the quantity, quality, and distribution of soil organic matter and of nutrient cycles within the soil profile (Tabatabai *et al.*, 1992; Miller and Dick, 1995; Omay *et al.*, 1997; Senwo and Tabatabai, 1998).

Various agricultural management practices such as cropping system, fertilizer application, cultivation practices, soil organic amendments and pesticide application can lead to the alteration of the microbial dynamic in the agro-ecosystem (Tilak *et al.,* 1995). In agro ecosystems, human intervention may affect soil biota and therefore it has a crucial impact on system productivity and its maintenance. Therefore, the depletion of organic matter level in heavily cultivated agricultural situations could considerably affect the future productivity of some soils. Since soil microorganisms can act as an indicator to show the fertility level and quality of soil, the assessment and precise study on microbial composition, their activity and quality of soil in an agro ecosystem is necessary. By keeping these views, the research has been carried out under the following heads:

1. Diversity of soil microorganisms (fungi and bacteria) in agro-ecosystem.
2. Soil microbial biomass carbon (C_{mic}) and soil respiration in agro-ecosystem.
3. Estimation of soil enzymes (dehydrogenase, urease and phosphatase) in agro-ecosystem.
4. Physico-chemical characteristics of soil (moisture content, pH, organic carbon, N, P and K) in agro-ecosystem.
5. Performance and nutrient contents of groundnut in agro-ecosystem.

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).

Prakash and Khan (1971) observed that soil moisture was an important factors governing population of soil microflora, which are profoundly influenced by seasonal fluctuations. Hattori (1973) reported that agriculture activities of man greatly modify the distribution of soil microbes.

Jalaluddin (1975) studied the quantitative and qualitative changes in microbial population of IR-8 rice field and soils. He observed that highest numbers of fungal and bacterial colonies were found in the rhizosphere region of fertilized plots.

Many soil microorganisms are known to be intolerant to low soil moisture contents (Harris, 1981; Paul and Clark, 1989) and changes in soil moisture status can result in rapid shifts in the magnitude of soil microbial biomass (Bottner, 1985; Schnurer *et al.*, 1986).

Dkhar and Mishra (1987) observed that the microbial populations were higher in the soils of permanent agriculture as compared to that of old slash and burn type of shifting agriculture. They further reported that the soil of the valley land harboured maximum microbial populations followed by terrace land agriculture and minimum in the soil of jhum land agriculture.

Tiwari *et al.* (1989) reported that soil moisture significantly alters the microbial population, its activity and relationship between parameters.

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.

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. The soil microbial community has not been well characterized in agro-ecosystem (Wardle, 1995), particularly in conventional tillage and no-tillage.

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) hypothesised that reduction in soil microbial diversity will result in reduction in the functional capability of soil. Garland (1997) also showed 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. Beare *et al.* (1997) describe the effects of changing land-use and agricultural intensification on the structure and diversity of decomposer communities in the tropics and suggest some priorities for future research. The specific impact of soil management, seasonal conditions affect an amount of soil microbial activity as well as enzymatic activities (Batra *et al.* 1997).

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. Tiwari *et al.* (2002) stated that microbial activities in soil, despite their importance in many of the soil processes, are frequently disturbed as shown by altered soil enzyme activities as a result of agricultural exploitations and tillage practices.

Fungal population

Ghatak and Roy (1939) studied the soil fungi of paddy field and reported that microflora of cultivated soil was characteristically different from virgin soil.

Saksena (1955) did pioneer work in India on the ecological factors governing the distribution of fungi. He also observed that there is a direct correlation between fungal population and phosphate and nitrate contents of the soil. Dutta and Ghosh (1964) isolated 165 species of fungi from 22 soil samples collected at various stages of cultivation and crop growth from paddy fields of Orissa.

Latter *et al.* (1967) in their comparative study on four moorland soils in England observed that marked differences in the fungal flora was due to pH, temperature, waterlogging and oxygenation conditions in these soils. In addition they noticed that *Trichoderma* sp. and *Penicillium* sp. and unidentified white sporulating fungal species were isolated with greater frequency in summer than other seasons.

Clark and Paul (1970) estimated that fungal biomass is twice the biomass of bacteria in many soils and fungi are responsible for about 80% of the total soil respiration. Morrall (1974) found limited correlation between soil fungi and a number of edaphic and vegetational factors, which influence the soil environment.

Dedalauri (1975) pointed out that the distribution of soil fungi is determined by the combined effect of moisture, temperature and organic carbon. Wong (1975) reviewed the literature on soil fungi and concluded that distribution of soil fungi is based primarily upon various soil factors. According to him moisture and pH are most important factors.

Saprophytic soil fungi are active in decomposition of cellulose and lignin (Alexander, 1977). Upadhyay and Rai (1979) reported that *Trichoderma* was recorded very frequently and in high population from forest and some other

containing high organic matter and low pH. *Aspergillus* dominated over *Penicillia* in cultivated soils.

Tate and Terry (1980) indicated that, within the moisture ranges detected in the surface soils, increased moisture stimulated microbial activity, where as moisture ranges reach saturation, increased moisture inhibited aerobic activities and stimulated anaerobic process.

According to Widden (1981) the great amount of spatial heterogeneity in distribution of microfungi population may sometimes mask the effects of seasonal changes. Baath and Soderstrom (1982) studied the soil biomass at three sites. They found that in the organic soil layer the amount of hyphae showed seasonal periodicity at all three sites and this periodicity was correlated to the soil moisture content.

Mirchink (1988) and Christensen (1989) reported that soil fungi are main decomposers of organic matter in soils and play an essential role in the processes that form humus.

Rygiewicz and Anderson (1994) mentioned that fungi have been shown to contribute as much as 19% to total soil CO_2 evolution.

Bacterial population

Winogradsky (1925) was one of the first soil bacteriologists to systematically observe soil particles and record the types of bacterial colonies and cells found on them. Seasonal variation in bacterial numbers in several European forest soils was studied by Feher (1933). By separating particles into different size

groups by centrifugation, he was able to observe that the majority of bacteria in the soil were either large cocci or coccobacilli, some of which resembled *Azotobacter*.

Jones and Mollison (1948) showed that if bacteria were suspended in nutrient agar when making soil-agar films for counting, and then incubated for a short time, the colonies that developed could be stained and observed. It has been estimated that only 0.1 % of the soil bacteria exist in a free state in the gravitational water (Novogrudsky, 1950).

It has been stated from time to time that most of the bacteria that occur in soil are attached to soil particles and do not occur in large numbers in the soil solution (Waksman, 1952). Rouatt and Katznelson (1961) showed that, whilst *Pseudomonas* sp. was common in the rhizophere, *Arthrobacter* sp. occurred more commonly in the soil.

Allison (1973) also reported that cultivation has markedly influenced the bacterial population. Acidity significantly influences microbial abundance and it has been observed that high acidity (pH<4.2) contains the lowest population of algae, cellulolytic microbes, Nitrosomonas, Nitrobacter and denitrifiers (Ayanaba and Omayuli, 1975).

The number of bacteria found in soils is usually higher than those of other groups (Alexander, 1977) and is the principle agents for the cycling of nitrogen, sulphur and phosphorus.

Hayashi and Furusaka (1979) studied the anaerobic bacteria occurring in paddy soils and reported that *Propioni bacterium* was most dominant (34% of all isolates) isolate.

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 greater tolerance to acidity and through reduced competition from other microorganisms.

Baldensperger (1981) studied the diurnal variations of the number of colony forming bacteria and total bacteria and discussed their relationship with physico-chemical characters of the rice field soil. Lie (1981) reported that low soil pH restricts legume productivity and adversely affects the survival, growth and nitrogen fixation of rhizobia as well as legume-*Rhizobium* symbiosis.

Osa-Afiana and Alexander (1982) stated that abiotic factors greatly alter the survival of a bacterial species either promoting its decline or favouring its persistence.

Merrien *et al.* (1989) reported that in France, N_2 fixation supplied 10% to 80% of the plant N in field, with the greatest fixation occurring with low amount of soil N assimilation. In soil with high level of available N, nodule formation is decreased or even inhibited at very high N levels.

Liljeroth *et al.* (1990) stated that the total numbers of rhizosphere bacteria increased at higher nitrogen fertilization level while the numbers of N_2- fixing bacteria decreased.

The application of farmyard manure and NPK fertilizers improved population of *Azotobacter*, soil microorganisms and nodulation of soybean (Nambiar, 1994).

Thies *et al.* (1995) suggested that enrichment of soil bradyrhizobial populations was host-specific, that symbiotic legumes can enrich their soil environment with microsymbionts up to a threshold level and that such enrichment can be curtailed by soil management practices that suppress nodulation.

Kahindi *et al.* (1997) reported that among the nitrogen (N_2)-fixing bacteria, the rhizobia in symbiosis with legumes are generally the most important in agriculture, although *Frankia*, cyanobacteria and heterotrophic free-living N_2-fixers may fix significant amounts of nitrogen under specific conditions. Rhizobial populations generally increase in response to the presence of the host legume. Due to the high degree of host-specificity between legume hosts and rhizobial species, loss of a single rhizobial species can result in loss of N_2-fixation by that legume, although many legumes can be nodulated by several species of rhizobia. 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 ecosystems.

Lahav (Lavian) and Steinberger (2001) showed that sequencing bacterial functional diversity in agroecosystems would be affected by plant growing stages and human activity (agricultural practice).

Maccio *et al.* (2002) reported that optimal bacteria root attachment to excised peanut roots was dependent on pH and calcium limitation in the medium.

Fertilizer

Waksman (1922) studied the effect of chemical fertilizers on the soil microflora and he established that plot receiving commercial fertilizers, applied

separately and in combination gave higher total fungal population than controls. Waksman and Starkey (1924) reported that various chemicals fertilizers like potassium chloride, calcium phosphate, potassium nitrate, ammonium sulphate and wood ash extract exert a beneficial effect on the fungal population.

Sumner and Somers (1953) showed that a large number of microorganisms including bacteria, actinomycetes and fungi might hydrolyse urea intracellularly. Macura (1958) reported marked increase in the number of bacteria and fungi in the rhizosphere following the spraying of urea.

Broadbent *et al.* (1958) reported that when urea is added to soil it can be rapidly hydrolyzed to NH_4+ ions and CO_2 by urease enzymes in the soil, especially when the soil is warm and moist.

Kaufman and William (1964) studied the effect of mineral fertilization and soil reaction on total number and types of soil fungi. They reported that the nitrogenous fertilizers had the greatest effect on composition of the soil fungal population followed by phosphorus and potassium. Gasser (1964) reported that the hydrolysis of urea to ammonium carbonate in soil through urease activity is the main cause for the rise in pH of the soils on urea application.

Bagyaraj and Rangaswami (1967) stated the effect of fertilizers on the microflora of soil and the rhizosphere of Ragi. They also reported that ammonium sulphate increased bacteria and fungi, superphosphate increased actinomycetes while muriate of potash had little effect on soil microbial population.

Kuster and Gardiner (1968) examined the influence of fertilizers on microbial activities in soil. They reported that the addition of K_2HPO_4 increased

microbial activity, while $CaCO_3$ either singly or in combination with other fertilizers resulted in a slight decrease.

Cook (1969) had drawn attention to the growing importance of urea as a nitrogen fertilizer in world agriculture and to the need for research to reduce the problems encountered in use of these fertilizers. Bache and Heathcote (1969) and Heathcote (1970), also reported the positive effects of farmyard manures or cow dung increasing nutrient supply, pH, organic carbon and cation exchange capacity of savanna soils.

Dooley and Dickinson (1970) recorded slightly larger population of fungi in peat soils amended with high levels of ammonium sulphate in comparison to the soils where potassium concentrations were increased.

Mishra (1971) while working on the rhizosphere fungal flora of *Oryza sativa* L. grown in pots containing different doses of ammonium nitrate, urea, super phosphate and potassium sulphate, stated that rhizosphere and non-rhizosphere fungal population was always higher in fertilized soils than those of corresponding controls.

Trolldenier (1973) reported that number of bacteria in the rhizosphere depends on the chemical state of nitrogen and potassium fertilizers. With ammonium as a nitrogen source a greater number of bacteria are found than nitrate. Lloyd and sheaffe (1973) indicated that continuous application of urea for 10 years did not alter the proportion of ureolytic bacteria (24%) in field conditions.

Mishra and Das (1975) studied the effect of six different combinations of inorganic fertilizers and farmyard manure on the bacterial flora in the rhizosphere

of a transplanted paddy, at tillering, pre-flowering and grain formation stages. The bacterial population of rhizosphere in both treated and untreated soils was significantly higher than that found in corresponding non-rhizosphere soils. In rhizosphere soils there was no discernable trend in change of bacterial population at varying fertilizers levels.

Ventura and Yoshida (1977) stated that the most of the ammonia volatilization losses occurred during the first 9 days application of nitrogen fertilizers to rice soils.

Schinner *et al.* (1980) reported that compound fertilization inhibits urease activity after six weeks but activities of intracellular dehydrogenase and microbial biomass increased significantly. They also reported that addition of cupric sulphate inhibited dehydrogenase and urease activities.

Trolldenier (1981) reported that rhizosphere microorganisms are influenced directly and indirectly by fertilization. Direct effect concerns with changes in pH by limiting or nitrogen application. As the microbial population in the rhizosphere depends on decomposable organic substances released from roots, the qualitative and quantitative changes brought about in these substances by the fertilizers indirectly affects microorganisms.

Sahrawat (1982) suggested that for efficient and judicious use of fertilizer nitrogen, it is imperative to assess the nitrogen supplying power of soils. According to his results soil organic carbon and total nitrogen contents seem to be good indices of available nitrogen in tropical wetland rice soils.

Domsch (1986) indicated that in agricultural soils, ploughing, tillage, application of fertilizers and biocides and type of cultivation affect the microorganisms.

Stewart (1991) stated that the intensive cultivation, chemical fertilizer application and adverse climatic conditions influence the soil biological health and organic carbon.

Kang (1993) reported that repeated application of inorganic fertilizer nutrient also cause a decline in soil productivity through excessive soil erosion, nutrient runoff and deteriorated soil chemical properties.

However, Elliot and Lynch (1994) and Pankhurst *et al.* (1996) indicated that broad functional diversity might be additionally important in influencing the resilience of soils.

Agbenin and Goladi (1997) stated that continuous cultivation caused significant losses of C, N and P. The N+P or N+P+K fertilization could not mitigate these losses. Losses of N and P were mainly in organic forms. However, combination of farmyard manure with N+P and N+P+K fertilization enabled C, N and P to be maintained equal to, or greater than, the native site soil. It was concluded that farmyard manure applied alone, or in combination with N+P or N+P+K fertilization, was effective in maintaining soil quality under continuous cultivation in the savanna. In contrast, continuous inorganic fertilization was deleterious to soil quality because of depletion of organic matter, the reservoir of plant available N and P in weathered, tropical soils.

Katayama *et al.* (1998) reported that the applications of fertilizers are known to directly affect often the composition of the soil microbial community under plant monoculture and fallow soils (Ruppel and Makswitat, 1998). Plant species are also known to influence microbial (Grayston *et al.*, 1998) and micro-faunal (Yeates *et al.*, 1997) diversity of the rhizosphere, and microbial activity.

Bardgett and Shine (1999) reported that the microbial community in soil is indirectly affected by the changes in the plant community composition, which result from the application of fertilizers. The urease and alkaline phosphatase activities of soils increased significantly with a combination of inorganic fertilizers and organic amendments (Goyal *et al.*, 1999). Saviozzi *et al.* (1999) reported that FYM treatments showed higher amounts of TOC and N, LF-C, total and water-soluble carbohydrates, phenolic substances, CEC, specific respiration of biomass, hydrolytic and urease activities, similar amounts and characteristics of humified organic matter and lower concentrations of Cu, Zn and Cr. Both FYM and SS were inadequate treatments for the restoration of soil organic matter lost as a consequence of cultivation.

Levels of inorganic nitrogen (N), in particular nitrate N, were significantly higher in the fertilized than in the unfertilized grassland (Bardgett and McAlister, 1999).

Sarathchandra *et al.* (2001) determined the effect of fertilizer inputs on biological characteristic that may be used as indicator of soil quality.

Animal manure-P is relatively more mobile but less available for plants than inorganic fertilizer-P. Long-term application of cattle manure did not result in

excessive accumulation of P in the surface 0-30 cm soils, but promoted microbiological activities and P cycling in soil (Parham *et al.*, 2002).

Microbial biomass

Gray and William (1971) and Gray (1976) observed that the activity of much of the soil biomass is severely limited by nutrient availability and many soil organisms have very low metabolic rates or spend most of their lifetime in dormant or resting phases. Soil microbial biomass act as a pool of biologically active C, N, P and S (Jenkinson and Powlson, 1976; Jenkinson and Ladd, 1981; Brookes *et al.*, 1985) and has been widely used in investigations of nutrient dynamics and transformation in soil.

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. Relatively constant relationships between biomass C and mineral N was generally established for some African soil (Ayanaba *et al.*, 1976) and between biomass C and ATP for some Australian soil by Oades and Jenkinson (1979).

Ayanaba *et al.* (1976) and Powlson *et al.* (1987) indicated that changes in soil management cause microbial biomass to increase or decrease much faster than the total amount of soil organic matter so that microbial biomass carbon as a percentage of total organic carbon can provide a sensitive indicator of less detectable trends in total soil organic carbon loss or accumulation.

Anderson and Domsch (1980), Insam and Haselwandter (1989) and Witter (1996) reported that in managed systems, practices which favour the accumulation of organic matter in soil increase both microbial biomass and its proportion of total soil organic matter; conversely, microbial biomass declines rapidly if inputs of labile carbon to the soil are reduced.

Jenkinson and Ladd (1981) stated that microbial biomass is considered to be a transformation agent of soil organic materials and a labile reservoir of nutrients. Information on its amount, activity, and composition is essential for evaluating the function of soil ecosystems.

Jensson and Persson (1982) mentioned that the active phase of soil organic matter is intimately related to the biomass serving as the main energy source for the biomass and receiving its organic output and dying cells.

McGill *et al.* (1986) and Anderson and Domsch (1986) mentioned that microbial biomass carbon reflects the long term amount of C input into a soil.

Powlson *et al.* (1987) reported that the biomass measurement could reveal changes brought about by soil management long before such changes can be detected in total organic carbon and microbial biomass carbon as a percentage of total organic carbon can provide a sensitive indicator of less detectable trends in total soil organic carbon loss or accumulation.

Jenkinson (1988) observed that soil microbial biomass is a small but labile component of the soil organic matter. It is thought to exert a key controlling influence on the rate at which N, C and other nutrient cycle through agricultural

and other ecosystems. The importance of soil microbial biomass in the cycling of C, N and P is well documented (van Veen *et al.*, 1989).

Anderson and Domsch (1989) reported that generally, microbial biomass C comprises about 2-4% of total organic C. The soil microbial biomass constitutes a labile fraction of the soil organic matter and serves as a source and sink of plant nutrients (Singh *et al.*, 1989).

Smith and Paul (1990) reported that soil biomass has a key role in decomposition of organic matter, in the immobilization and mineralization of C, N, P and S in soil and nutrient turnover.

Singh *et al.* (1991) mentioned that recognition of the importance of soil microorganisms has led to increased interest in measuring the nutrients held in their biomass

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 (Wardle, 1992; Hassink, 1994). Gupta (1992) observed that soil texture affected the size and turnover of soil microbial biomass. In fertile soil, the soil biota may have a biomass of 20t ha^{-1} with forms ranging from microscopic bacteria to earthworms (Lee and Pankhurst, 1992).

Singh and Singh (1993), Ghoshal and Singh (1994) and Singh *et al.* (1995) mentioned that the effects of cropping systems and residue placement on the soil microbial biomass have been characterized. Stress by heavy metal toxicity and

low pH has been shown to result in a reduction in the size of soil microbial biomass (Witter *et al.*, 1993; Bardgett *et al.*, 1994).

Henrot and Robertson (1994) stated that microbial biomass could provide an index of soil fertility because it represents an important labile pool of soil nutrients and plays an important role in preventing nutrient loss from the soil.

Brookes (1995) reported that the microbial biomass, which is a small fraction of the soil's total organic matter content, is a source and sink of nutrients and controls soil organic matter mineralization. Disturbing the biological equilibrium with changes in the composition and activity of the micro-flora can damage soil fertility both in the short and long term.

Maithani (1996) revealed that values of microbial biomass could provide one of the most satisfactory estimates of the restoration of soil microbial populations. Lavahun *et al.* (1996) stated that the total microbial biomass and the ratio of bacterial to fungal biomass are affected by soil management practices such as tillage, manuring and fertilization and crop rotation.

Shibahara and Inubushi (1997) and Kampichler *et al.* (1998) stated that microbial biomass has also been found to be an early indicator of changes that could occur in soil organic matter due to a particular management system.

Soil respiration

Soil respiration may be considered as the sum total of all soil metabolic functions in which CO_2 is produced (Lundegardh, 1927). Carbon dioxide evolution has been used as an index of microbial activity of agricultural and forest soils (Julia and Pedziwik, 1985).

Rovira (1953) showed that the evolution of CO_2 from soil populations increased with increasing soil moisture contents until near saturation. At the saturation point, microbial activity was depressed by poor aeration and the reduced availability of O_2.

Gaarder (1957) found that O_2 uptake and CO_2 evolution were low when the soil moisture content was only 5-10% of the water-holding capacity, but increased rapidly with increasing moisture content. Soil organic matter content influenced the relationship between respiration and moisture content. According to Stotzky (1960) soil respiration is closely related to the other microbial parameters such as number, nitrogen transformation etc.

Macfadyen (1970) reported that 50% of the total soil respiration is contributed by the roots. CO_2 evolution has been found to be closely related to various soil characteristics viz. organic carbon content, microbial population, nitrogen transformation, litter decomposition and enzyme activities (Singh and Gupta, 1977; Orchard and Cook, 1983; Singh, 1984; Keeney *et al.*, 1985; Cropper *et al.*, 1985).

Gupta and Singh (1977) reported that most of the organic matter added to the soil in the form of litter is processed through microbial and micro faunal activity resulting in the production of CO_2 and release of nutrients. The rate of soil respiration is taken as a measure of the metabolic activity of soil.

Ross and Claims (1978) studied the influence of temperature on respiratory activity as measured by CO_2 production with soils at temperature ranges from 5 to 30° C. CO_2 production with time was similar in most of the soil. Nannipieri *et al.*

(1978) noted that CO_2 evolution and urease activity were related to bacterial and fungal biomass.

Bohn *et al.* (1979) reported that CO_2 content of soil affects the soil pH, nutrient availability, redox potential, species composition and a number of soil microbes.

Sato (1981) mentioned that the rate of CO_2 evolution correlated with the number of Gram-negative bacteria, while number of cellulose decomposing microorganisms did not. Gupta and Singh (1981) reported maximum rate of carbon dioxide evolution in the rainy summer months and lowest during the winter months.

Parker *et al.* (1983) reported that total soil respiration is an important ecosystem attribute that provides an estimate of the turnover of soil organic matter). Linn and Doran (1984) observed a greater soil respiration in 0-15 cm soil layer due to surface accumulation of organic matter.

Keeney *et al.* (1985) and Kostva and Tsilosani (1985) reported that there have been lots of reports on CO_2 evolution and microbial population in forest, grassland and agricultural soils. Das and Mishra (1986) found that the rate of CO_2 evolution is more precise index of microbial activity than that of the dehydrogenase activity.

Kursar (1989) showed that soil respiration includes microbial decomposition of litter, root exudation and dead roots as well as respiration by root symbionts.

The seasonal variations in CO_2 evolution rates from the soil showed highest rates in rainy season, moderate in summer and low during winter. Microbial activity

(measured as output of carbon dioxide from soil) was influenced by vegetation type, substrate availability and abiotic factors in grassland and forest ecosystem of Haryana (Rout and Gupta, 1989).

Turco *et al.* (1994) showed that soil metabolic activity has been assessed in a number of different ways indicating the status of the total community or some specific component of the community.

Wardle and Ghani (1995) also found that qCO_2 undoubtedly provides a useful measure of microbial efficiency. Some disturbances such as fertilization and liming can either increase or decrease qCO_2 values depending on whether the disturbance alleviates stress (reducing qCO_2) or is more extreme than the stress it alleviates (enhancing qCO_2). Franzluebbers *et al.* (1995) showed crop management practices impact soil productivity by altering the soil environment, which in turn affects microbial growth and decomposition processes that transform plant-produced C to soil organic matter (SOM) or CO_2. Mean soil CO_2 evolution was greater during the growing season than during fallow in all crops.

Silvola *et al.* (1996) mentioned that the CO_2 released in soil respiration is formed from organic matter, which differs in age and stability, ranging from soluble root exudates to more persistent plant remains.

Alvarez *et al.* (2001) reported that carbon dioxide emission from soil plays an important role in the global carbon cycle. Temperature after tillage was higher in the plowed soils than under no-tillage, being higher the soil water content in the later treatment. Plowing the soil did not produce an immediately impact on soil surface CO_2-C emission, but induced an important CO_2-C flush few days later.

Eriksen and Jensen (2001) showed diurnal variations in temperature were important for the CO_2 flux.

Nakada *et al.* (2002) reported that CO_2 flux from bare soil in agricultural field showed significant diurnal changes, and these patterns were highly correlated with the soil surface temperatures. Moreover, a negative linear relationship between soil CO_2 flux and ambient CO_2 concentration was found in diurnal fluctuations. The soil horizon above 10cm depth would be a major CO_2 source of soil respiration at about 70% in August and 40% in February. The depth of soil horizon in which soil microbial activity was significantly higher was not settled and would have a seasonal variation.

Soil enzymes

Soil is a living system where all biochemical activities proceed through enzymatic process. Ramirez-Martinez and McLaren (1966b) and Paulson and Kurtz (1969) reported that soil enzyme activity is independent of the microbial population. Most of the enzymes are added to soils by decaying microbial tissues, plant residues and animal remains.

Kiss *et al.* (1975) showed that enzymes accumulated in soil are present as free enzymes, such as exoenzymes released from cells, endoenzymes released from proliferating cells). Each of the organic and microbial fractions in soil has special influence on enzyme activity (McLaren, 1975).

Skujins (1976) reported that the enzymatic activity of a soil depends both on the abiotic factors such as extracellular enzymes, active enzymes within dead and the living microbial cell. Soil enzymes are biologically significant as they catalyse

various reactions in soil and participate in nutrient cycling (Skujins, 1976; Ladd, 1978; Dick, 1994).

Tate (1977) mentioned that soil enzymes play an important role in soil mineralization processes and have been related to other soil biological properties (Frankenberger and Dick, 1983). Several worker have studied dehydrogenase, urease and phosphatase activities in different systems under different climate, land use and soil conditions (Beri *et al.*, 1978; Baruah and Mishra, 1984a; Rao and Ghai, 1985; Tiwari *et al.*, 1989).

Numerous reports are available on the activity of enzymes in agricultural soils (Burns, 1978; Ross and Cairns, 1982; Frankenberger and Dick, 1983; Sarathchandra *et al.*, 1984; Speir *et al.*, 1984; Stott *et al.*, 1985).

Dash *et al.* (1981) reported that positive correlations between enzymes activities and organic C and N.

Tabatabai (1982) showed that cropping history, soil amendments and environmental factors have a special influence in affecting the enzyme activity in soil. Studies on the extracellular enzyme activities in ecosystem have shown that vegetation, agriculture chemicals and industrial pollutants have marked influence on soil enzymes. Like other biochemical reactions in soils, however, enzymes activities are associated with organic matter distribution profile and generally decrease with depth.

Rao and Ghai (1985) mentioned that in reclaimed alkali soils, there was marked improvement in physico-chemical properties and enzyme activities of soil under trees and grass cover for 12 years.

Rastin *et al.* (1988) showed that major biological process such as mineralization, immobilisation, nitrification, nitrate reduction etc. are the result of microbial activities and are catalysed by enzymes.

Chrost (1991) mentioned that the enzymes regenerate the inorganic nutrients from organic material and have been reported as the rate-limiting step in the cycling process. Soil temperature affects the enzyme activities indirectly through influencing microbial proliferation, and also directly, by modifying enzyme kinetics. Hydrogen ion concentration modifies the enzyme reaction site, as well as the stability of immobilized enzymes in the soil matrix. Temperature, pH and nutrient supply have been reported as some of the controlling factors of the enzymes activities in upland soils (Sinsabaugh *et al.*, 1991).

Dick (1994) reported that enzymes activities in soil catalyse various reactions necessary for decomposition of organic matter, cycling of nutrients, and formation of organic matter and soil structure. The analysis of soil enzymes could be useful to identify positive or negative effects of residue management, soil compaction, tillage, crop rotation and soil contamination during reasonable time periods.

Gupta and Malik (1996) revealed that soil metabolic activity, enzymatic activity, decomposition of litter and root and microbial biomass turnover in relation to vegetation, climate and resource quality factors have been analysed for both natural and managed systems.

Aon and Colaneri (2001) showed that enzymatic activities are candidate "sensors" of soil stress to management practice that may sensitively warn us about soil degradation.

Dehydrogenase

Lenhard (1956) first introduced the concept of estimating biological activity in soil by measuring dehydrogenase activity and he measured by using the method of reduction of 2,3,5 triphenyl tetrazolium chloride (TTC) to triphenyl formazan. Casida *et al.* (1964) detected relatively constant dehydrogenase activity regardless small fluctuations in microbial numbers.

Dehydrogenase has been widely used to measure catabolic activities in soil, which is correlated with microbial activity (Paterson, 1967; Skujins, 1976). Skujins and McLaren (1968) compared the dehydrogenase activity of geologically preserved soils with freshly collected desert and cultivated soils and detected measurable amount of dehydrogenase activity in fresh soils. The activity did not reflect the microbial numbers but was thought to reflect the rate of the overall metabolism.

Ross (1970) reported that dehydrogenase activity depends more upon the metabolic state of the microbial population of the soil than the activity of specific free enzymes acting on particular substrates.

Pancholy and Rice (1972) found that there were no significant decrease in the activities of urease and invertase after 30 days storage at 4°C; however, significant loss in dehydrogenase activity was noted after 15 to 30 days at 4°C.

Skujins (1973) reported that dehydrogenase activity did not correlate with microbial numbers and phosphatase, which showed scattered activity values throughout the profiles. The activity of dehydrogenase may act as an indicator of the microbiological redox system in soils and can be considered a good measure of microbial oxidative activity (Casida, 1977; Tabatabai, 1982).

Skujins (1978) reported that dehydrogenase activity is considered to because by a broad group of endocellular enzymes, which transfer hydrogen and electrons from substrates to appropriate acceptors during the initial stages of oxidation of organic compounds.

Smith and Pugh (1979) demonstrated that the dehydrogenase assay could provide a valid indicator of soil microbial activity.

Consuelo and Teodoro (2002) found that the Mediterranean forest soil properties (pH, K, Ca, Mg, and soil moisture) showed significant correlations with dehydrogenase activity. Izaguirre-Mayoral *et al.* (2002) indicated that in the legume species, acid phosphatase and dehydrogenase activities were significantly higher in rhizospheric than in non-rhizospheric soils.

Urease

Sumner (1962) first isolated the enzyme urease in crystalline form from bean meal. Rotini (1935) reported the presence of urease in soils and confirmed the enzymatic nature of urea decomposition in soils.

Kuprevich (1951) considered urease activity as an indicator of total biological activity and fertility of soil. Stojanovic (1959) and Vasilenko (1962) reported that urease enzyme activity is not a stable indicator of the biological

activity of the soil. They opined that the difference in the amount of urea hydrolyzed could be attributed to change in the conditions of the soil due to season.

It is well established; that soil microorganisms can produce urease and there are reports that urease activity in soils may increase on addition of organic substances that promote microbial activity (Chin and Kroontje, 1963; Moe, 1967; Balasubramanian *et al.*, 1972). Bremner and Douglas (1971) tested 100 compounds to evaluate the inhibitors of urease activity in soils. They found that dihydric phenol and thinones were the most effective organic inhibitors and silver and mercury salts were the most effective inorganic inhibitors.

Zantua and Bremner (1976, 1977) showed that soil urease increased after the addition of organic substances promoting microbial growth but subsequently decreased and eventually stabilized at the initial level.

Burns (1978, 1982) reported that urease activity would be influenced by the type and density of vegetational cover, climate and soil type.

Moller (1981) noticed that urease activity was found to correlate significantly with C/N ratio and soil pH values. They regarded the activity of urease as an indicator of the biological activity of the tested soils. Dash *et al.* (1981) could establish a positive correlation between urease activity, organic C and total N.

McNaughton *et al.* (1997) revealed that urease enzyme is a microbial product that can accumulate in cell free form in the soil because they are highly resistant to environmental degradation.

Klose and Tabatabai (2000) found that the total, intracellular, extracellular and specific urease activities in the soils were significantly affected by crop rotation, but not by N fertilization. Urea was applied at four different rates, ranging from 0 to 240 kg N ha^{-1}. The levels of fertilizer N did not affect the urease activity, soil organic matter content, and N_{biom} content (Roscoe *et al.*, 2000).

Phosphatase

Hoffman and Elias-Azar (1965) reported that the intensity of phosphatase activity in soils has been found to be related to soil physical and chemical properties, such as soil pH, contents of nitrogen, organic matter and plant available phosphorus.

Khan (1970) reported that the addition of fertilizer P increases phosphatase activity in soil. The phosphatase activity in soils mediates the release of inorganic phosphorus from organically bound phosphorus returned to soil in leaf-litter, dead root systems and other organic debris.

In soil ecosystems, phosphatase and arylsulphatase are believed to play pivotal roles in phosphorous and sulphur cycle, respectively (Speir and Ross, 1978).

Phosphatase has also been shown to vary with soil depth (Harison, 1979), Seasonal (Harison and Pearce, 1979), soil type parent material (Burangulova and Khaziev, 1965). Plants may take up some forms of organic P from soils (Islam *et al.* 1979), however most organic P must first undergo an enzymatic hydrolysis to inorganic P to become available for plants.

Garcia *et al.* (1993) indicated that phosphatase activity might be an indicator of organic matter in the composting process. Soil microorganisms and plant can utilize soil organic P by means of phosphatases (Hino, 1989; Pant *et al.*, 1994).

Kang and Freeman (1999) revealed that phosphatase enzyme mediates the release of inorganic phosphorous from organically bound phosphorous returned to soil as litter and other organic debris. The intensity of phosphatase is important as it affects the rate of phosphorous cycling. Hydrogen ion concentration is a dominant controlling factor for the phosphatase activities in soil.

Nutrients

Cambell (1978) showed that the N content of organic matter increases under cropping systems involving legumes.

Berendse *et al.* (1987b) reported that nutrients mineralized from soil organic matter are the primary source of energy for plant growth in many ecosystems.

Carbon dynamics are predictably rapid in the tropics because of high rates of decomposition and mineralization of labile soil organic matter; particularly following the conversion of tropical forest to agricultural systems (Ayanaba *et al.*, 1976; Mao *et al.*, 1992; Luizao *et al.*, 1992). Cool and humid conditions favour carbon accumulation in soil (Silvola *et al.*, 1996).

In dry land farming systems, straw and fertilizer application increased available nutrient pools of N and P and the rates of nitrogen and phosphorus mineralization also increased in wet periods (Singh and Singh, 1989).

Hendrix *et al.* (1990) and Lavelle *et al.* (1994) emphasized the importance of soil fauna in decomposition and mineralization of organic residues, formation of organic matter, nutrient cycling and soil structure. Long-term field studies are required to analyse the effects of disturbance, climate change and management practices on soil organic matter.

Only limited information is available on nitrogen mineralization and N uptake patterns of plants in various ecosystems. Patil and Sarkar (1993) studied mineralization and immobilization of nitrogen in agricultural soil amended with straw and ^{15}N-labelled urea, they found that soil N contributed more than labeled nitrogen to the inorganic N pool.

Most of the readily decomposable organic C added to soil is rapidly consumed by microorganisms (van Veen and Kulkman, 1990; Ladd *et al.*, 1995). Analysis of soil biological processes regulating soil fertility and nutrient conservation are essential for defining sustainable production systems (Gupta and Malik, 1996).

Liaghat and Prasher (1996) reported that in many soils, N deficiency is considered to be one of the major limiting factors for crop production and N fertilizer is among the most widely used and effective fertilizers. However, it is estimated that 20-60% of the fertilizer applied by farmers is lost through run-off, resulting in unacceptable levels of water pollution. This can be reduced if biologically fixed forms of N are used.

Aon and Colaneri (2001) stated that three properties among the physico-chemical ones, organic carbon (OC), total nitrogen (TN), and water-filled pore

space (WFPS), exhibited strong relationships with the enzymatic activities measured (acid and alkaline phosphatases, β-glucosidase, urese, FDA hydrolytic activity, dehydrogenase) irrespective of season and presence of crop.

Belay *et al.* (2002) opined that the levels of total N were higher in the balanced than in simple fertilizer treatments. Soil microbial biomass and numbers of bacteria, actinomycetes and fungi were influenced by, and exhibited qualitative changes in response to long-term fertilization.

Chapter-1

Study site, climate and experimental design

1.1. Location

The present investigation was carried out at an upland experimental block of Agronomy division, Indian Council of Agricultural Research (ICAR) for North Eastern Hill (NEH) region complex at Barapani Shillong; Meghalaya on Groundnut (*Arachis hypogaea* L.) cultivation in northeast India.

The geographical position of the study site is at 25^0 38' N latitude and 91^0 52' E longitudes and is situated at an altitude of 850 msl.

1.2. Soil

The soil of Meghalaya has been broadly divided into four categories viz., (1) red loamy soil, (2) lateritic soil (3) red and yellow soil and (4) alluvial soil. The soil of the experimental site is sandy loam (54.50%) with moderate permeability, silt (30.80%) and clay (14.45%). The soil pH was slightly acidic and ranged from pH 4.9 to pH 6.0.

1.3. Climate

The climate of the study area is humid and sub-tropical. The low clouds brought in by the south and west monsoon get interrupted in the southern face of Khasi hills and cause extremely heavy rainfall along the Cherapunjee range through long peninsular belt. The rain starts from middle of April and it continues till late October. In the first year, maximum rainfall was observed in the month of

July and minimum was observed in the month of April, whereas in the second year, the maximum rainfall was observed in the month of June and minimum was observed in the month of October. The maximum relative humidity and temperature was observed in the month of September and July in the first year, and in the second year it was observed in the month of July and August respectively. The minimum relative humidity and temperature was observed in the month of April both in the first and second the years (Fig. 1.2).

1.4. Experimental design

The experiment was designed to carry out the effect of fertilizers on soil microorganisms (fungi and bacteria), their activities and soil nutrients under the cultivation of groundnut. It was also designed to carry out the relationship of soil microorganisms and their activities with fertilization practice on the performance of groundnut. High yielding variety of groundnut ICGS-76 (International culture of groundnut selection-76) from International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad was sown for the present investigation.

The experimental field was divided into four blocks with three replicates, each for different treatments and levels of fertilizer. Soil samples were collected from two depths i.e. surface (0-10 cm) and subsurface (10-20 cm) soil layers. The optimum fertilizers dosage for groundnut was applied into the field as recommended by ICAR (Table 1.1). Experimental block without treatment (control) was also set up to check the effect of fertilizers on microbial activities, physico-chemical properties of soil and plant responses. The fertilizer treatments were:

Table 1.1. Types of fertilizer treatments and doses

Treatments	Source	Dose	
1. Control (CTRL)	-	-	
2. Inorganic fertilizers (N+P+K)	N=urea	20 kg/h	Recommended dose
	P=single super phosphate	60 kg/h	
	K=muriate of potash	40 kg/h	
3. Organic fertilizer (FYM)	FYM=farmyard manure (Cow dung)	10 t/h	
4. Combination of inorganic and organic fertilizers [(N+P+K) + (FYM)]	N	10 kg/h	50% of recommended
	P	30 kg/h	
	K	20 kg/h	
	FYM	5 t/h	

According to the types of fertilizer treatment, each of the experimental plots viz., control, inorganic, organic and combinations of inorganic and organic were designated as CTRL, NPK, FYM and NPK+FYM respectively.

The experimental block was set up in a slope land terrace, with a well drainage system. Each of the plots has an area of 4 X 3 sq. meters with three replicates each. Before sowing and adding fertilizers the field was properly ploughed. After the application of fertilizers, groundnut was sown in a 10 X 30 cm spacing rows by rows as recommended by ICAR (Fig. 1.3 and 1.4).

1.5. Soil sampling

Soil samples were collected randomly at monthly intervals during two crop cycles from each different treatment at two-depths (0-10 cm and 10-20 cm) from April to October in 2001and 2002 (Fig. 1.1). Soil sample collected in the month of April was considered as pre-sowing and pretreatment of fertilizer, while that collected in the month of October was considered as post harvest soil sample. Each of the replicates soil from different treatments was mixed thoroughly in sterilized plastic bags to obtain a composite sample. The samples were brought to the laboratory on the same day and kept in the refrigerator at 4^0C.

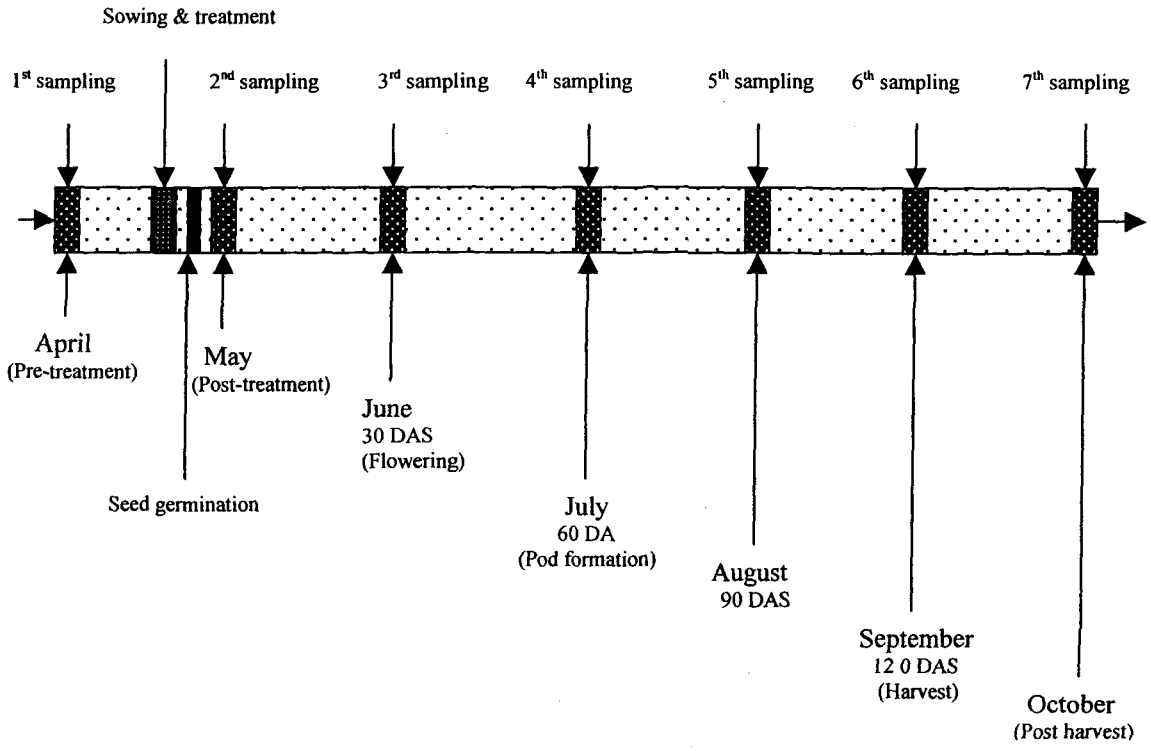


Fig. 1.1. Soil sampling period, stages of groundnut plant and period of soil treatment.

1.6. Description of groundnut

Groundnut is grown in the region as a kharif crop and also predominantly grown as a sole crop at ICAR, Barapani, which significantly increases the total productivity. In Meghalaya, groundnut can be grown successfully in terraces, but due to high rainfall and high humidity, weed pauses serious problem (Hazarika *et al.*, 2001). Groundnut is usually sown in the month of May to middle of June and completes its life cycle from 115 to 120 days. Seed germination starts after 7 days of sowing, flowering starts after 30 days and pod formation starts after 60 days of sowing (Table 1.2).

Table 1.2. Details of groundnut plant

Plant character	Description
Seed variety	ICGS-76
Crop	Kharif
Date of sowing	May to middle of June
Seed germination	7 DAS
Flowering	30 DAS
Pod formation	60 DAS
Harvest	115-120 DAS
Optimum fertilizers (NPK)	N_{20} P_{60} K_{40} kg/h

DAS=day after sowing.

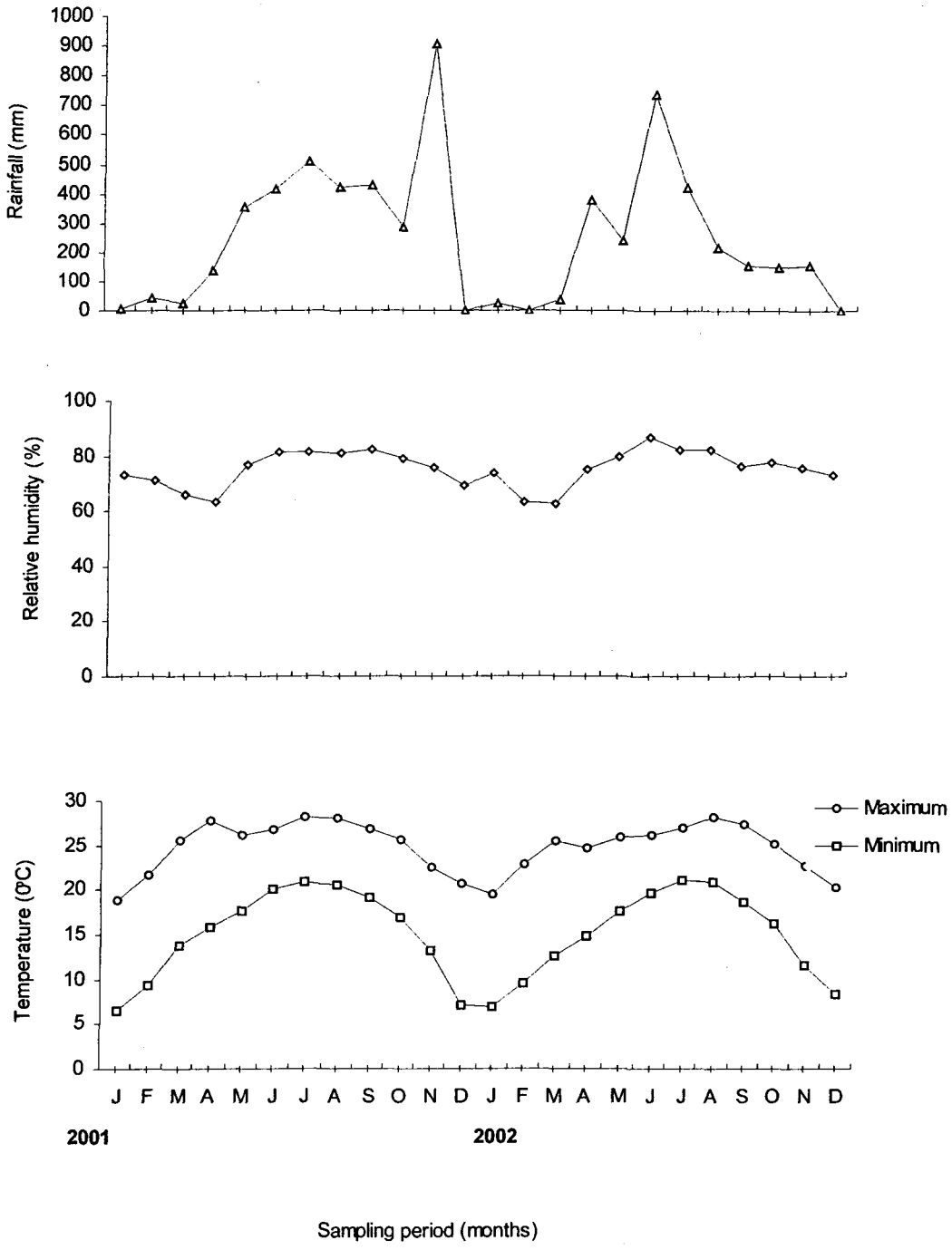


Fig. 1.2. .Rainfall, relative humidity and temperature during the period of 2001-2002.

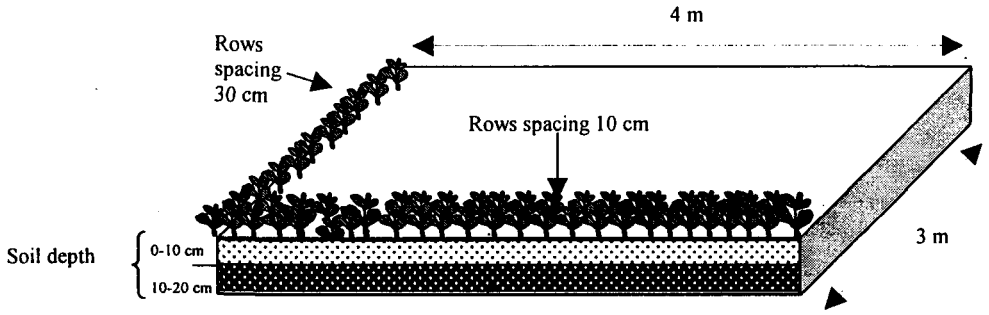


Fig.1.3. Experimental plot showing two-soil depths (0-10 cm and 10-20 cm), plot area and rows spacing of groundnut plant.

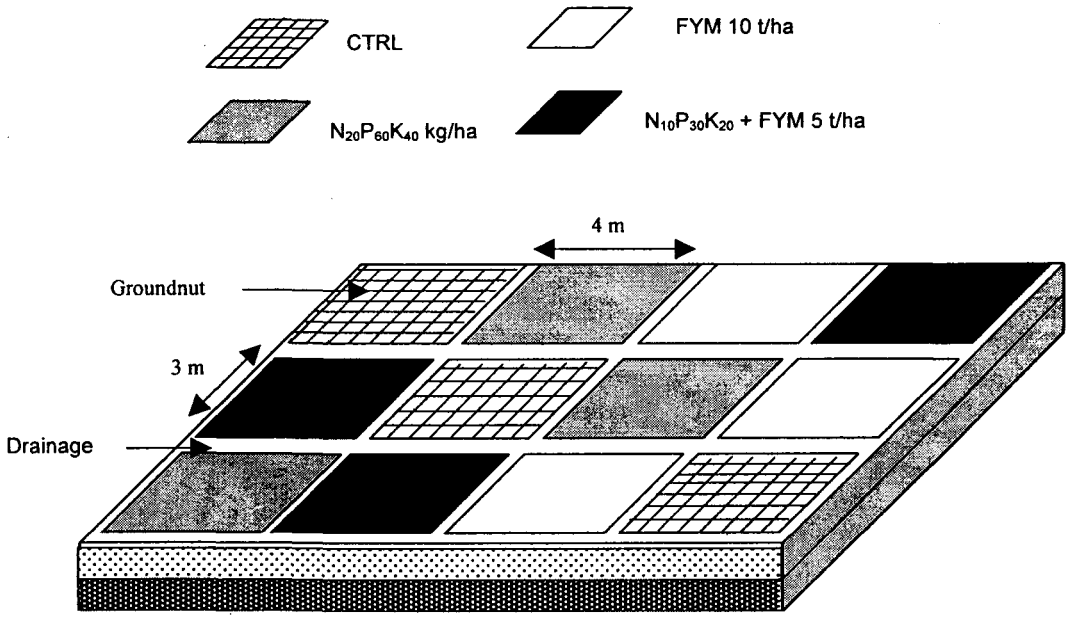


Fig.1.4. Experimental field showing different plots

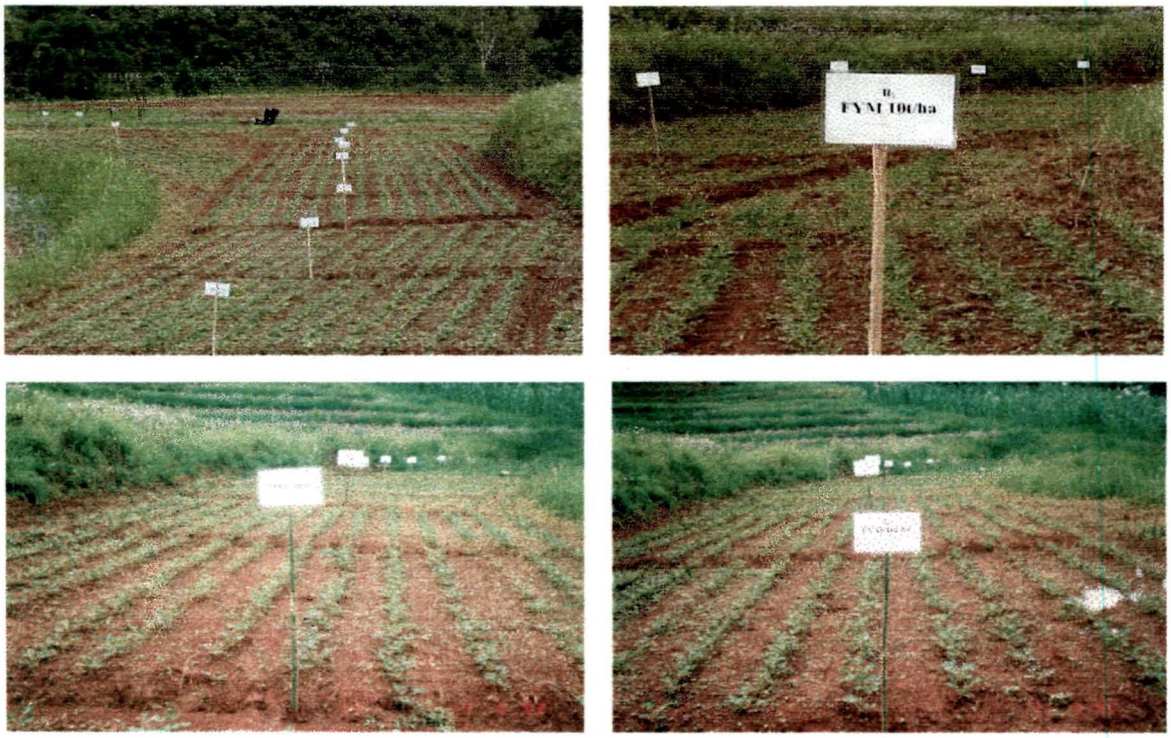


Plate 1.1. Experimental field showing groundnut plants at initial stage

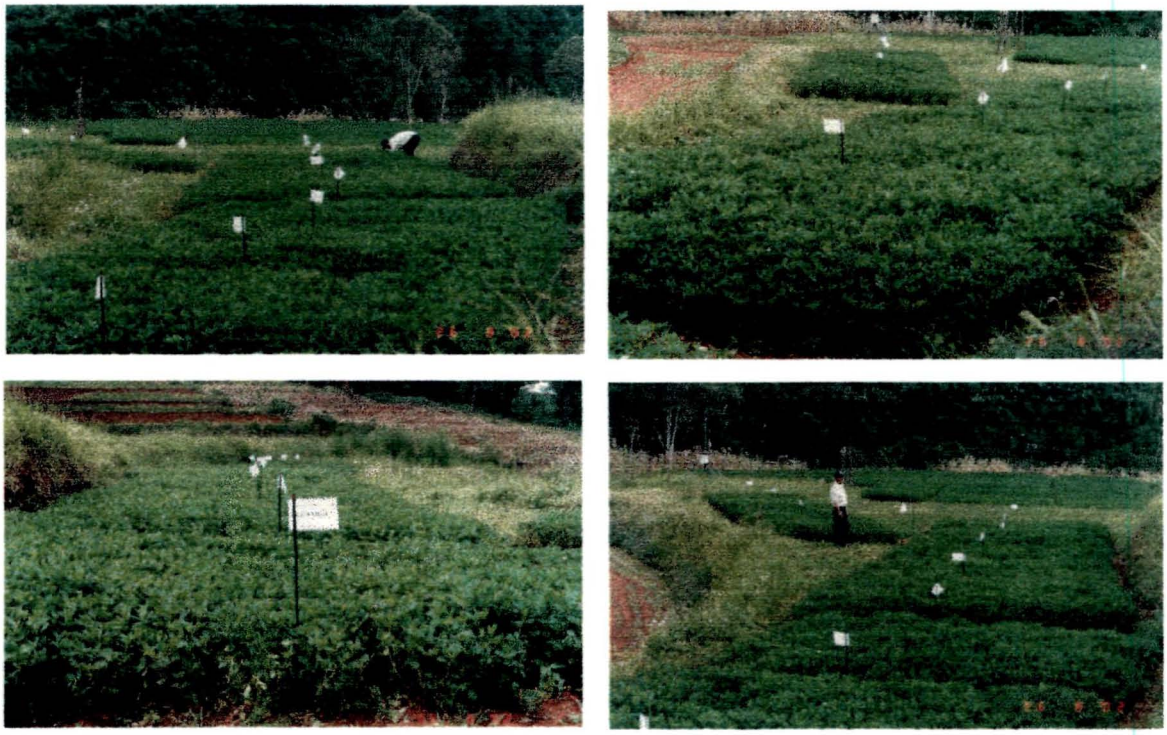


Plate 1.2. Experimental field showing groundnut plants at mature stage

Chapter-2

Diversity of soil microorganisms (fungi and bacteria) in agro-ecosystem

2.1. Introduction

Microorganisms in agricultural soils are known to exert profound influences on the soil's fertility status, in particular with respect to the availability of plant nutrients, as well as the suppression of soil borne plant diseases (Kennedy and Smith, 1995). It was also known that the soil environment can influenced the diversity of soil microbes; addition of organic or inorganic fertilizers plays a very important role for their diversity and activities. Abundant microorganisms live both within and on crop plants. They possess functional diversity-the diversity of metabolism and interspecific relationships. The selective utilization of the existing diversity of microbial species and functions provides opportunities to improve agricultural production (Shen, 1997). It is therefore, primordial to obtain a thorough understanding of how, and to what extent, the microbial diversity in soils is, or can be, affected by agricultural practices (Abawi and Widmer 2000; Mazzola, 1999; Nusslein and Tieje, 1999). It is often postulated that many healthy soils show a certain degree of resilience, i.e. they possess the capacity to return to their original status following a disturbance or stress (Van Bruggen & Semenov, 2000). In particular, disturbance of soil microbial system may not lead to great effects on soil functioning as a result of the functional redundancy present in the system (Turco *et al.*, 1994 and Kennedy and Smith, 1995). In order to understand the effects

agronomical measures on soil functioning and health, it is primordial that the key effects on soil micro biota- such as interactions, shift in community structure and activities- are elucidated.

Soil microorganisms play an important role in improving physical and chemical characteristics of soil. They carry out specific function such as biological nitrogen fixation, nitrification, denitrification, phosphate solubilization and mobilization, cellulose and lignin decomposition and production of growth promoting hormones (Tillak *et al.,* 1995). Therefore, in order to maximize the beneficial effects of microbial activity, it is necessary to understand the factors influencing microbial diversity and activity. Agriculture activities, such as tillage, intercropping, rotation, drainage, use of pesticides and fertilizers have significant implications for the microorganisms present in the soil (Hengeveld, 1996; Lovejoy, 1994; McLaughlin and Mineau, 1995; Ropper and Gupta, 1995).

Most researcher dealing with the application of fertilizers have been interested in how they influence plant performance, and, perhaps, leaching losses and soil chemistry. Few studies have examined effects on the diversity of a number of soil biological components. Fertilizers can have adverse effects on soil quality (e.g. leaching of excess nutrients such as N into the wider ecosystem). The applications of fertilizers are known to directly affect often the composition of soil microbial community under plant monoculture (Katayama *et al.*, 1998) and fallow soil (Ruppel and Makswitat, 1998).

Most microbiological characteristics did not respond to many years of fertilizer treatments suggesting that the microbial communities in the soil are similar and the fertilizer amendments are insufficient to induce changes (either direct or indirect due to plant effects) in these communities. However, the consistent decrease in functional diversity of soil microflora and nematode population with the application of N, but not P, indicates that N application has impact on community structure (Sarathchandra *et al.*, 2001).

2.2. Methodology

2.2.1. Enumeration of microbial populations

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 dilution.

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 ± 1^0 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.

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

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 Subramaniam (1917), Barnet and Hunter (1972) and Domsch *et al.* (1980). The following formula was used for the determination of relative abundance of fungal species:

$$\text{Re}lative\ abundance\ (\%) = \frac{Total\ number\ of\ the\ colonies\ of\ individual\ species}{Total\ \ number\ of\ colonies\ of\ all\ species} X100$$

Rose Bengal Agar medium (Martin, 1950)

Agar	20 g
$KH_2\ PO_4$	10 g
$MgSO_4.7H_2O$	0.5 g
Peptone	5 g
Dextrose	10 g
Rose bengal	3.3 ml
Streptomycin	30 mg
Distilled water	1000 ml

2.2.4. 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 dilution 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 ± 1^0 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.

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

Where, D_W = *Dry weight of the soil (g)*

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

$$\text{Re}lative\ abundance\ (\%) = \frac{Total\ number\ of\ the\ colonies\ of\ individual\ species}{Total\ number\ of\ colonies\ of\ all\ species} X100$$

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)

2.2.5. 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 dominance (C); (Simpson, 1949)

$$C = \sum(n_i / N)^2$$

(3) Index of similarity (Sorensen) S and Jaccard (J) (Krebs, 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

$$J = j / r X 100$$

Where, *j*=number of species found in both of two sites

r=number of species found in only one site or the other

2.3. Results

2.3.1. Fungal population

The colony form unit (CFU) of fungi increased from pre-fertilizers treatment (April) to post treatment (May) throughout the investigation. The fungal population

dropped sharply at post harvest except at subsurface soil layer. The highest fungal population was recorded in NPK treated soil throughout the investigation (Fig. 2.3.1).

In the first year at surface soil layer, the fungal population ranged from 7.27 X 10^3 to 108.15 X 10^3 CFU in FYM plot and NPK plot in the months of October and May respectively whereas, at subsurface soil layer it ranged from 0.88 X 10^3 to 41.66 X 10^3 CFU in NPK plot in the months of October and May respectively.

In second year at surface soil layer, fungal population ranged from 12.998 X 10^3 to 84.003 X 10^3 CFU in FYM and NPK plots in the month of April and August respectively whereas, at subsurface soil layer it ranged from 3.671 X 10^3 to 26.923 X 10^3 CFU in NPK plot in the month of April and May respectively.

The one-way analysis of variation (ANOVA) result showed insignificance variation ($P< 0.05$) of fungal population between treatments (Table 2.3.19). While the fungal population varied significantly ($p< 0.001$) between surface and sub-surface soil layers (Table 2.3.20).

The fungal population at surface soil layer was positively correlated with the population at subsurface soil layer (Table 2.3.21).

The correlation coefficient result also indicated that at the surface soil layer in CTRL plot, fungal population was positively correlated with ambient temperature, total nitrogen and microbial biomass carbon whereas, at subsurface soil layer the population was positively correlated with soil temperature, total nitrogen and dehydrogenase enzyme activity (Tables 2.3.22 and 2.3.23).

In NPK treated plot at surface soil layer, fungal population was positively correlated with organic carbon, microbial biomass carbon and dehydrogenase enzyme activity, whereas at subsurface soil layer, the population was positively correlated with organic carbon, total nitrogen, soil respiration and microbial biomass carbon (Tables 2.3.22 and 2.3.23).

In FYM treated plot at surface soil layer, fungal population was positively correlated with ambient temperature, total nitrogen, soil respiration and microbial biomass carbon and at subsurface soil layer; fungal population was positively correlated with dehydrogenase enzyme activity (Tables 2.3.22 and 2.3.23).

In NPK+FYM treated plot at surface soil layer, fungal population was positively correlated with ambient temperature, total nitrogen, available phosphorus and microbial biomass carbon, whereas at subsurface soil layer, the population was positively correlated with available phosphorus, soil respiration, microbial biomass carbon and dehydrogenase enzyme activity (Tables 2.3.22 and 2.3.23).

The total list of fungal species isolated during the study period from CTRL, NPK, FYM and NPK+FYM plots at surface and subsurface soil layers is shown in tables 2.3.1 - 2.3.8. Altogether 56 fungal species and 2 sterile mycelia were isolated. *Aspergillus sp., Penicillium sp.* and *Trichoderma sp.* were the dominant fungal species. *Aspergillus versicolor, Eupenicillium lapidosum, Idriella lunata* were isolated only at surface soil layer in NPK+FYM, NPK and FYM, NPK and NPK+FYM plots respectively. *Ramichloridium schulzeri, Ulocladium consortiale* were isolated only at subsurface soil layer at NPK and FYM plots (Tables 2.3.9).

Shannon index of general diversity of fungal species in the first year (2001) at surface soil layer ranged from 1.06 to 2.83 in FYM plot in the months of May and August respectively whereas, at subsurface soil layer, it ranged from 0.55 to 2.70 in FYM plot in the months of September and April respectively. In the second year (2002) at surface soil layer, it ranged from 1.35 to 2.45 in NPK+FYM and FYM plots in the month of April and August respectively whereas at subsurface soil layer, it ranged from 1.15 to 2.40 in NPK+FYM plot in the months of August and May respectively (Fig. 2.3.2).

Simpson dominance index of fungal species in the first year (2001) at surface soil layer ranged between 0.06 and 0.57 in FYM and NPK+FYM in the months of May and June respectively whereas, at subsurface soil layer, it ranged between 0.08 and 0.56 in FYM and CTRL plots in the months of April and September respectively. In the second year (2002) at surface soil layer, it ranged between 0.09 and 0.33 in NPK and NPK+FYM plots in the months of April, while at subsurface soil layer it ranged between 0.10 to 0.35 in CTRL and NPK+FYM plots in the month of September and August respectively (Fig. 2.3.3).

Sorensen and Jaccard similarity index showed a similar result throughout the study period. In first year at surface soil layer, the maximum similarity index of Sorensen (0.892) and Jaccard (0.805) were observed at paired treatments of FYM x NPK+FYM plots, whereas the least index of Sorensen (0.795) and Jaccard (0.659) were displayed at paired treatments of CTRL x NPK+FYM plots. In the second year, the maximum Sorensen index (0.905) and Jaccard index (0.826) were observed at paired treatments of NPK x FYM plots, while the minimum of Sorensen index (0.762)

and Jaccard index (0.615) were displayed at paired treatments of CTRL x FYM plots (Table 2.3.4).

At subsurface soil layer in the first year, the maximum similarity index of Sorensen (0.816) and Jaccard (0.689) were displayed at paired treatment of FYM x NPK+FYM plots and a least similarity of Sorensen (0.649) and Jaccard (0.480) were observed at paired treatment of NPK x FYM plots. In second year, the maximum similarity index of Sorensen (0.906) and Jaccard (0.829) were displayed at paired treatments of FYM x NPK+FYM plots, whereas least index of Sorensen (0.656) and Jaccard (0.488) were displayed at paired treatments of NPK x FYM plots (Table.2.3.4).

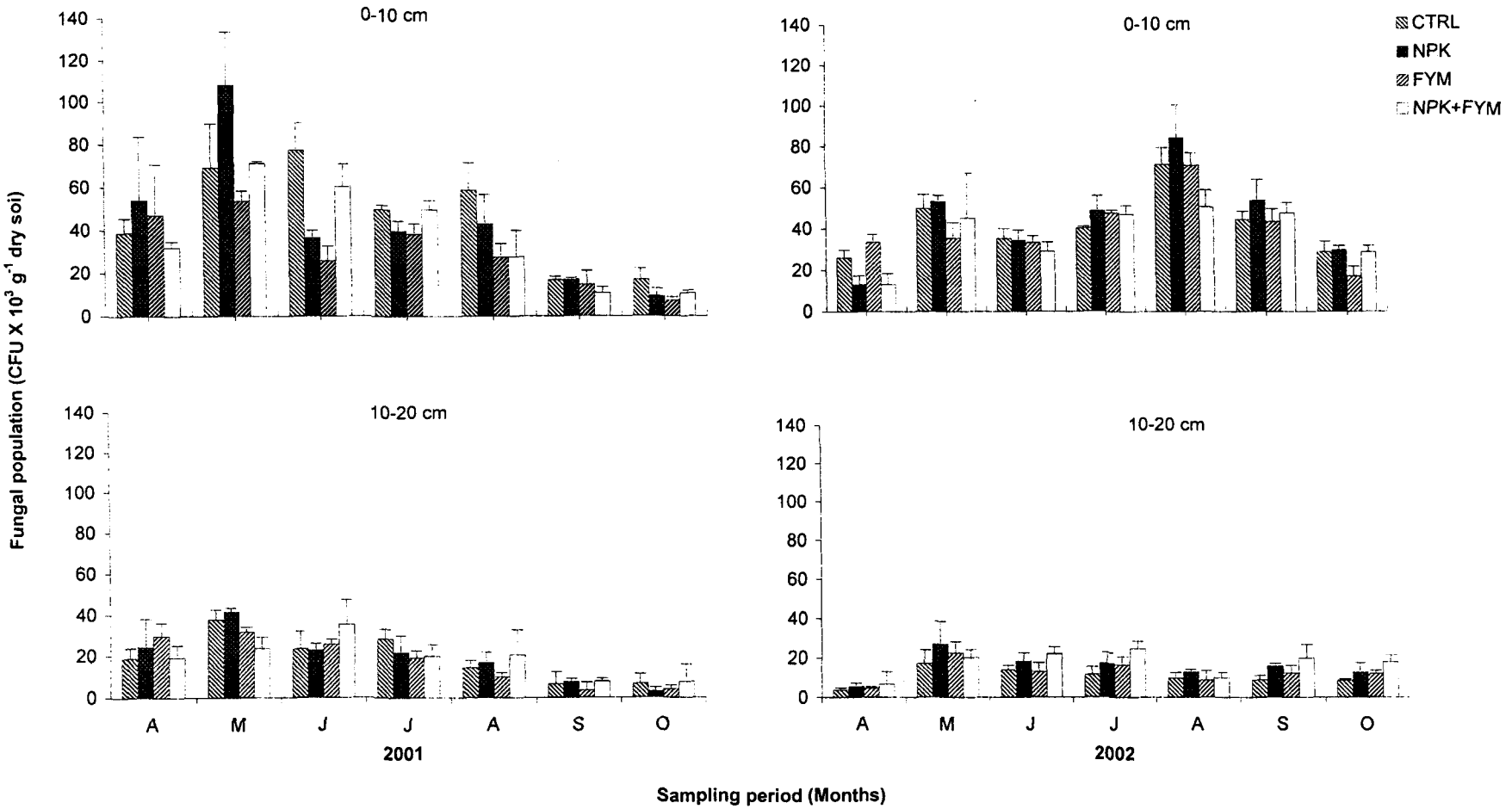


Fig. 2.3.1. Fungal population in groundnut field soil at 0-10 cm and 10-20 cm depths.

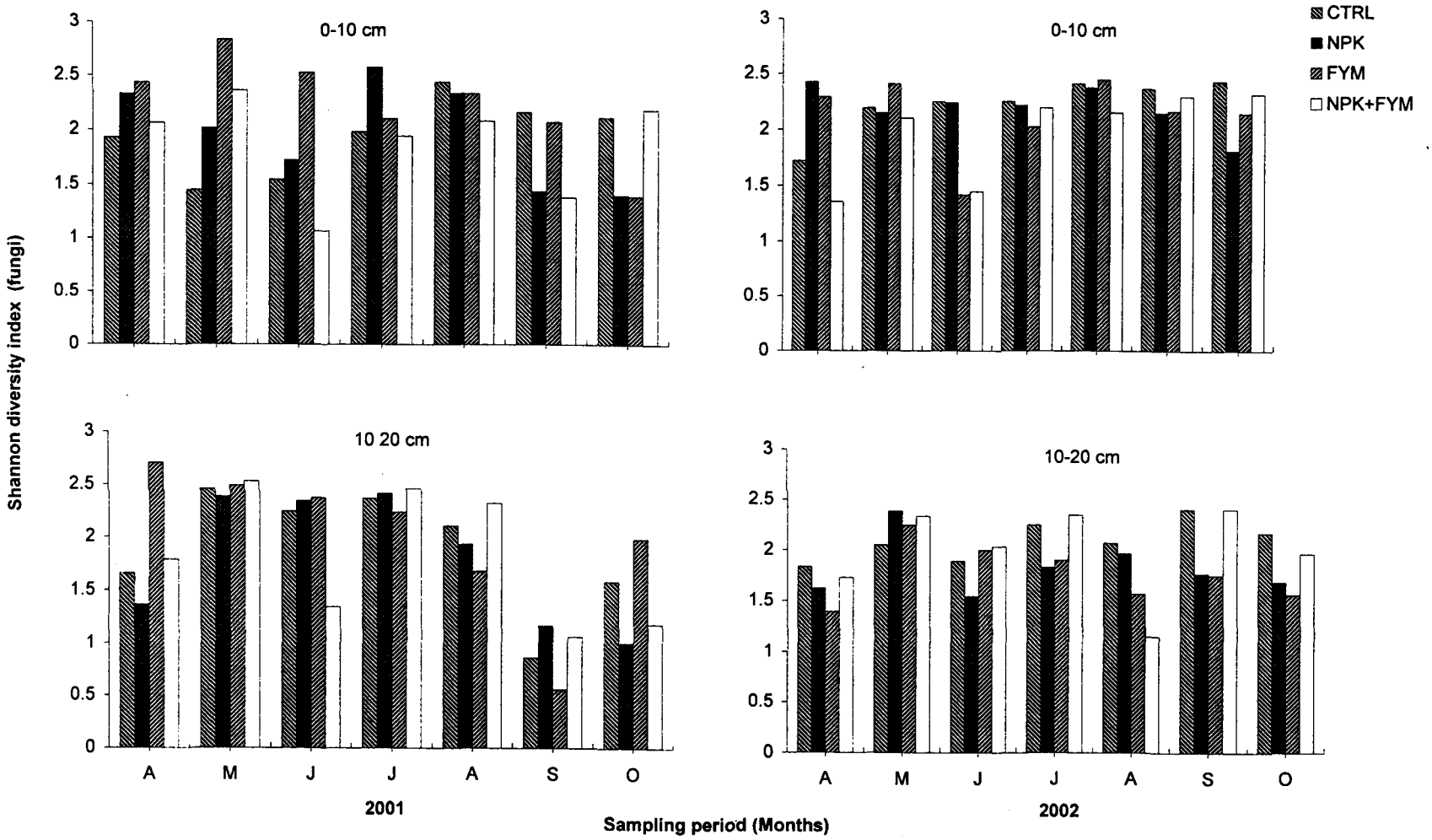


Fig. 2.3.2. Shannon diversity index of fungi in groundnut field soil at 0-10 cm and 10-20 cm depths.

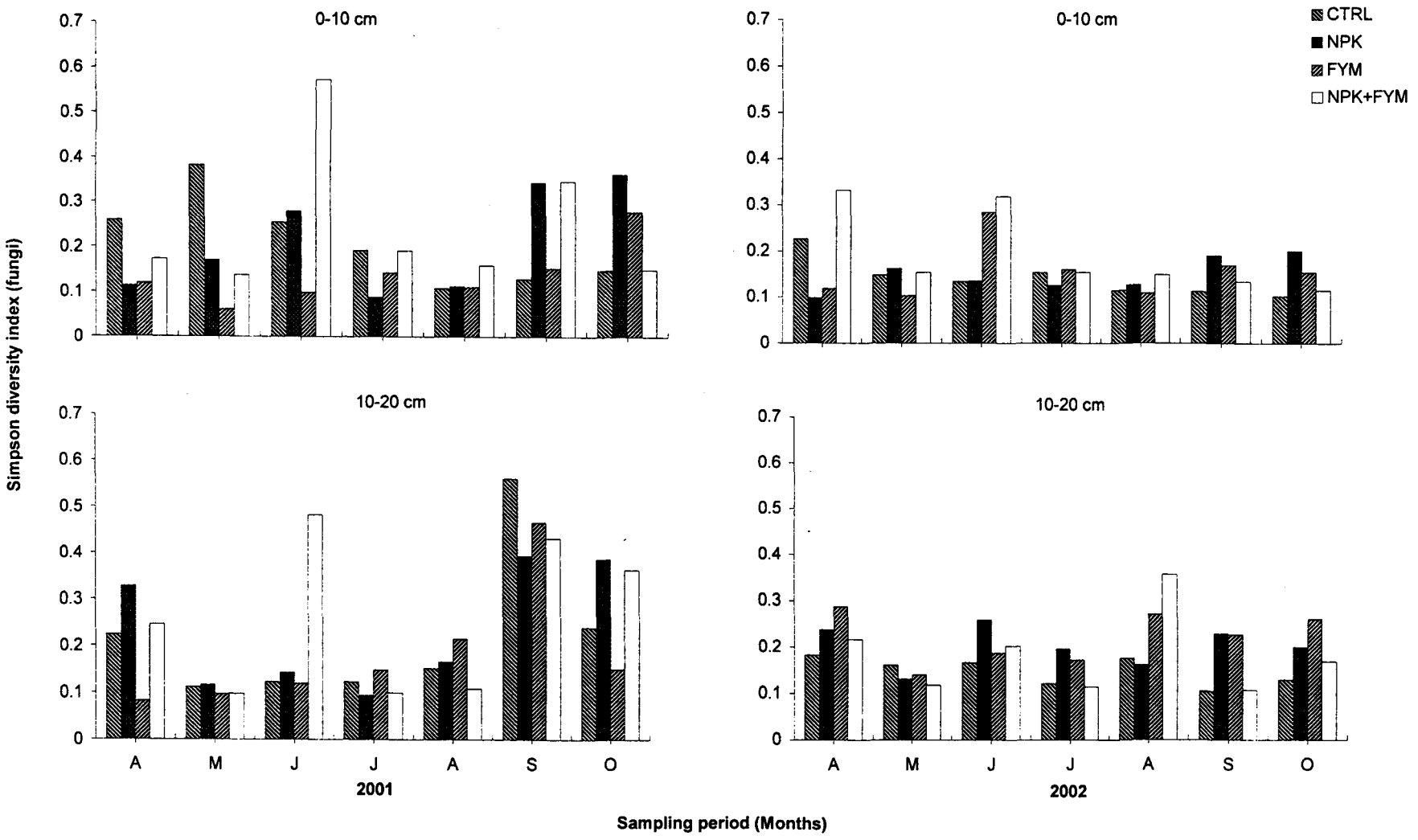


Fig. 2.3.3. Simpson diversity index of fungi in groundnut field soil at 0-10 cm and 10-20 cm depths.

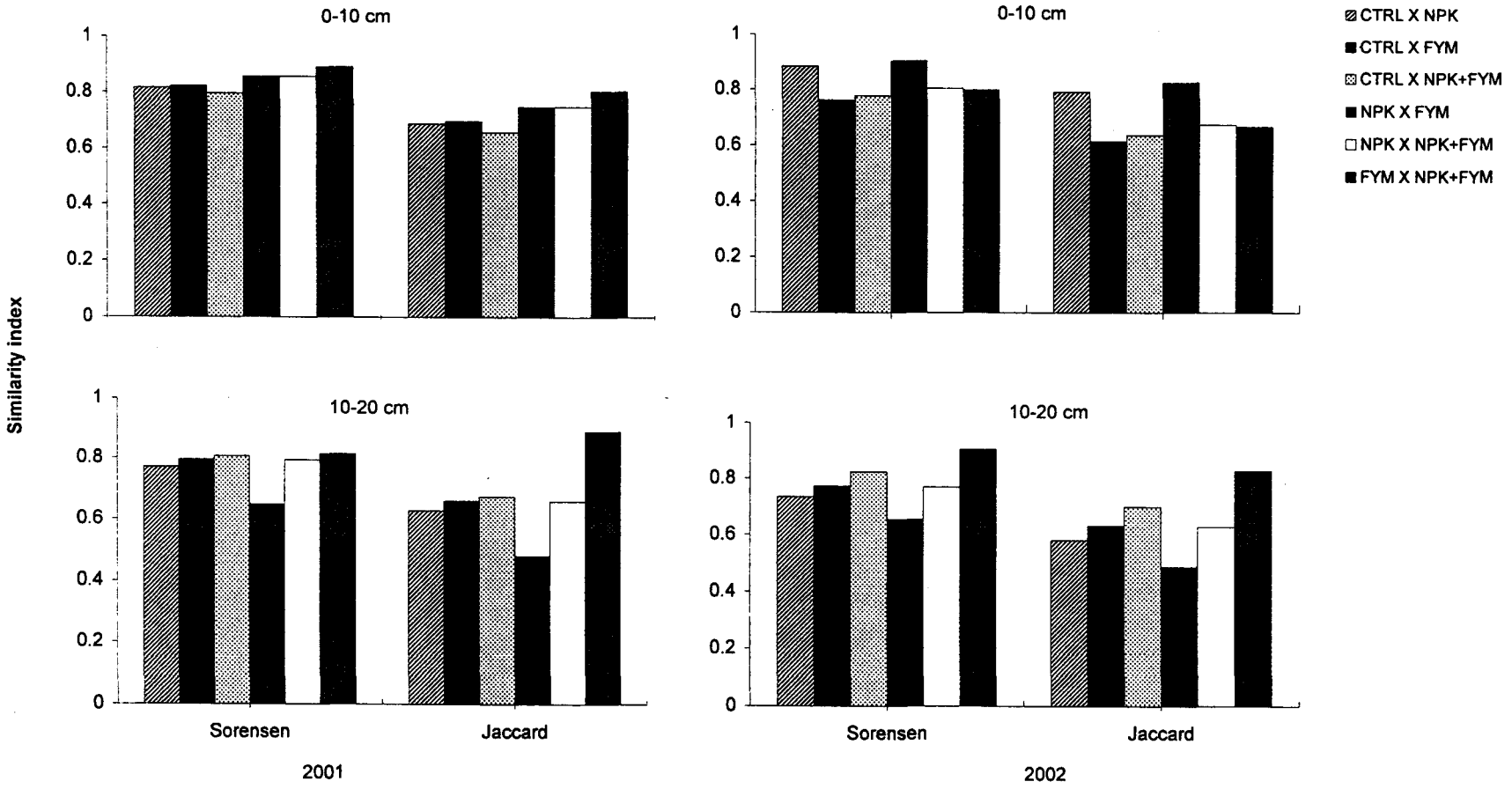


Fig. 2.3.4. Coefficient of Sorensen and Jaccard similarity index of soil fungi in paired treatment comparisons in groundnut field at 0-10 cm and 10-20 cm depths.

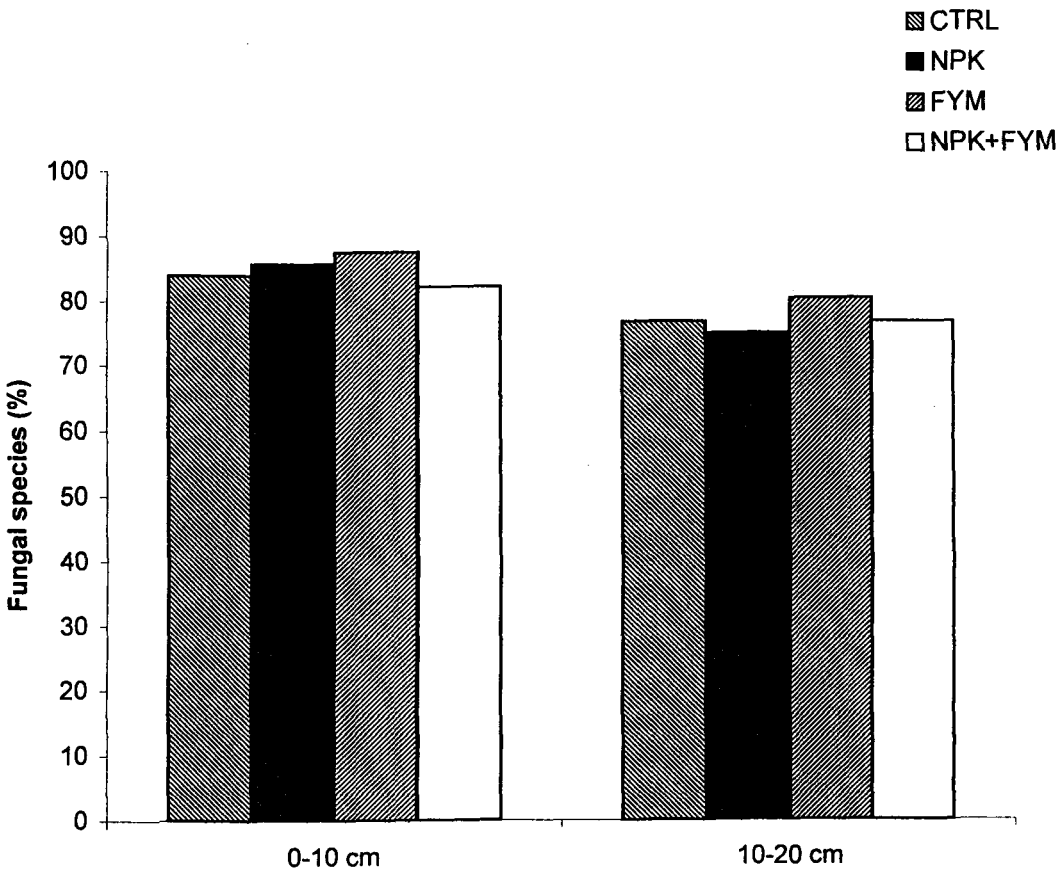


Fig. 2.3.5. Distribution of fungal species (%) in different plots at 0-10 and 10-20 cm soil depths.

Table 2.3.1. Monthly variation in the population of fungal species per gram dry soil X 10^3 in control (CTRL) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	0.476 (0.962)	-	-	-	0.422 (1.619)	-	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	-	1.295 (2.912)	2.583 (8.952)
3	*A. clavatus*	2.208 (5.693)	-	-	-	6.896 (11.792)	0.451 (2.683)	-	0.422 (1.619)	3.754 (7.562)	0.443 (1.259)	1.326 (3.295)	-	-	-
4	*A. flavus*	-	-	-	-	2.758 (4.710)	-	-	0.422 (1.619)	2.503 (5.041)	9.126 (25.929)	-	0.894 (1.256)	-	0.865 (2.999)
5	*A. niger*	-	-	25.673 (33.4)	-	-	-	-	-	-	-	-	0.453 (0.637)	-	-
6	*Aspergillus sp.*	-	-	-	-	-	-	-	-	3.754 (7.562)	-	-	-	-	-
7	*Cladosporium cladosporioides*	-	-	-	-	-	-	-	-	-	-	-	0.453 (0.637)	-	-
8	*Chaetomium globosum*	0.449 (1.159)	-	-	-	2.758 (4.716)	-	-	-	-	-	0.888 (2.208)	-	-	-
9	*Chaetomium sp.*	-	-	-	-	-	0.888 (5.288)	-	-	-	-	-	-	-	-
10	*Colletotrichum dematium*	-	-	-	-	-	-	-	-	-	-	-	12.016 (16.872)	-	-
11	*Cylindrocarpon magnusianum*	-	-	-	-	-	-	-	-	-	-	-	-	-	1.291 (4.476)
12	*C. olidum*	0.449 (1.159)	-	0.436 (0.566)	-	-	-	-	-	3.754 (7.562)	0.443 (1.259)	-	-	-	-
13	*Fusarium semitectum*	0.449 (1.159)	-	0.436 (0.566)	-	0.468 (0.803)	-	-	-	-	-	-	0.453 (0.637)	-	-
14	*F. sporotrichioides*	-	-	0.436 (0.566)	-	-	-	-	-	-	1.303 (3.703)	1.326 (3.295)	10.68 (14.998)	-	-
15	*Gongoronella butleri*	-	-	-	-	-	-	-	0.422 (1.619)	-	-	-	-	-	-

16	*Humicola fuscoatra*	2.644 (6.818)	3.099 (4.558)	0.859 (1.116)	0.393 (1.896)	2.758 (4.716)	2.656 (15.748)	-	0.422 (1.619)	2.503 (5.041)	3.05 (8.67)	1.326 (3.295)	-	-	-
17	*H. grisea*	-	-	-	-	-	-	-	-	-	3.911 (11.12)	-	-	0.440 (0.990)	-
18	*Idriella lunata*	-	-	-	-	-	-	-	-	-	-	-	-	2.59 (6.591)	-
19	*Mammaria echinobotryoides*	0.885 (2.284)	-	6.848 (8.9)	0.476 (0.962)	1.379 (2.352)	-	-	-	1.251 (2.52)	-	-	0.894 (1.256)	-	-
20	*M. vinacea*	-	-	1.285 (1.666)	-	-	-	-	-	-	-	1.326 (3.295)	-	-	-
21	*Mucor racemosus*	0.449 (1.159)	2.695 (3.896)	-	1.401 (2.830)	-	-	-	-	-	-	-	-	-	-
22	*Oidiodendron echinulatum*	0.449 (1.159)	-	-	-	-	-	0.883 (4.102)	-	-	-	-	-	-	-
23	*O. griseum*	0.449 (1.159)	-	0.436 (0.566)	0.476 (0.962)	0.468 (0.803)	-	0.883 (4.102)	-	-	-	-	-	-	-
24	*Penicillium artrovenetum*	2.208 (5.693)	-	-	-	-	2.656 (15.748)	0.883 (4.102)	-	-	3.05 (8.67)	-	4.005 (5.624)	5.183 (13.183)	0.865 (2.999)
25	*P. canescens*	-	-	0.436 (0.566)	0.476 (0.962)	-	-	-	-	-	-	-	0.453 (0.637)	-	1.291 (4.476)
26	*P. chrysogenum*	1.322 (3.401)	0.458 (0.662)	-	0.476 (0.962)	2.758 (4.716)	2.656 (15.748)	5.277 (24.39)	-	-	-	-	0.453 (0.637)	-	0.864 (2.999)
27	*P. frequentans*	0.885 (2.284)	-	-	-	-	-	-	4.999 (23.809)	-	-	-	-	3.886 (8.736)	-
28	*P. funiculosum*	0.449 (1.159)	-	-	-	-	-	0.448 (2.082)	-	-	-	1.326 (3.295)	-	-	-
29	*P. granulatum*	-	0.902 (1.305)	-	-	-	-	-	-	-	-	1.326 (3.295)	-	0.440 (0.990)	-
30	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	-	0.867 (1.951)	1.291 (4.476)
31	*P. lanosum*	1.291 (4.476)	-	-	4.207 (8.498)	-	0.451 (2.683)	-	-	-	3.911 (11.12)	-	-	-	2.583 (8.952)

32	*P. purpurogenum*	0.885 (2.284)	-	-	-	1.378 (2.362)	-	-	-	-	-	2.652 (6.591)	2.67 (3.749)	3.886 (8.736)	-
33	*P. restrictum*	-	-	-	-	-	-	-	2.484 (9.523)	-	-	-	-	0.867 (1.951)	-
34	*P. rubrum*	-	-	19.255 (25.0)	-	0.468 (0.803)	2.656 (15.748)	-	-	-	-	-	4.005 (5.624)	0.440 (0.990)	0.865 (2.999)
35	*P. waksmanii*	5.906 (15.922)	0.458 (0.662)	-	14.025 (28.3)	9.658 (16.509)	1.326 (7.892)	8.093 (12.195)	8.695 (33.4)	-	1.303 (3.703)	3.978 (9.887)	4.005 (5.624)	7.772 (17.472)	3.875 (13.428)
36	*Penicillium sp.*	-	10.781 (15.564)	-	7.012 (14.184)	2.758 (4.716)	-	-	-	-	-	13.262 (32.595)	13.351 (18.747)	-	-
37	*Phoma eupyrena*	-	4.043 (5.884)	-	-	-	-	-	-	-	1.303 (3.703)	0.888 (2.208)	-	-	-
38	*P. medicaginis*	-	0.902 (1.305)	-	-	-	-	-	0.422 (1.619)	-	0.443 (1.259)	-	-	-	-
39	*Plectosphaerella cucumerina*	-	-	-	2.341 (4.726)	0.468 (0.803)	0.451 (2.683)	0.448 (2.082)	-	15.081 (30.249)	-	2.652 (6.591)	0.894 (1.256)	3.458 (7.775)	2.583 (8.952)
40	*Pythium intermedium*	-	-	-	1.878 (3.792)	-	-	0.883 (4.102)	-	2.09 (4.209)	-	-	-	-	-
41	*Rhizopus oryzae*	-	-	-	-	-	-	-	0.422 (1.619)	1.251 (2.52)	-	-	-	-	-
42	*Staphylotrichum coccosporum*	-	-	-	0.476 (0.962)	-	-	-	-	-	-	-	-	-	-
43	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	7.772 (17.472)	-
44	*T. polysporum*	18.518 (47.619)	40.431 (58.365)	20.539 (26.7)	-	11.034 (18.867)	-	6.596 (30.487)	4.999 (23.809)	3.754 (7.562)	5.215 (14.814)	3.978 (9.887)	5.34 (7.499)	3.886 (8.776)	5.167 (17.905)
45	*T. viride*	-	2.258 (3.253)	-	14.025 (28.3)	6.896 (11.792)	-	-	-	-	1.303 (3.703)	3.978 (9.887)	0.453 (0.637)	0.440 (0.990)	0.865 (2.995)
46	*Verticillium albo-atrum*	-	-	-	0.939 (1.896)	1.379 (2.352)	2.656 (15.748)	1.319 (6.123)	-	7.509 (15.124)	0.443 (1.259)	-	2.67 (3.749)	-	-
47	*Green Sterile mycelia*	-	3.099 (4.558)	-	-	-	-	-	-	2.503 (5.041)	-	-	-	-	-
48	*White Sterile mycelia*	-	-	-	-	4.137 (7.075)	0.451 (2.683)	1.319 (6.097)	-	-	-	-	6.675 (9.373)	0.440 (0.990)	3.875 (13.428)

Table 2.3.2. Monthly variation in the population of fungal species per gram dry soil X 10^3 in $N_{20}P_{60}K_{40}$ kg/ha (NPK) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001						2002							
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	-	-	-	-	-	1.287 (3.241)	-	-	-	-	1.709 (5.741)
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	2.68 (3.191)	-	-
3	*A. clavatus*	9.102 (16.786)	5.319 (4.914)	0.426 (1.214)	-	-	-	-	1.257 (9.671)	-	1.302 (3.796)	-	-	-	-
4	*A. flavus*	-	-	-	-	6.702 (15.625)	-	-	-	1.287 (3.241)	-	-	-	-	-
5	*A. niger*	9.102 (16.786)	-	10.05 (28.571)	-	-	-	-	-	-	-	-	-	0.442 (0.822)	-
6	*Aspergillus sp.*	-	23.936 (22.113)	-	4.103 (10.344)	1.34 (3.125)	-	-	-	-	-	-	-	-	-
7	*Cladosporium cladosporioides*	-	-	-	-	-	-	-	-	-	-	-	-	-	1.275 (4.284)
8	*C. herbarium*	-	-	-	-	-	-	-	-	-	-	2.66 (5.503)	-	-	-
9	*Cladosporium sp.*	-	-	0.840 (2.392)	-	-	-	-	-	-	-	-	-	-	-
10	*Chaetomium globosum*	-	0.451 (0.418)	-	1.367 (3.448)	-	-	-	0.842 (6.479)	-	-	-	1.34 (1.595)	-	-
11	*Colletotrichum dematium*	0.442 (0.815)	-	-	-	-	-	-	-	3.861 (7.256)	-	-	1.34 (1.595)	-	-
12	*Cylindrocarpon magnusianum*	-	-	0.426 (1.214)	-	1.34 (3.125)	-	-	-	-	-	-	-	0.442 (0.822)	-
13	*C. olidum*	0.442 (0.815)	-	0.426 (1.214)	-	-	-	-	-	-	-	-	-	-	-
14	*Eupenicillium lapidosum*	-	-	-	-	-	-	-	-	-	-	-	-	19.505 (36.284)	-
15	*Fusarium semitectum*	-	0.451 (0.418)	-	0.464 (1.172)	-	-	0.450 (4.857)	-	-	-	1.33 (2.751)	1.34 (1.595)	-	-

16	*F. sporotrichioides*	-	-	-	-	-	-	0.450 (4.857)	-	-	-	-	6.702 (7.978)	-	-
17	*Gongoronella butleri*	-	-	-	-	2.68 (6.25)	-	0.450 (4.857)	-	-	-	-	-	-	-
18	*Humicola fuscoatra*	2.6 (4.796)	18.617 (17.199)	-	1.367 (3.448)	-	-	-	0.427 (3.288)	2.574 (4.837)	0.872 (2.543)	2.66 (5.503)	-	-	-
19	*Idriella lunata*	-	-	-	-	-	-	-	-	-	-	-	1.34 (7.978)	-	-
20	*Mammaria echinobotryoides*	5.025 (9.592)	-	-	1.367 (3.448)	8.042 (18.75)	-	-	-	3.861 (7.256)	-	-	5.361 (6.382)	-	-
21	*Mortierella hyalina*	-	0.451 (0.418)	-	-	-	-	-	0.842 (6.479)	-	-	-	-	-	-
22	*M. vinacea*	0.871 (1.607	-	0.426 (1.214)	-	-	-	-	-	3.861 (7.256)	-	5.33 (11.007)	-	1.300 (2.418)	-
23	*Mucor racemosus*	0.871 (1.607)	0.451 (0.418)	0.426 (1.214)	-	-	-	-	-	-	0.872 (2.543)	-	-	-	-
24	*O. griseum*	3.906 (7.194)	-	0.426 (1.214)	-	1.34 (3.125)	-	-	-	-	-	-	-	-	-
25	*Penicillium artrovenetum*	-	-	-	-	-	2.246 (13.180)	-	-	-	3.046 (8.883)	-	1.34 (1.595)	2.600 (4.837)	-
26	*P. canescens*	-	0.451 (0.418)	-	1.36 (3.448)	2.68 (6.25)	-	5.305 (57.142)	1.685 (12.959)	-	-	-	-	-	-
27	*P. chrysogenum*	0.871 (1.607)	13.297 (12.285)	0.426 (1.214)	1.367 (3.448)	-	0.457 (2.683)	-	1.257 (9.671)	-	-	1.33 (2.751)	1.34 (1.595)	0.871 (1.620)	2.551 (8.568)
28	*P. frequentans*	-	-	-	2.735 (6.896)	-	-	-	-	1.287 (3.241)	-	-	-	-	-
29	*P. funiculosum*	-	0.451 (0.418)	-	1.367 (3.448)	-	-	0.450 (4.857)	-	-	-	-	-	-	-
30	*P. granulatum*	-	0.451 (0.418)	-	-	-	-	-	-	-	0.872 (2.543)	-	6.702 (7.978)	1.300 (2.418)	-
31	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	-	-	10.204 (34.275)
32	*P. lanosum*	-	0.451 (0.418)	-	2.735 (6.896)	-	-	-	-	-	3.046 (8.883)	-	-	-	-

33	*P. purpurogenum*	-	0.890 (0.823)	-	-	-	-	0.888 (9.571)	-	-	3.046 (8.883)	-	5.361 (6.382)	1.300 (2.418)	-
34	*P. restrictum*	-	-	-	2.735 (6.896)	-	-	-	-	-	-	2.66 (5.503)	-	-	-
35	*P. rubrum*	2.6 (4.796)	-	0.426 (1.214)	-	-	1.802 (10.576)	-	-	-	-	-	1.34 (1.595)	-	3.826 (12.853)
36	*P. waksmanii*	7.802 (14.388)	11.968 (11.056)	1.255 (3.571)	4.103 (10.344)	4.021 (9.375)	-	-	2.1 (16.15)	-	3.906 (11.389)	5.33 (11.007)	2.68 (3.191)	7.901 (7.256)	6.277 (21.422)
37	*Penicillium sp.*	-	0.451 (0.418)	-	-	5.361 (12.5)	-	-	-	-	-	11.560 (23.858)	16.085 (19.147)	10.403 (19.351)	-
38	*Phoma eupyrena*	-	0.451 (0.418)	-	-	-	-	-	-	-	-	5.33 (11.007)	-	0.442 (0.822)	-
39	*P. medicaginis*	0.442 (0.815)	0.890 (0.823)	1.255 (3.571)	-	-	-	-	0.842 (6.479)	-	-	-	-	-	-
40	*Phoma sp.*	-	-	-	-	1.34 (3.125)	-	-	-	-	-	-	-	-	-
41	*Plectosphaerella cucumerina*	3.908 (7.194)	-	-	0.916 (2.310)	1.34 (3.125)	1.345 (7.892)	-	0.427 (3.288)	6.435 (12.094)	0.872 (2.543)	-	8.042 (9.575)	0.871 (1.620)	1.275 (4.284)
42	*Pythium intermedium*	-	-	-	-	-	-	-	0.427 (3.288)	-	0.872 (2.543)	-	-	0.871 (1.620)	-
43	*P. irregulare*	-	-	-	-	-	-	-	0.842 (6.479)	2.574 (4.837)	-	-	-	-	-
44	*Rhizopus oryzae*	-	0.451 (0.418)	-	2.735 (6.896)	-	-	-	-	-	-	5.33 (11.007)	-	0.871 (1.620)	-
45	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	2.600 (4.837)	-
46	*T. polysporum*	-	26.595 (24.57)	15.075 (42.857)	6.839 (17.241)	5.361 (12.5)	9.421 (55.118)	-	1.685 (12.959)	18.018 (33.865)	5.208 (15.186)	6.66 (11.007)	20.107 (23.934)	3.901 (7.256)	2.558 (8.568)
47	*T. viride*	-	1.328 (1.229)	0.426 (1.214)	-	1.34 (3.125)	0.901 (5.288)	-	0.427 (3.288)	1.287 (3.241)	1.302 (3.796)	-	-	-	-
48	*Verticillium albo-atrum*	-	-	-	-	-	0.901 (5.288)	1.326 (14.285)	-	-	9.114 (26.575)	-	-	0.442 (0.822)	-
49	*Green Sterile mycelia*	-	-	2.512 (17.241)	-	-	-	-	-	5.148 (9.675)	-	-	-	-	-
50	*White Sterile mycelia*	6.501 (11.99)	-	-	6.839 (10.344)	-	-	-	-	-	-	-	1.34 (1.595)	1.3 (2.418)	-

Table 2.3.3. Monthly variation in the population of fungal species per gram dry soil X 10^3 in farmyard manure 10 t/ha (FYM) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001						2002							
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	-	-	0.911 (6.279)	-	-	2.59 (7.315)	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	3.978 (5.624)	0.899 (2.071)	-
3	*A. clavatus*	9.247 (19.607)	1.338 (3.4)	1.324 (5.154)	-	2.739 (10.0)	-	-	7.635 (22.779)	1.735 (4.901)	-	-	-	-	-
4	*A. flavus*	-	-	-	-	-	-	-	1.272 (3.796)	1.295 (3.657)	-	-	-	-	-
5	*A. niger*	-	1.338 (3.4)	-	-	-	0.462 (3.186)	-	-	-	-	0.911 (1.914)	-	-	-
6	*Aspergillus sp.*	-	-	-	-	-	-	2.728 (37.037)	-	-	-	-	-	-	-
7	*Cladosporium cladosporioides*	-	-	-	-	-	-	-	-	-	-	-	-	-	0.432 (2.548)
8	*C. herbarium*	-	-	-	-	-	-	-	-	-	-	6.802 (14.285)	-	-	-
9	*Cladosporium sp.*	-	-	0.450 (1.758)	-	-	-	-	2.544 (7.593)	-	-	-	-	-	-
10	*Chaetomium globosum*	1.321 (2.801)	-	-	-	1.369 (5.0)	-	-	-	-	-	-	1.326 (1.874)	-	-
11	*Colletotrichum dematium*	-	-	-	-	0.465 (1.700)	1.361 (9.372)	-	-	-	-	-	1.326 (1.874)	0.899 (2.071)	-
12	*Cylindrocarpon magnusianum*	0.885 (1.878)	1.338 (3.4)	-	-	-	-	-	-	-	-	-	-	-	-
13	*C. olidum*	-	2.679 (6.7)	-	-	-	-	-	-	-	-	-	-	-	-
14	*Eupenicillium lapidosum*	-	-	-	-	-	-	-	-	-	-	-	-	1.342 (3.092)	-
15	*Fusarium semitectum*	0.449 (0.953)	2.679 (6.7)	0.450 (1.758)	-	-	-	-	-	-	-	-	-	-	-

16	*F. sporotrichioides*	-	-	-	-	-	-	-	-	-	-	-	10.61 (14.998)	-	-
17	*Humicola fuscoatra*	-	1.338 (3.333)	1.324 (5.154)	1.41 (4.901)	2.739 (10.0)	-	-	-	-	-	-	1.326 (1.874)	-	-
18	*H. grisea*	-	-	-	-	-	-	-	3.816 (11.389)	-	0.443 (1.341)	-	-	-	-
19	*Mammaria echinobotryoides*	3.963 (8.403)	1.338 (3.4)	2.648 (10.309)	-	0.465 (1.700)	-	-	1.272 (3.796)	-	-	2.721 (5.714)	-	-	-
20	*Mortierella hyalina*	-	-	-	-	-	-	-	-	1.735 (4.901)	1.305 (3.946)	-	-	-	-
21	*M. vinacea*	-	1.338 (3.4)	1.324 (5.154)	-	-	-	-	-	3.886 (10.972)	-	0.462 (0.971)	-	-	-
22	*Mucor racemosus*	0.449 (0.953)	1.338 (3.4)	0.450 (1.7580	-	-	-	-	-	-	-	-	-	-	-
23	*Oidiodendron echinulatum*	-	2.677 (6.7)	0.450 (1.758)	-	-	-	-	-	-	-	-	-	-	-
24	*O. griseum*	0.885 (1.878)	1.338 (3.4)	1.324 (5.173)	-	-	-	-	-	-	-	-	-	-	-
25	*Penicillium artrovenetum*	0.885 (1.878)	-	-	-	-	0.462 (6.279)	-	-	-	-	6.802 (14.288)	1.326 (1.874)	5.368 (12.368)	-
26	*P. canescens*	3.963 (8.403)	-	1.324 (5.173)	-	0.465 (1.700)	-	-	-	-	-	0.462 (0.971)	-	-	0.432 (2.548)
27	*P. chrysogenum*	-	2.677 (6.7)	-	2.82 (9.803)	0.465 (1.700)	1.362 (9.345)	-	3.816 (11.389)	2.59 (7.315)	-	-	1.326 (1.874)	0.899 (2.071)	-
28	*P. frequentans*	-	-	-	-	-	-	-	-	6.476 (18.288)	-	-	-	-	-
29	*P. funiculosum*	0.885 (1.878)	-	-	-	-	-	-	-	-	-	-	-	-	-
30	*P. granulatum*	0.449 (0.953)	-	-	-	-	-	0.463 (6.378)	-	-	-	-	-	-	0.432 (2.548)
31	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	-	1.342 (3.092)	3.816 (22.488)
32	*P. lanosum*	-	1.338 (3.333)	-	1.41 (4.901)	-	1.361 (9.372)	-	-	-	-	-	2.652 (3.749)	-	-
33	*P. purpurogenum*	-	2.677 (6.7)	-	-	-	-	-	-	-	0.443 (1.341)	0.462 (0.971)	3.653 (3.749)	-	0.432 (2.548)

34	*P. restrictum*	1.321 (2.803)	1.338 (3.4)	1.324 (5.154)	-	-	-	-	-	-	-	-	-	-	0.852 (5.022)
35	*P. rubrum*	3.963 (8.403)	2.677 (6.7)	5.298 (20.618)	-	-	2.724 (18.69)	-	-	-	0.443 (1.341)	0.462 (0.971)	3.978 (5.624)	-	0.852 (5.022)
36	*P. waksmanii*	10.568 (22.408)	4.016 (10.0)	2.649 (10.309)	5.641 (19.607)	4.109 (15.0)	-	-	1.272 (3.796)	3.886 (10.972)	1.305 (3.946)	8.163 (17.142)	7.597 (11.248)	2.684 (6.184)	3.396 (20.014)
37	*Penicillium sp.*	2.642 (5.602)	-	2.649 (10.309)	7.052 (24.509)	4.109 (15.0)	-	0.463 (6.378)	1.704 (5.087)	-	19.528 (59.194)	12.244 (25.714)	13.262 (18.747)	13.422 (30.921)	-
38	*Phoma eupyrena*	-	-	-	1.41 (4.901)	2.739 (10.0)	-	-	-	-	-	-	-	-	-
39	*P. medicaginis*	0.885 (1.878)	2.677 (6.7)	1.324 (5.154)	-	-	0.911 (6.279)	-	-	-	-	-	-	0.899 (2.071)	-
40	*Phoma sp.*	-	-	-	-	2.739 (10.0)	-	-	-	-	-	-	-	-	-
41	*Plectosphaerella cucumerina*	0.885 (1.878)	-	-	1.41 (4.901)	-	-	-	3.816 (11.389)	1.735 (4.901)	0.443 (1.341)	0.911 (1.914)	2.652 (3.749)	1.342 (3.092)	0.852 (5.022)
42	*Pythium intermedium*	-	-	-	1.41 (4.901)	-	-	-	1.272 (3.796)	-	0.443 (1.341)	-	-	-	0.432 (2.548)
43	*P. irregulare*	-	-	-	-	-	-	-	-	-	-	-	-	-	0.432 (2.548)
44	*Pythium sp.*	-	-	-	-	0.465 (1.700)	-	-	-	-	-	-	-	0.899 (2.071)	-
45	*Rhizopus oryzae*	-	-	-	-	-	-	-	1.272 (3.796)	1.295 (3.657)	-	0.462 (0.971)	-	1.342 (3.092)	-
46	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	1.342 (3.092)	-
47	*T. polysporum*	-	-	-	-	-	-	-	-		6.527 (19.731)	6.802 (14.285)	10.61 (14.998)	9.395 (21.645)	3.816 (22.488)
48	*T. viride*	-	1.793 (4.466)	-	2.82 (9.803)	4.109 (15.0)	0.462 (3.186)	1.364 (18.518)	-	5.181 (14.63)	1.749 (5.288)	-	-	1.342 (3.092)	0.852 (5.022)
49	*Verticillium albo-atrum*	-	-	-	-	0.465 (1.700)	4.087 (28.037)	2.278 (30.925)	-	1.295 (3.657)	-	-	2.652 (3.749)	-	-
50	Green Sterile mycelia	3.963 (8.410)	2.677 (6.7)	-	-	-	-	-	3.816 (11.389)	-	-	-	-	-	-
51	White Sterile mycelia	0.449 (0.953)	-	0.887 (3.466)	4.231 (14.705)	-	-	-	-	1.735 (4.901)	0.874 (2.644)	-	2.652 (3.749)	-	-

Table 2.3.4. Monthly variation in the population of fungal species per gram dry soil X 10^3 in $N_{10}P_{30}K_{20}$ kg/ha + farmyard manure 5 t/ha (NPK+FYM) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	-	-	-	-	-	2.557 (5.659)	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	-	1.34 (2.803)	-
3	*A. clavatus*	5.405 (16.194)	-	-	-	0.473 (1.961)	-	0.470 (3.291)	5.486 (41.972)	6.393 (14.148)	-	-	-	-	1.256 (4.411)
4	*A. flavus*	-	-	-	1.42 (2.857)	0.473 (1.961)	-	-	-	-	-	2.247 (4.725)	-	-	-
5	*A. niger*	0.459 (1.378)	-	-	-	-	-	-	-	-	-	2.247 (4.725)	-	1.34 (2.803)	-
6	*A. versicolor*	-	-	-	-	-	-	-	-	-	-	-	-	-	1.256 (4.411)
7	*Aspergillus sp.*	-	4.098 (9.375)	-	-	-	-	4.155 (28.864)	0.429 (3.288)	-	2.587 (8.952)	-	-	-	-
8	*C. herbarium*	-	-	0.448 (0.723)	-	-	0.465 (4.432)	-	-	-	-	-	-	-	1.256 (4.411)
9	*Cladosporium sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	2.512 (8.822)
10	*Chaetomium globosum*	2.702 (8.107)	-	-	-	-	-	-	0.847 (6.479)	-	-	-	-	-	-
11	*Chaetomium sp.*	-	4.098 (9.375)	-	-	-	-	-	-	-	-	-	-	-	-
12	*Colletotrichum dematium*	-	-	-	-	-	0.465 (4.432)	0.470 (3.291)	-	1.278 (2.829)	-	-	-	-	-
13	*Cylindrocarpon magnusianum*	-	-	-	-	-	-	0.470 (3.291)	-	2.557 (5.659)	-	-	-	-	-
14	*Fusarium semitectum*	-	1.366 (3.125)	-	2.84 (5.714)	1.392 (5.747)	0.465 (4.432)	2.77 (19.23)	-	-	-	-	-	-	-
15	*F. sporotrichioides*	-	-	-	-	-	-	-	-	-	-	-	2.702 (5.356)	-	-

16	*Humicola fuscoatra*	10.81 (32.38)	1.366 (3.125)	0.448 (0.723)	-	0.473 (1.961)	-	-	-	-	0.439 (1.521)	-	8.108 (16.068)	1.34 (2.803)	-
17	*Idriella lunata*	-	-	-	-	-	-	-	-	-	-	-	1.351 (2.678)	-	-
18	*Mammaria echinobotryoides*	1.351 (4.048)	-	-	1.42 (2.857)	2.785 (11.494)	-	-	-	-	-	-	-	-	1.256 (4.411)
19	*Mortierella hyalina*	0.459 (1.378)	1.366 (3.125)	0.448 (0.723)	-	-	-	-	-	-	0.866 (2.999)	-	-	-	-
20	*M. vinacea*	-	-	-	-	-	-	-	-	7.672 (16.977)	-	1.328 (2.829)	1.351 (2.678)	-	-
21	*Oidiodendron echinulatum*	0.459 (1.378)	1.366 (3.125)	-	-	-	-	-	-	-	-	-	-	-	-
22	*O. griseum*	4.054 (12.160)	-	2.638 (4.255)	-	-	-	0.470 (3.291)	-	-	-	-	-	-	-
23	*Penicillium artrovenetum*	-	-	-	-	-	5.479 (51.948)	-	-	-	-	3.984 (8.488)	-	4.0 (8.41)	1.256 (4.411)
24	*P. canescens*	-	1.366 (3.125)	0.883 (1.425)	1.42 (2.857)	2.785 (11.494)	-	-	-	1.278 (2.829)	-	-	-	1.34 (2.803)	-
25	*P. chrysogenum*	0.907 (2.715)	6.83 (31.26)	5.277 (8.51)	-	4.178 (17.241)	0.465 (4.432)	-	0.429 (3.288)	2.557 (5.659)	-	1.328 (2.829)	-	1.34 (2.803)	2.512 (8.822)
26	*P. frequentans*	-	-	0.448 (0.723)	-	-	2.739 (25.974)	-	-	-	-	-	-	-	-
27	*P. funiculosum*	-	-	-	-	0.473 (1.961)	-	-	-	-	-	-	-	1.34 (2.803)	-
28	*P. granulatum*	-	-	-	-	-	-	0.470 (3.291)	-	-	-	2.217 (4.725)	-	4.0 (8.41)	-
29	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	-	5.34 (11.213)	6.281 (22.055)
30	*P. lanosum*	-	-	-	1.42 (2.857)	-	-	0.470 (3.291)	-	-	-	-	-	-	-
31	*P. purpurogenum*	-	-	-	-	-	-	-	-	2.557 (5.659)	-	1.328 (2.829)	1.351 (2.678)	-	-

32	*P. restrictum*	-	2.732 (6.25)	-	-	-	-	-	-	-	-	-	-	-	-
33	*P. rubrum*	-	1.366 (3.125)	0.883 (1.425)	5.681 (11.428)	-	-	-	-	-	0.439 (1.521)	-	4.054 (8.034)	-	1.256 (4.411)
34	*P. waksmanii*	-	1.366 (3.125)	-	-	2.785 (11.494)	-	-	0.429 (3.288)	-	0.439 (1.521)	13.28 (28.296)	4.054 (8.034)	5.34 (11.213)	3.768 (13.233)
35	*Penicillium sp.*	-	-	2.638 (4.255)	14.209 (28.57)	0.473 (1.961)	-	0.470 (3.291)	-	-	12.936 (44.762)	10.624 (22.637)	8.108 (16.068)	13.34 (28.034)	-
36	*Phoma eupyrena*	-	1.366 (3.125)	0.448 (0.723)	-	-	-	-	-	-	-	-	-	-	-
37	*P. medicaginis*	1.810 (5.431)	2.782 (6.25)	-	-	-	-	-	0.429 (3.288)	1.278 (2.829)	-	1.328 (2.829)	-	-	-
38	*Phoma sp.*	-	-	0.448 (0.723)	-	-	-	-	-	-	-	-	-	-	-
39	*Plectosphaerella cucumerina*	0.885 (1.878)	-	-	1.42 (2.857)	-	-	-	-	12.787 (28.296)	0.866 (2.999)	2.217 (4.725)	1.351 (2.678)	-	2.512 (8.822)
40	*P. irregulare*	-	-	-	-	-	-	-	-	-	-	2.656 (5.659)	-	1.34 (2.803)	-
41	*Rhizopus oryzae*	0.459 (1.378)	-	-	-	-	-	-	-	-	-	-	-	-	-
42	*Staphylotrichum coccosporum*	-	-	0.448 (0.723)	-	-	-	-	-	-	-	-	-	-	-
43	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	1.34 (2.803)	-
44	*T. polysporum*	3.608 (10.822)	-	46.174 (74.468)	14.209 (28.57)	0.933 (3.866)	-	2.77 (19.23)	5.056 (38.384)	-	9.495 (32.855)	2.656 (5.659)	13.513 (26.78)	5.34 (11.213)	-
45	*T. viride*	-	4.098 (9.375)	-	4.261 (8.571)	6.963 (28.735)	0.465 (4.432)	0.927 (6.485)	-	3.836 (8.485)	0.866 (2.999)	-	2.702 (5.356)	-	-
46	*Verticillium albo-atrum*	-	-	-	1.42 (2.857)	-	-	-	-	-	-	-	-	-	-
47	*Green Sterile mycelia*	-	1.829 (4.785)	-	-	-	-	-	-	-	-	-	-	-	-
48	*White Sterile mycelia*	-	-	-	-	-	-	0.470 (3.291)	-	-	-	-	1.351 (2.678)	-	3.354 (11.776)

Table 2.3.5. Monthly variation in the population of fungal species per gram dry soil X 10^3 in Control (CTRL) groundnut field soil at 10-20 cm depth during the periods April– October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-		-	0.458 (1.619)	-	0.894 (13.400)	-	-	2.141 (12.518)	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	1.753 (14.346)	-	0.442 (4.250)
3	*A. clavatus*	6.605 (34.891)	2.621 (6.896)	1.265 (5.56)	-	0.890 (6.090)	-	1.729 (25.140)	1.223 (33.33)	2.141 (12.518)	-	-	0.876 (7.173)	-	0.442 (4.250)
4	*A. flavus*	-	-	-	0.458 (1.919)	-	-	-	-	-	-	0.437 (3.777)	-	-	-
5	*A. niger*	-	-	-	-	-	0.453 (6.800)	-	-	-	-	-	-	-	-
6	*Cladosporium cladosporioides*	-	-	-	-	-	-	-	-	-	-	-	0.876 (7.173)	-	-
7	*Cladosporium sp.*	-	-	-	-	0.451 (3.090)	-	-	-	-	-	-	-	-	-
8	*Chaetomium globosum*	-	0.877 (2.310)	2.531 (11.12)	0.902 (3.190)	-	-	-	-	-	-	2.574 (22.222)	-	0.437 (4.857)	-
9	*Chaetomium sp.*	0.448 (2.372)	-	-	-	-	-	-	-	-	-	-	-	-	-
10	*C. olidum*	-	-	1.265 (5.56)		-	-	-	-	-	-	-	-	-	-
11	*Fusarium semitectum*	-	2.621 (6.896)	-	-	-	-	-	-	-	-	-	-	-	-
12	*F. sporotrichioides*	-	0.445 (1.172)	-	-	-	-	-	-	-	-	-	4.371 (35.531)	-	-
13	*Gongoronella butleri*	-	0.877 (2.310)	-	-	-	-	-	0.416 (11.333)	-	-	-	-	-	-
14	*Humicola fuscoatra*	-	0.877 (2.310)	1.265 (5.56)	1.347 (4.761)	-	-	-	-	1.282 (7.496)	1.711 (12.181)	-	-	0.437 (4.857)	-
15	*H. grisea*	-	-	-	-	-	-	-	-	2.564 (14.992)	0.434 (3.090)	-	-	-	-

16	*Mammaria echinobotryoides*	3.965 (20.935)	2.261 (6.896)	1.265 (5.56)	-	-	-	-	-	0.435 (2.548)	-	-	-	-	-
17	*Mortierella hyalina*	-	0.877 (2.310)	-	-	-	-	-	0.416 (11.333)	-	-	-	-	-	-
18	*M. vinacea*	-	0.445 (1.172)	2.531 (11.12)	0.458 (1.619)	-	-	-	-	-	-	-	-	-	-
19	*Mucor racemosus*	-	0.445 (1.172)	1.265 (5.56)	0.458 (1.619)	-	-	-	-	-	-	-	-	-	-
20	*O. griseum*	-	-	-	0.902 (3.190)	-	-	-	-	-	-	-	-	-	-
21	*Penicillium artrovenetum*	3.959 (20.935)	-	-	4.093 (14.285)	0.451 (3.090)	-	-	0.416 (11.333)	-	0.434 (3.090)	0.437 (3.777)	0.445 (3.640)	0.437 (4.857)	0.442 (4.250)
22	*P. canescens*	-	-	-	-	0.451 (3.090)	-	-	-	0.435 (2.548)	-	-	-	-	-
23	*P. chrysogenum*	-	0.445 (1.172)	3.797 (16.67)	-	-	0.453 (6.800)	-	0.416 (11.333)	-	-	0.437 (3.777)	-	-	1.744 (16.75)
24	*P. frequentans*	-	-	-	-	0.451 (3.090)	-	-	-	1.717 (10.044)	-	-	-	0.437 (4.857)	-
25	*P. funiculosum*	-	-	-	-	1.329 (9.09)	-	-	-	-	-	0.862 (7.444)	-	-	-
26	*P. granulatum*	-	0.445 (1.172)	-	-	-		-	-	-	-	-	0.445 (3.640)	-	1.744 (16.75)
27	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	-	0.862 (9.571)	-
28	*P. purpurogenum*	-	6.553 (17.241)	-	-	-	-	0.864 (12.570)	-	-	-	-	0.445 (3.640)	0.437 (4.857)	-
29	*P. restrictum*	-	0.445 (1.172)	1.265 (5.56)	0.458 (1.619)	-	-	0.438 (6.378)	-	-	-	-	-	-	-
30	*P. rubrum*	1.768 (9.351)	-	-	-	-	-	-	-	-	-	-	0.876 (7.173)	-	0.442 (4.250)
31	*P. waksmanii*	1.319 (6.978)	7.863 (20.689)	5.063 (22.23)	2.695 (9.523)	2.659 (18.18)	-	-	0.416 (11.333)	0.435 (2.548)	3.409 (24.272)	1.287 (11.111)	0.876 (7.173)	1.287 (14.285)	1.302 (12.5)

32	*Penicillium sp.*	-	-	1.265 (5.56)	4.063 (14.285)	0.890 (6.09)	-	-	-	-	-	1.724 (14.85)	-	-	-
33	*Phoma eupyrena*	-	-	-	2.695 (9.523)	-	-	-	-	-	-	-	-	-	-	-
34	*P. medicaginis*	-	3.931 (10.344)	-	-	0.890 (6.090)	-	-	-	-	-	-	-	-	-	-
35	*Phoma sp.*	-	-	-	0.944 (4.901)	-	-	-	-	-	-	-	-	-	-	-
36	*Plectosphaerella cucumerina*								-	0.435 (2.548)	0.855 (6.090)	-	0.445 (3.640)	0.437 (4.857)	0.872 (8.375)
37	*Pythium intermedium*	-	-	-	0.458 (1.619)	-	-	-	-	-	2.132 (15.181)	-	-	-	-	-
38	*P. irregulare*	-	-	-	-	-	-	-	-	-	-	0.862 (7.444)	0.876 (7.173)	-	-	-
39	*Rhizopus oryzae*	-	2.621 (6.896)	-	-	-	-	-	0.416 (11.333)	-	-	-	-	-	-	-
40	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	0.437 (4.857)	-	-
41	*T. polysporum*	-	2.621 (6.896)	-	-	-	4.899 (73.4)	2.581 (37.523)	-	5.128 (29.985)	2.554 (18.181)	0.862 (7.444)	-	1.287 (14.285)	1.744 (16.75)	-
42	*T. viride*	-	-	-	6.738 (23.809)	3.989 (27.272)	-	-	-	-	2.554 (18.181)	-	-	0.437 (4.857)	-	-
43	*Verticillium albo-atrum*	-	-	-	0.902 (3.190)	2.218 (15.181)	-	0.438 (6.378)	-	0.435 (2.548)	-	-	-	1.724 (19.142)	-	-
44	*Green Sterile mycelia*	-	-	-	-	-	-	-	-	-	-	0.862 (7.444)	-	-	-	-
45	*White Sterile mycelia*	0.884 (4.675)	-	-	-	-	-	0.864 (12.570)	-	-	-	1.287 (11.111)	-	0.437 (4.857)	1.302 (12.5)	-

Table 2.3.6. Monthly variation in the population of fungal species per gram dry soil X 10^3 in $N_{20}P_{60}K_{40}$ kg/ha (NPK) groundnut field soil at 10-20 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	-	-	2.211 (27.84)	-	-	1.717 (6.380)	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	-	0.441 (2.755)	-
3	*A. clavatus*	7.782 (31.578)	-	0.840 (3.655)	1.347 (6.123)	2.649 (15.348)	-	-	0.854 (11.816)	1.717 (6.380)	-	-	-	-	-
4	*A. niger*	-	0.447 (1.789)	5.018 (21.822)	-	-	-	-	-	-	-	-	-	-	-
5	*Aspergillus sp.*	-	-	6.273 (27.277)	-	-	-	-	0.854 (11.816)	-	-	-	-	-	-
6	*Cladosporium sp.*	-	-	1.254 (5.456)	-	-	-	-	-	-	-	0.439 (2.548)	-	-	-
7	*Chaetomium globosum*	-	2.631 (10.526)	-	1.805 (8.205)	-	-	-	-	0.858 (3.190)	-	2.16 (12.518)	-	-	-
8	*Chaetomium sp.*	-	0.447 (1.789)	-	-	-	-	-	-	-	-	-	-	-	-
9	*Colletotrichum dematium*	0.868 (3.526)	-	-	1.347 (6.123)	-	-	-	-	7.692 (28.57)	1.28 (6.973)	-	-	-	-
10	*C. olidum*	-	-	0.426 (1.854)	-	-	-	-	2.984 (41.269)	-	-	-	-	-	-
11	*Fusarium semitectum*	-	0.881 (3.526)	0.426 (1.854)	-	-	-	-	-	-	-	-	-	-	-
12	*F. sporotrichioides*	-	-	-	-	-	-	-	-	-	-	-	0.442 (3.40)	-	-
13	*Gongoronella butleri*	-	-	0.426 (1.854)	1.347 (6.123)	-	-	-	-	-	-	-	-	-	-
14	*Humicola fuscoatra*	-	-	-	2.695 (12.247)	0.450 (2.615)	-	-	-	-	-	-	-	-	-
15	*H. grisea*	-	-	-	-	-	-	-	-	1.282 (4.761)	-	-	-	-	-

16	*Mammaria echinobotryoides*	2.591 (10.526)	-	-	1.347 (6.123)	3.973 (23.076)	-	-	-	-	-	-	-	-	-
17	*Mortierella hyalina*	-	-	-	-	-	-	-	-	-	-	0.439 (2.548)	-	-	-
18	*M. vinacea*	-	0.447 (1.789)	-	-	-	-	-	-	2.141 (7.952)	-	-	0.442 (3.40)	-	-
19	*Oidiodendron echinulatum*	-	0.447 (1.789)	-	-	1.324 (7.692)	-	-	-	-	-	-	-	-	-
20	*Penicillium artrovenetum*	-	-	-	-	-	0.450 (5.606)	-	-	-	1.28 (6.973)	4.32 (25.037)	-	0.441 (2.755)	-
21	*P. canescens*	-	-	0.426 (1.854)	1.347 (6.123)	-	-	-	-	-	-	-	-	-	-
22	*P. chrysogenum*	-	2.631 (10.526)	1.681 (7.310)	2.695 (12.247)	1.324 (7.692)	4.425 (55.67)	-	-	0.435 (1.619)	-	-	-	0.441 (2.755)	-
23	*P. frequentans*	-	-	0.840 (3.655)	-	-	-	-	-	0.435 (1.619)	-	-	-	-	-
24	*P. funiculosum*	-	-	-	-	-	-	-	-	-	-	0.866 (5.022)	-	-	-
25	*P. granulatum*	-	0.447 (1.789)	-	-	-	-	-	-	-	-	0.866 (5.022)	-	0.870 (5.429)	-
26	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	2.604 (20.0)	6.493 (40.518)	1.747 (13.4)
27	*P. purpurogenum*	-	3.947 (15.789)	-	-	0.450 (2.615)	-	-	-	-	-	-	-	-	0.873 (6.7)
28	*P. restrictum*	-	2.361 (10.528)	-	-	-	-	-	-	-	-	-	-	-	-
29	*P. rubrum*	11.662 (47.365)	-	0.426 (1.854)	-	-	-	-	-	-	-	0.439 (2.548)	3.046 (23.4)	-	-
30	*P. waksmanii*	0.440 (1.789)	7.894 (31.578)	1.681 (7.310)	3.153 (14.329)	-	-	-	0.854 (11.816)	-	3.841 (20.92)	5.174 (29.985)	1.302 (10.0)	2.597 (16.207)	3.94 (30.0)

31	*Penicillium sp.*	-	-	0.840 (3.655)	-	-	-	-	-	-	-	2.587 (14.992)	-	2.597 (16.207)	-
32	*Phoma eupyrena*	-	-	-	-	-	0.450 (5.666)	-	0.854 (11.816)	-	-	-	-	-	-
33	*P. medicaginis*	-	1.315 (5.263)	0.426 (1.854)	-	-	-	-	0.854 (11.816)	-	-	-	-	0.870 (5.429)	-
34	*Plectosphaerella cucumerina*		-	-	2.695 (12.247)	-	-	-	-	0.858 (3.190)	-	-	-	-	1.742 (13.4)
35	*Pythium intermedium*	-	0.447 (1.789)	0.426 (1.854)	-	-	-	-	-	-	-	-	-	-	-
36	*P. irregulare*	-	-	-	-	-	-	-	-	0.858 (3.190)	-	-	-	-	-
37	*Pythium sp.*	-	-	-	-	-	-		-	0.858 (3.190)	-	-	-	-	-
38	*Ramichloridium schulzeri*	-	-	-	-	-	-	-	-	-	-	-	0.442 (3.40)	-	-
39	*Rhizopus oryzae*	-	-	-	-	-	-	-	-	1.717 (6.380)	-	-	-	-	-
40	*T. polysporum*	-	-	-	-	-	-	-	-	3.846 (14.285)	7.682 (41.841)	-	2.604 (20.0)	1.298 (8.103)	3.05 (23.4)
41	*T. viride*	-	-	0.840 (3.655)	-	3.973 (23.076)	0.450 (5.666)	1.285 (42.918)	-	0.435 (1.619)	-	-	-	-	1.747 (13.4)
42	*Ulocladium consortiale*	-	-	-	-	-	-	-	-	-	-	-	0.872 ((6.70)	-	-
43	*Verticillium albo-atrum*	0.440 (1.789)	-	-	1.347 (6.123)	0.450 (2.615)	-	1.285 (42.918)	-	0.435 (1.619)	1.28 (6.973)	-	-	-	-
44	*Green Sterile mycelia*	1.295 (5.263)	-	0.840 (3.655)	-	2.649 (15.384)	-	-	-	1.717 (6.38)	-	-	-	-	-
45	*White Sterile mycelia*	-	0.447 (1.789)	-	0.941 (4.901)	-	-	0.437 (14.592)	-	-	2.996 (16.317)	-	1.302 (10.0)	.870 (5.429)	-

Table 2.3.7. Monthly variation in the population of fungal species per gram dry soil X 10^3 in farmyard manure 10 t/ha (FYM) groundnut field soil at 10-20 cm depths during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	1.398 (7.32)	-	0.449 (12.734)	-	1.711 (36.512)	1.310 (5.882)	-	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	0.443 (5.097)	0.453 (3.640)	1.731 (11.482)
3	*A. clavatus*	3.891 (13.043)	-	1.713 (6.7)	6.069 (31.771)	-	-	0.886 (16.75)	-	-	-	-	-	-	-
4	*A. flavus*	0.440 (1.478)	-	-	-	-	-	-	-	-	-	2.61 (15.785)	-	1.335 (10.706)	-
5	*A. niger*	0.440 (1.478)	0.449 (1.619)	2.557 (10.0)	-	-	-	-	-	-	-	-	-	-	-
6	*Aspergillus sp.*	-	-	-	-	-	-	1.322 (25.0)	-	-	-	-	-	-	-
7	*C. herbarium*	-	-	0.434 (1.70)	-	-	-	-	-	-	-	-	-	-	-
8	*Chaetomium globosum*	2.594 (8.695)	3.531 (12.714)	2.992 (11.7)	-	-	-	0.449 (8.5)	0.434 (9.264)	-	-	2.61 (15.785)	0.443 (5.097)	-	-
9	*Chaetomium sp.*	-	-	1.713 (6.7)	-	-	-	-	-	-	-	-	-	0.453 (3.640)	-
10	*Colletotrichum dematium*	-	-	-	0.475 (2.489)	-	-	0.449 (8. 5)	-	0.878 (3.941)	-	-	-	-	-
11	*Cylindrocarpon magnusianum*	0.440 (1.478)	-	0.434 (1.7)	-	-	-	-	-	-	0.873 (6.70)	-	-	-	-
12	*Fusarium semitectum*	-	1.772 (6.38)	-	-	0.455 (4.432)	-	-	-	-	0.443 (3.40)	-	-	-	-
13	*F. sporotrichioides*	-	-	-	-	-	-	-	-	-	0.873 (6.70)	-	0.443 (5.097)	-	-
14	*Gongoronella butleri*	-	-	0.434 (1.7)	-	-	-	-	-	-	-	-	-	-	-
15	*Humicola fuscoatra*	-	0.449 (1.619)	-	1.398 (7.32)	-	-	-	-	0.445 (2.0)	-	-	-	-	-

16	*Mammaria echinobotryoides*	0.886 (2.913)	0.449 (1.619)	-	-	0.455 (4.432)	-	0.449 (8.500)	-	-	-	-	-	-	-
17	*Mortierella hyalina*	-	-	-	-	-	-	-	-	1.756 (7.882)	0.443 (3.40)	-	-	-	-
18	*M. vinacea*	-	-	0.434 (1.70)	1.398 (7.32)	-	-	-	-	-	-	-	-	-	-
19	*Mucor racemosus*	0.440 (1.478)	-	-	-	-	-	-	-	-	-	-	-	-	-
20	*Oidiodendron echinulatum*	0.440 (1.478)	1.772 (6.38)	-	-	-	-	-	-	-	-	-	-	-	-
21	*O. griseum*	-	-	0.434 (1.70)	-	-	-	-	-	-	-	-	-	-	-
22	*Penicillium artrovenetum*	-	-	-	0.937 (4.904)	-	-	-	0.434 (9.264)	-	-	0.874 (5.288)	-	0.894 (7.173)	0.865 (5.741)
23	*P. canescens*	0.886 (2.913)	0.449 (1.619)	1.713 (6.7)	1.398 (7.32)	0.455 (4.432)	-	-	-	-	-	-	-	-	-
24	*P. chrysogenum*	-	3.531 (12.714)	-	-	-	-	-	1.711 (36.512)	0.445 (2.0)	-	-	-	-	-
25	*P. frequentans*	0.440 (1.478)	-	6.393 (25.0)	-	-	-	-	-	1.756 (7.882)	-	-	-	-	-
26	*P. funiculosum*	0.886 (2.9130	-	-	-	-	-	-	-	-	-	-	-	-	-
27	*P. granulatum*	-	2.208 (7.952)	-	-	-	-	-	-	-	0.443 (3.40)	-	-	-	-
28	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	3.916 (44.877)	0.453 (3.640)	5.607 (37.189)
29	*P. lanosum*	0.440 (1.478)	-	-	-	-	-	-	-	-	-	-		-	-
30	*P. restrictum*	0.440 (1.478)	-	-	-	-	-	-	-	-	-	-		-	-
31	*P. rubrum*	2.594 (8.695)	1.772 (6.38)	1.713 (6.7)	0.475 (2.489)	-	-	-	-	-	0.443 (3.40)	0.874 (5.288)	1.749 (20.089)	-	0.865 (5.741)

32	*P. waksmanii*	2.594 (8.695)	2.645 (9.523)	1.713 (6.7)	0.937 (4.904)	2.68 (26.109)	-	-	0.434 (9.264)	-	0.873 (6.70)	1.305 (7.892)	-	-	3.875 (25.706)
33	*Penicillium sp.*	-	2.645 (9.523)	-	-	2.68 (26.109)	-	-	-	-	1.303 (10.0)	4.791 (28.966)	-	4.005 (32.199)	-
34	*P. medicaginis*	4.332 (14.521)	3.531 (12.714)	0.434 (1.7)	-	-	-	0.886 (16.75)	-	-	-	-	-	-	-
35	*Plectosphaerella cucumerina*	0.885 (1.878)	-	-	0.944 (7.32)	-	-	-	-	1.756 (7.882)	0.443 (3.40)	-	-	-	1.291 (8.568)
36	*Pythium intermedium*	2.166 (7.26)	-	-	-	-	-	-	-	0.445 (2.0)	-	-	-	-	-
37	*P. irregulare*	-	-	-	-	-	-	-	-	2.621 (11.764)	3.050 (23.40)	0.874 (5.288)	-	-	-
38	*Rhizopus oryzae*	-	0.449 (1.619)	-	-	-	-	-	-	1.756 (7.882)	-	-	-	-	-
39	*Staphylotrichum coccosporum*	-	-	-	0.475 (2.489)	-	-	-	-	-	-	-	0.443 (5.097)	-	-
40	*Trichoderma harzianum*	-	-	-	-	-	-	-	-	-	-	-	-	0.453 (3.640)	-
41	*T. polysporum*	2.594 (8.695)	-	2.557 (10.0)	-	2.68 (26.109)	2.206 (62.546)	0.445 (8.500)	-	6.553 (29.411)	4.354 (33.40)	2.61 (15.785)	1.305 (14.992)	4.005 (32.199)	-
42	*T. viride*	-	-	-	2.335 (12.225)	0.898 (8.735)	-	0.449 (8.500)	-	2.188 (9.823)	0.873 (6.70)	-	-	-	0.865 (5.741)
43	*Ulocladium consortiale*	0.440 (1.478)	-	-	-	-	-	-	-	-	-	-	-	-	-
44	*Verticillium albo-atrum*	-	-	-	0.475 (2.489)	-	-	-	-	-	-	-	-	-	-
45	*Green Sterile mycelia*	1.736 (6.38)	-	-	-	-	-	-	-	0.445 (2.0)	-	-	-	-	-
46	*White Sterile mycelia*	-	2.208 (7.952)	-	-	-	0.895 (25.187)	-	-	-	-	-	-	0.453 (3.64)	-

Table 2.3.8. Monthly variation in the population of fungal species per gram dry soil X 10^3 in $N_{10}P_{30}K_{20}$ kg/ha + farmyard manure t/ha (NPK+FYM) groundnut field soil at 10-20 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Fungal Species	2001						2002							
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Acremonium murorum*	-	-	-	0.471 (2.372)	-	-	-	-	1.724 (8.551)	0.862 (3.9410	-	-	-	-
2	*Aspergillus alutaceus*	-	-	-	-	-	-	-	-	-	-	-	-	-	0.861 (4.785)
3	*A. clavatus*	8.510 (44.24)	0.455 (1.924)	-	2.773 (13.956)	-	1.329 (16.67)	0.899 (11.837)	0.432 (6.367)	1.287 (6.381)	-	-	-	-	-
4	*A. flavus*	-	-	-	2.773 (13.956)	-	-	-	-	1.287 (6.381)	-	1.295 (5.263)	-	-	-
5	*A. niger*	-	-	-	-	-	-	-	-	-	-	2.59 (10.526)	-	-	-
6	*Aspergillus sp.*	-	3.583 (15.118)	-	-	-	-	-	-	-	1.724 (7.882)	-	-	-	-
7	*Cladosporium sp.*	-	-	2.592 (5.505)	-	-	-	-	-	-	-	-	-	-	-
8	*Chaetomium globosum*	-	2.239 (9.451)	-	2.773 (13.956)	-	-	-	0.432 (6.367)	-	-	-	-	-	-
9	*C. olidum*	0.456 (2.372)	-	-	-	-	-	-	-	-	-	-	-	-	-
10	*F. semitectum*	-	0.455 (1.924)	0.441 (0.935)	0.471 (2.372)	-	-	-	-	-	-	-	-	0.886 (5.429)	-
11	*F. sporotrichioides*	-	-	-	-	-	-	-	-	5.148 (25.256)	-	-	-	-	-
12	*Gongoronella butleri*	-	0.455 (1.924)	-	-	-	-	-	-	-	-	-	-	-	-
13	*Humicola fuscoatra*	1.798 (9.351)	1.341 (5.659)	-	1.386 (6.978)	-	-	-	-	-	3.436 (15.705)	-	-	-	-
14	*H. grisea*	-	-	-	-	-	-	-	0.432 (6.367)	-	-	-	-	-	-
15	*Mammaria echinobotryoides*	1.342 (6.978)	0.465 (1.924)	-	1.386 (6.978)	1.838 (8.94)	-	-	0.852 (12.546)	0.862 (4.275)	-	-	-	-	-

16	*Mortierella hyalina*	0.456 (2.372)	-	-	-	-	-	-	-		0.862 (3.941)	-	-	-	-
17	*M. vinacea*	-	-	-	1.858 (9.351)	1.371 (6.67)	-	-	-	1.287 (6.381)	-	0.867 (3.526)	-	-	-
18	*Mucor racemosus*	-	0.455 (1.924)	-	0.471 (2.372)	1.371 (6.67)	-	-	-	-	-	-		-	-
19	*Oidiodendron echinulatum*	-	0.898 (3.791)	0.441 (0.935)	-	-	-	-	-	-	-	-	-	-	-
20	*O. griseum*	1.342 (6.978)	0.455 (1.924)	-	-	-	-	-	-	-		-	-	-	-
21	*Penicillium artrovenetum*	-	-	0.441 (0.935)	1.386 (6.978)	-	1.329 (16.67)	-	1.272 (18.726)		-	0.867 (3.526)	-	0.886 (5.429)	1.285 (7.142)
22	*P. canescens*	-	-	-	0.471 (2.372)	1.838 (8.94)	-	-	-	-	-	-	-	-	-
23	*P. chrysogenum*	-	0.455 (1.924)	-	0.471 (2.372)	1.371 (6.67)	4.878 (61.166)	-	-	-	0.437 (2.0)	0.867 (3.526)	-	1.322 (8.103)	0.861 (4.785)
24	*P. frequentans*	-	-	-	-	-	-	-	-	0.862 (4.275)	-	-	-	-	-
25	*P. funiculosum*	-	-	0.441 (0.935)	-	-	-	-	-	-	0.862 (3.941)	-	-	0.886 (5.429)	-
26	*P. granulatum*	-	-	-	-	-	-	4.026 (53.0)	-	-	-	-	-	0.886 (5.429)	-
27	*P. jensenii*	-	-	-	-	-	-	-	-	-	-	-	4.360 (43.546)	1.322 (8.103)	5.141 (28.571)
28	*P. lanosum*	-	-	0.441 (0.935)	-	-	-	-	-	-	-	-	-	-	-
29	*P. purpurogenum*	-	-	-	-	-	-	-	-	-	0.437 (2.0)	-	3.916 (39.370)	-	-
30	*P. restrictum*	-	-	-	-	-	-	-	-	1.287 (6.381)	-	-	-	-	1.285 (7.142)
31	*P. rubrum*	-	1.796 (7.583)	0.441 (0.935)	-	1.371 (6.67)	0.451 (5.666)	-	-	-	-	-	0.874 (8.735)	-	3.836 (21.142)

32	*P. waksmanii*	-	2.684 (11.325)	2.592 (5.505)	-	2.743 (13.4)	-	-	-	-	0.437 (2.0)	3.886 (15.789)	-	1.772 (10.858)	2.57 (14.285)
33	*Penicillium sp.*	-	4.026 (16.987)	-	-	4.115 (20.0)	-	-	0.852 (12.546)	-	8.584 (39.239)	5.181 (21.052)	-	0.886 (5.429)	-
34	*Phoma eupyrena*	-	-	2.592 (5.505)	-	-	-	-	-	-	0.437 (2.0)	-	-	-	-
35	*P. medicaginis*	1.342 (6.978)	1.796 (7.583)	-	-	-	-	-	-	-	-	-	-	-	-
36	*Plectosphaerella cucumerina*		-	-	2.773 (13.956)	-	-	-	2.544 (37.453)	1.724 (8.551)	0.862 (3.941)	2.59 (10.526)	-	0.886 (5.429)	-
37	*Pythium intermedium*	0.4546 (2.372)	-	-	-	-	-	-	-	-	-	0.867 (3.526)	-	0.886 (5.429)	-
38	*P. irregulare*	-	-	-	-	-	-	-	-	1.287 (6.381)	-	0.867 (3.526)	-	-	-
39	*Pythium sp.*	-	-	-	-	1.371 (6.67)	-	-	-	-	-	-	-	-	-
40	*Staphylotrichum coccosporum*	-	-	-	-	-	-	-	-	-	-	-	0.874 (8.735)	-	-
41	*T. polysporum*	3.140 (16.32)	1.796 (7.583)	33.34 (70.657)	-	1.371 (6.67)	-	-	-	-	2.149 (9.823)	2.59 (10.526)	-	3.968 (24.311)	1.285 (7.142)
42	*T. viride*	-	0.455 (1.924)	0.441 (0.935)	0.471 (2.372)	1.834 (8.94)	-	0.899 (11.837)	-	2.149 (10.657)	0.862 (3.941)	-	-	0.886 (5.429)	0.861 (4.785)
43	*Verticillium albo-atrum*	-	-	-	0.471 (2.372)	-	-	1.798 (23.674)	-	-	-	0.867 (3.526)	-	-	-
44	*Green Sterile mycelia*	0.456 (2.372)	-	-	-	-	-	-	-	1.287 (6.381)	-	-	-	-	-
45	*White Sterile mycelia*	-	-	2.592 (5.505)	-	-	-	-	-	-	-	1.295 (5.263)	-	0.886 (5.429)	-

Table 2.3.9. List of fungi isolated from control (CTRL), $N_{20}P_{60}K_{40}$ kg/ha, FYM 10 t/ha and $N_{10}P_{30}K_{20}$ kg/ha +FYM 5 t/ha soils of groundnut field at 0-10 cm and 10-20 cm depths during the study periods April – October (2001- 2002).

Sl. No	Fungal species	Soil treatments							
		CTRL		NPK		FYM		NPK+FYM	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
1	*Acremonium murorum*	+	+	+	+	+	+	+	+
2	*Aspergillus alutaceus*	+	+	+	+	+	+	+	+
3	*A. clavatus*	+	+	+	+	+	+	+	+
4	*A. flavus*	+	+	+	-	+	+	+	+
5	*A. niger*	+	+	+	+	+	+	+	+
6	*A. versicolor*	-	-	-	-	-	-	+	-
7	*Aspergillus sp.*	+	-	+	+	+	+	+	+
8	*Chaetomium globosum*	+	+	+	+	+	+	+	+
9	*Chaetomium sp.*	+	+	-	+	+	+	+	-
10	*Cladosporium cladosporioides*	+	+	+	-	+	-	-	-
11	*C. herbarium*	-	-	+	-	+	+	+	-
12	*Cladosporium sp.*	-	+	+	+	+	-	+	+
13	*Colletotrichum dematium*	+	-	+	+	+	+	+	-
14	*Cylindrocarpon magnusianum*	+	-	+	-	+	+	+	-
15	*C. olidum*	+	+	+	+	-	-	-	+
16	*Eupenicillium lapidosum*	-	-	+	-	+	-	-	-
17	*Fusarium semitectum*	+	+	+	+	+	+	+	+
18	*F. sporotrichioides*	+	+	+	+	+	+	+	+
19	*Gongoronella butleri*	+	+	+	+	-	+	-	+
20	*Humicola fuscoatra*	+	+	+	+	+	+	+	+
21	*H. grisea*	+	+	-	+	+	-	-	+
22	*Idriella lunata*	+	-	+	-	-	-	+	-
23	*Mammaria echinobotryoides*	+	+	+	+	+	+	+	+
24	*Mortierella hyaline*	-	+	+	+	+	+	+	+
25	*M. vinacea*	+	+	+	+	+	+	+	+
26	*Mucor racemosus*	+	+	+	-	-	+	-	+
27	*Oidiodendron echinulatum*	+	+	-	+	+	+	+	+
28	*O. griseum*	+	-	+	-	+	+	+	+
29	*Penicillium artrovenetum*	+	+	+	+	+	+	+	+
30	*P. canescens*	+	+	+	+	+	+	+	+
31	*P. chrysogenum*	+	+	+	+	+	+	+	+
32	*P. frequentans*	+	+	+	+	+	+	+	+
33	*P. funiculosum*	+	+	+	-	+	+	+	+
34	*P. granulatum*	+	+	+	+	+	+	+	+
35	*P. jensenii*	+	+	+	+	+	+	+	+
36	*P. lanosum*	+	-	+	-	+	+	+	+
37	*P. purpurogenum*	+	+	+	+	+	-	+	+
38	*P. restrictum*	+	+	+	+	+	+	+	+
39	*P. rubrum*	+	+	+	+	+	+	+	+
40	*P. waksmanii*	+	+	+	+	+	+	+	+
41	*Penicillium sp.*	+	+	+	+	+	+	+	+
42	*Phoma eupyrena*	+	+	+	+	+	-	+	+
43	*P. medicaginis*	+	+	+	+	+	+	+	+
44	*Phoma sp.*	-	+	+	-	+	-	+	-
45	*Plectosphaerella cucumerina*	+	+	+	+	+	+	+	+
46	*Pythium intermedium*	+	+	+	+	+	+	-	+
47	*P. irregulare*	-	+	+	+	+	+	+	+
48	*Pythium sp.*	-	-	-	+	+	-	-	+
49	*Ramichloridium schulzeri*	-	-	-	+	-	-	-	-
50	*Rhizopus oryzae*	+	+	+	+	+	+	+	-
51	*Staphylotrichum coccosporum*	+	-	-	-	+	+	+	+
52	*Trichoderma harzianum*	-	+	+	-	+	+	+	-
53	*T. polysporum*	+	+	+	+	+	+	+	+
54	*T. viride*	+	+	+	+	+	+	+	+
55	*Ulocladium consortiale*	-	-	-	+	-	+	-	-
56	*Verticillium albo-atrum*	+	+	+	+	+	+	+	+
57	*Green Sterile mycelia*	+	+	+	+	+	+	+	+
58	*White Sterile mycelia*	+	+	+	+	+	+	+	+

2.3.2. Bacterial population

The colony form unit (CFU) of bacterial population increased from pre-fertilizer treatments to post treatments throughout the investigation. It was also observed that the population markedly decreased at post harvest (Fig. 2.3.6).

The maximum bacterial population was recorded in FYM fertilizer treatment throughout the investigation except at subsurface soil layer in 2001. In 2001 at surface soil layer, bacterial population ranged between 0.551 X 10^5 CFU in the month of April in CTRL plot and 13.351 X 10^5 CFU in the month of September in FYM plot. At subsurface soil layer, it ranged between 0.216 X 10^5 CFU in the month of April in FYM plot and 8.829 X 10^5 CFU in the month of September in NPK plot. In 2002 at surface soil layer, the bacterial population ranged between 3.867 X 10^5 CFU in the month of September in NPK+FYM plot and 16.961 X 10^5 CFU in the month of July in NPK plot. At 10-20 it ranged between 1.085 X 10^5 CFU in the month of October in CTRL plot and 5.735 X 10^5 CFU in the month of June in FYM plot.

The analysis of variance (ANOVA) showed no significant variation on bacterial population between treatments at 0-10 cm and 10-20 cm soil layers (Table 2.3.19). It was also observed that the analysis of variance result showed a significant variation ($p < 0.001$) on bacterial population between 0-10 cm and 10-20 cm soil layers (Table 2.3.20).

The bacterial population at surface soil layer was positively correlated with the population at subsurface soil layer (Table 2.3.21).

In CTRL plot at surface soil layer, bacterial population was positively correlated with microbial biomass carbon and rainfall whereas at subsurface soil layer, the population was positively correlated with organic carbon and potassium (Table 2.3.22).

In NPK treated plot at surface soil layer, bacterial population was positively correlated with rainfall, whereas at subsurface soil layer, the population was positively correlated with pH, organic carbon, microbial biomass carbon, urease activity and rainfall (Tables 2.3.22 and 2.3.22).

In FYM treated at surface soil layer, the bacterial population was positively correlated with available phosphorus, while at subsurface soil layer, the population was positively correlated with rainfall (Tables 2.3.22 and 2.3.22).

In NPK+FYM treated plot at subsurface soil layer, the bacterial population was positively correlated with microbial biomass carbon and rainfall (Table 2.3.23).

Altogether 8 bacterial species were isolated and the total list of isolated bacterial species is shown in tables 2.3.10 - 2.3.17. *Arthrobacter sp. Bacillus sp. and Rhizobium sp.* were the dominant bacterial species during the study period and *Arthrobacter* sp. was isolated only from NPK and FYM treated soils at subsurface soil layer (Table 2.3.18).

Shannon index of general diversity of bacterial species in the first year (2001) at surface soil layer ranged from 0.36 to 1.67 in FYM plot in the month of May and in

CTRL plot in the month of June respectively whereas at subsurface soil layer it ranged from 0.09 to 1.58 in NPK plot in the month of October and in NPK+FYM in the month of May respectively. In the second year (2002) at surface soil layer, it ranged from 0.67 to 1.69 in NPK+FYM plot in the months of April and July respectively, while at subsurface soil layer, it ranged from 0.52 to 1.72 in CTRL and NPK+FYM plots in the month of October (Fig. 2.3.7).

Simpson dominance index of fungal species in the first year (2001) at surface soil layer, ranged between 0.20 and 0.82 in CTRL and FYM in the months of June and April respectively, while at subsurface soil layer, it ranged between 0.20 and 0.79 in NPK+FYM and CTRL in the months of June and August respectively. In the second year (2002) at surface soil layer, it ranged between 0.20 and 0.84 in NPK+FYM and NPK in the month of July, while at subsurface soil layer, it ranged between 0.19 to 0.65 in NPK+FYM and CTRL in the month of October (Fig. 2.3.8).

Sorensen similarity index and Jaccard similarity index displayed a similar result throughout the investigation. At surface soil layer in 2001, Sorensen and Jaccard similarity index showed a maximum of 1.0 at paired treatment of CTRL x FYM, NPK x NPK+FYM plots and a minimum similarity of 0.933 and 0.875 at paired treatment of CTRL x NPK, CTRL x NPK+FYM, NPK x FYM, FYM x NPK+FYM plots. In 2002 maximum similarity index of Sorensen and Jaccard was 1.0 at paired treatment of CTRL x NPK+FYM plots, while the minimum was 0.857 and 0.750 at paired treatment of CTRL x NPK, NPK x NPK+FYM plots (Fig. 2.3.9)

At sub-surface soil layer in 2001, Sorensen and Jaccard similarity index showed a maximum of 1.0 at paired treatment of CTRL x NPK+FYM, NPK x FYM

plots and a minimum similarity of 0.875 and 0.778 at paired treatments of NPK x NPK+FYM plots. In 2002, maximum similarity index of Sorensen and Jaccard was 1.0 at paired treatments of FYM x NPK+FYM plots and minimum was 0.833 and 0.714 at paired treatment of CTRL x FYM, CTRL x NPK+FYM plots (Table 2.3.9).

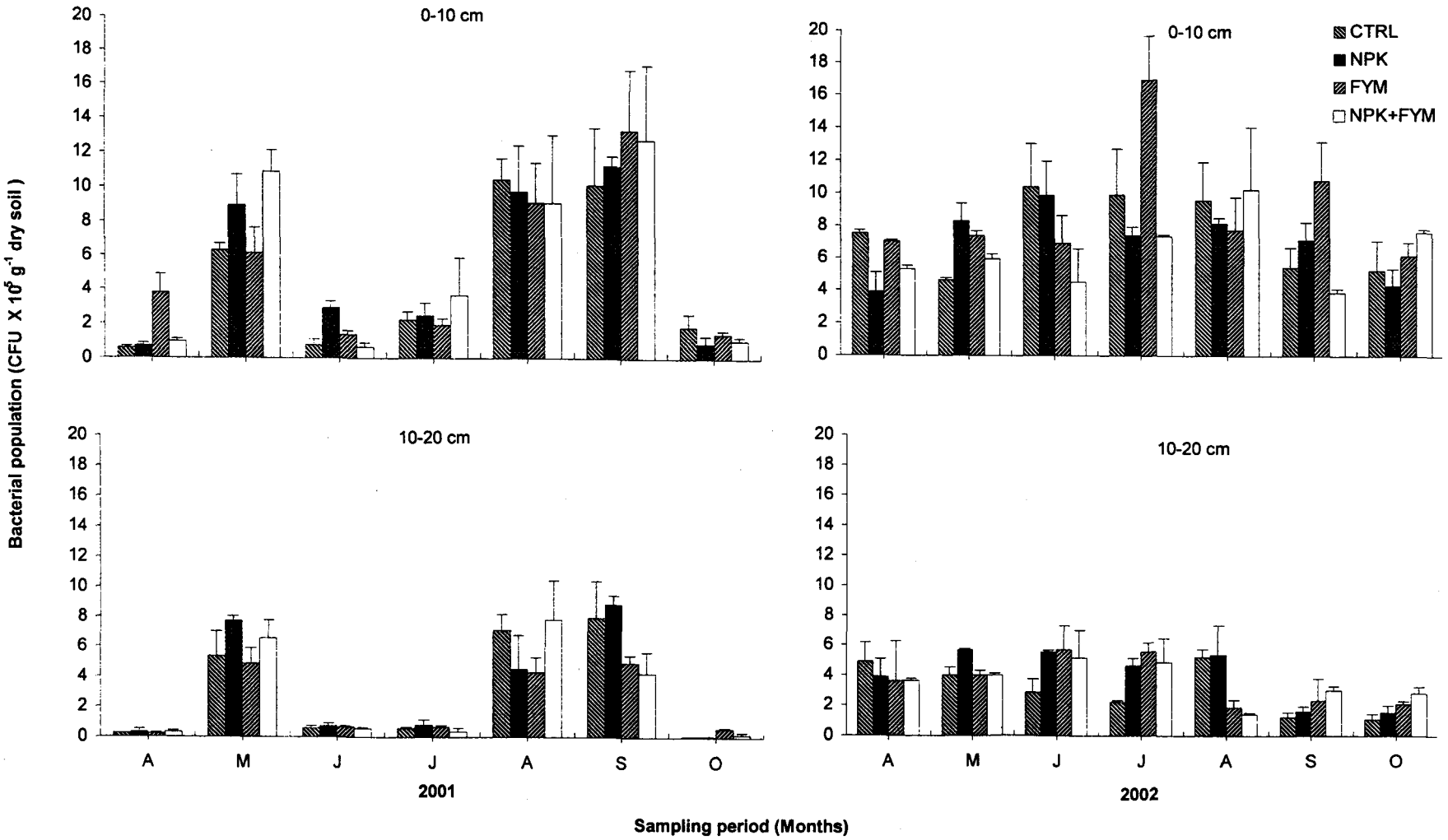


Fig. 2.3.6. Bacterial population in groundnut field soil at 0-10 cm and 10-20 cm depths.

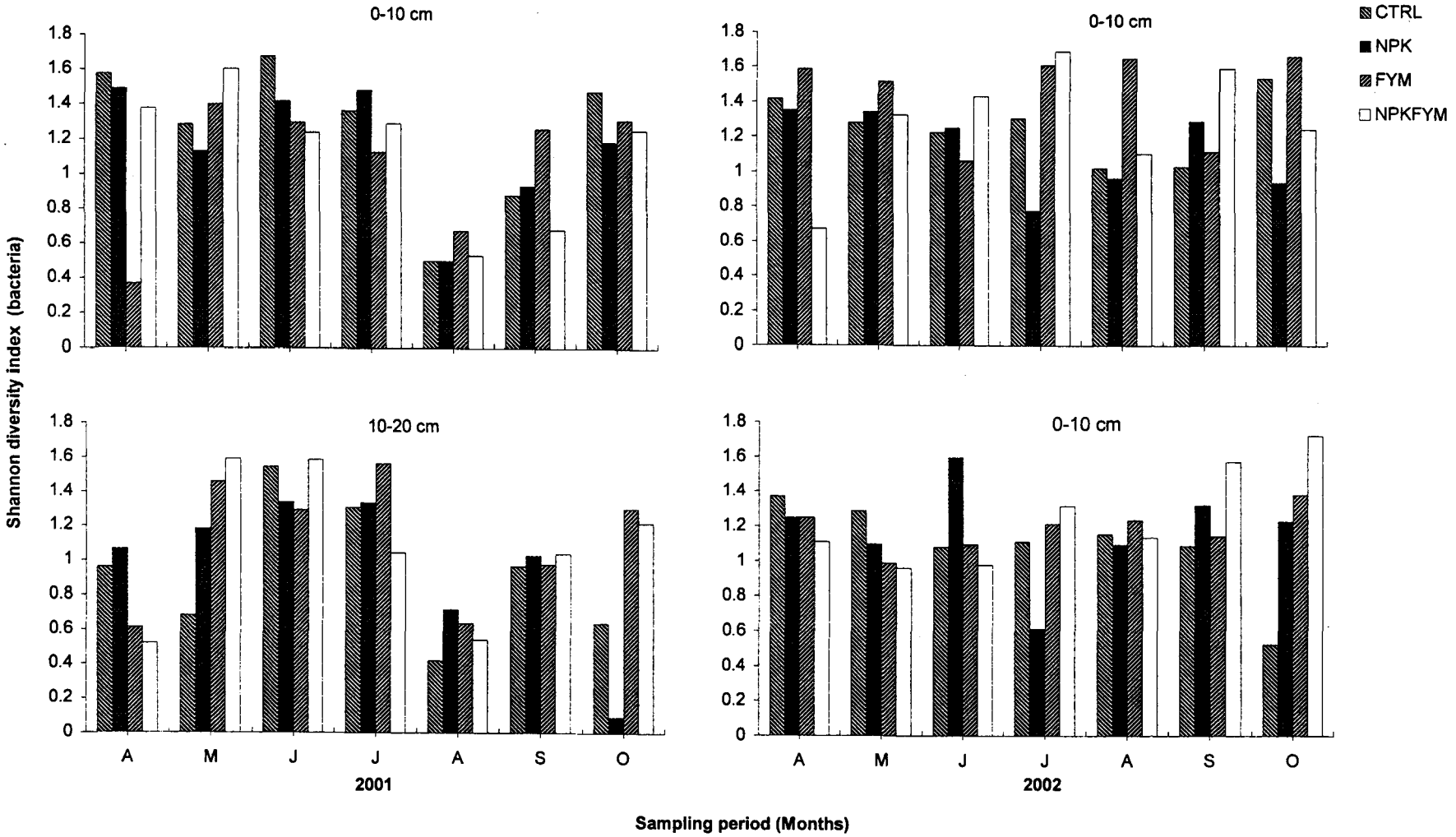


Fig. 2.3.7. Shannon diversity index of bacteria in groundnut field soil at 0-10 cm and 10-20 cm depths.

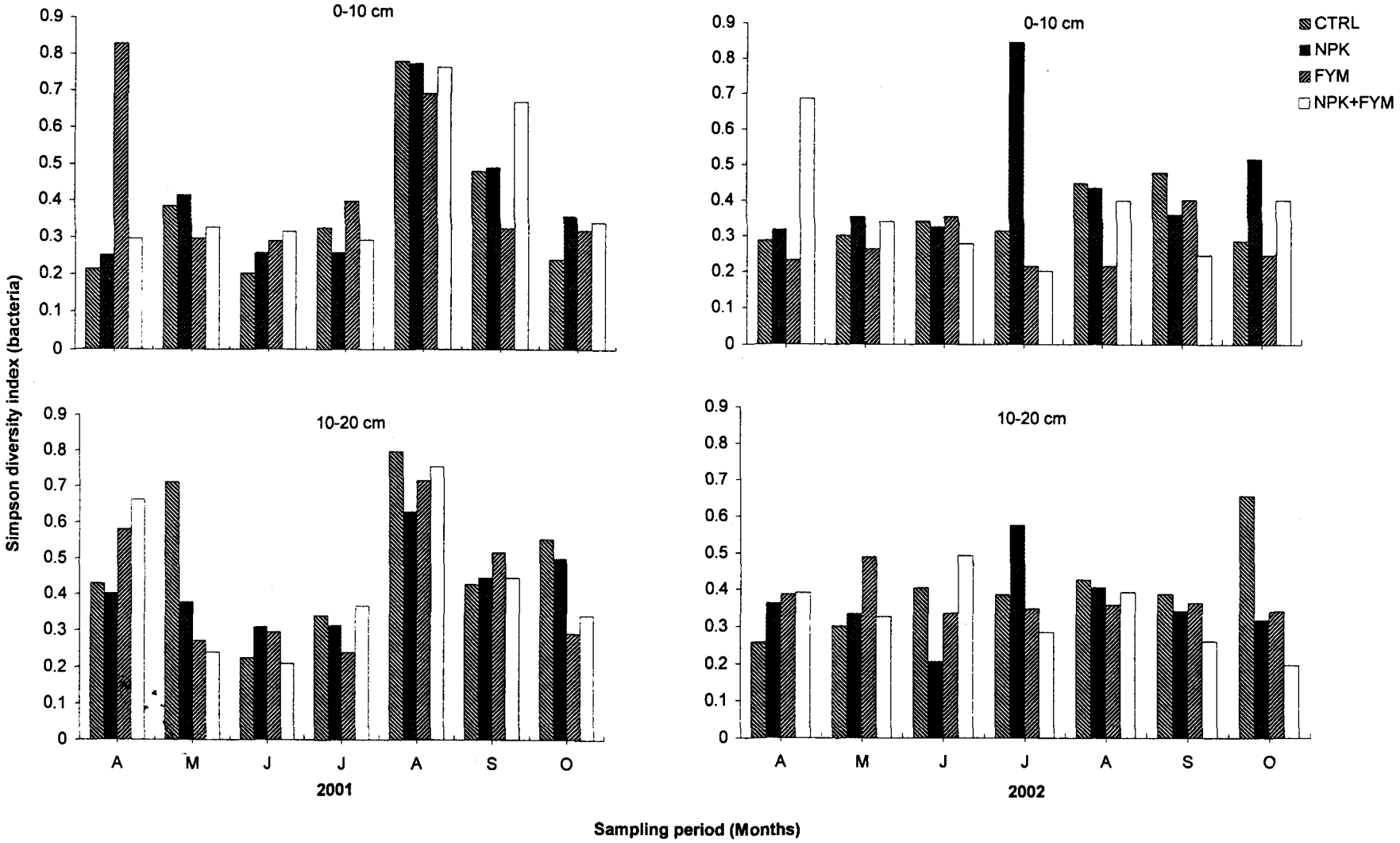


Fig. 2.3.8. Simpson diversity index of bacteria in groundnut field soil at 0-10 cm and 10-20 cm depths.

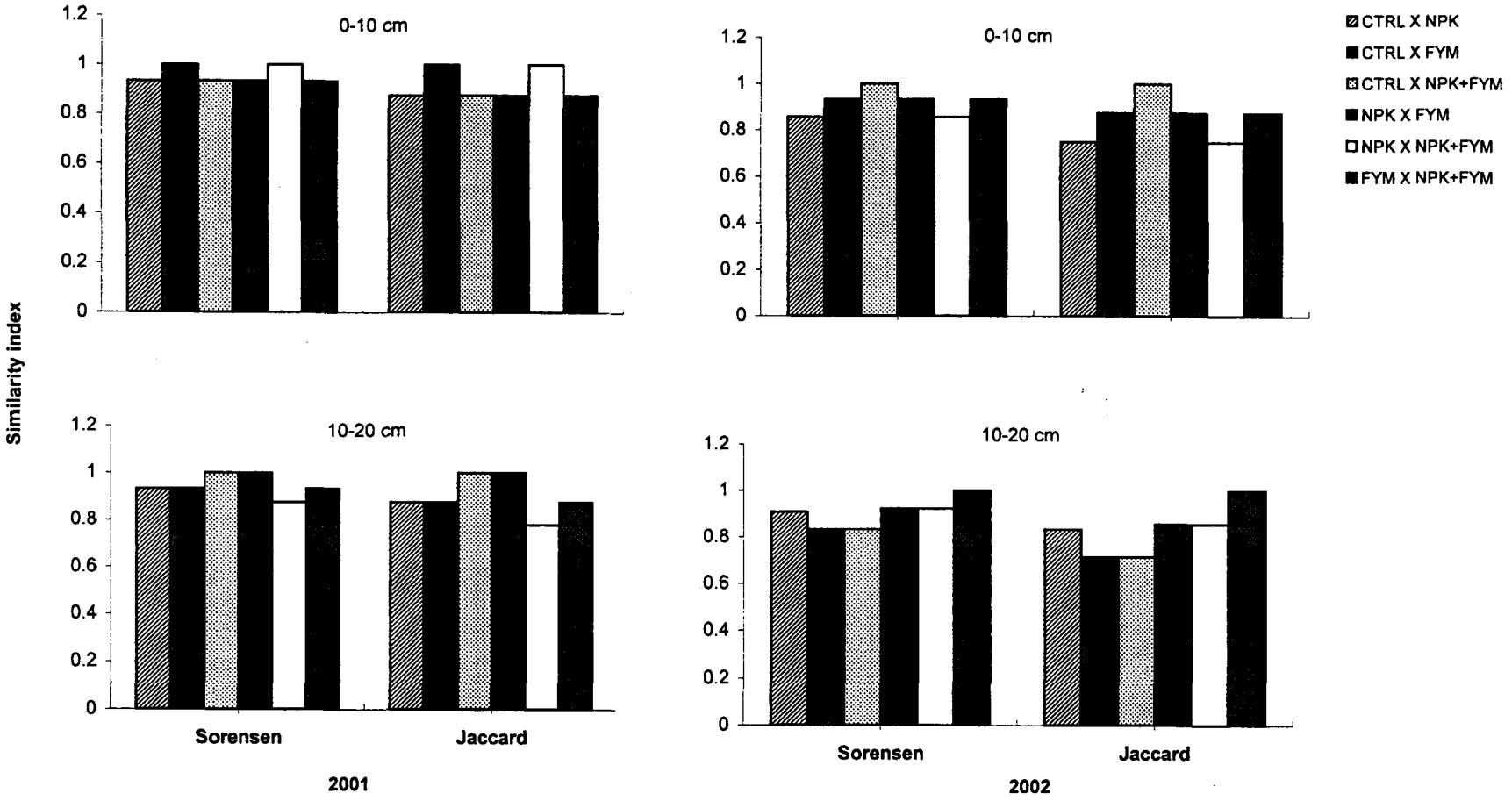


Fig. 2.3.9. Coefficient of Sorensen and Jaccard similarity index of soil bacteria in paired treatment comparisons in groundnut field at 0-10 cm and 10-20 cm soil depths.

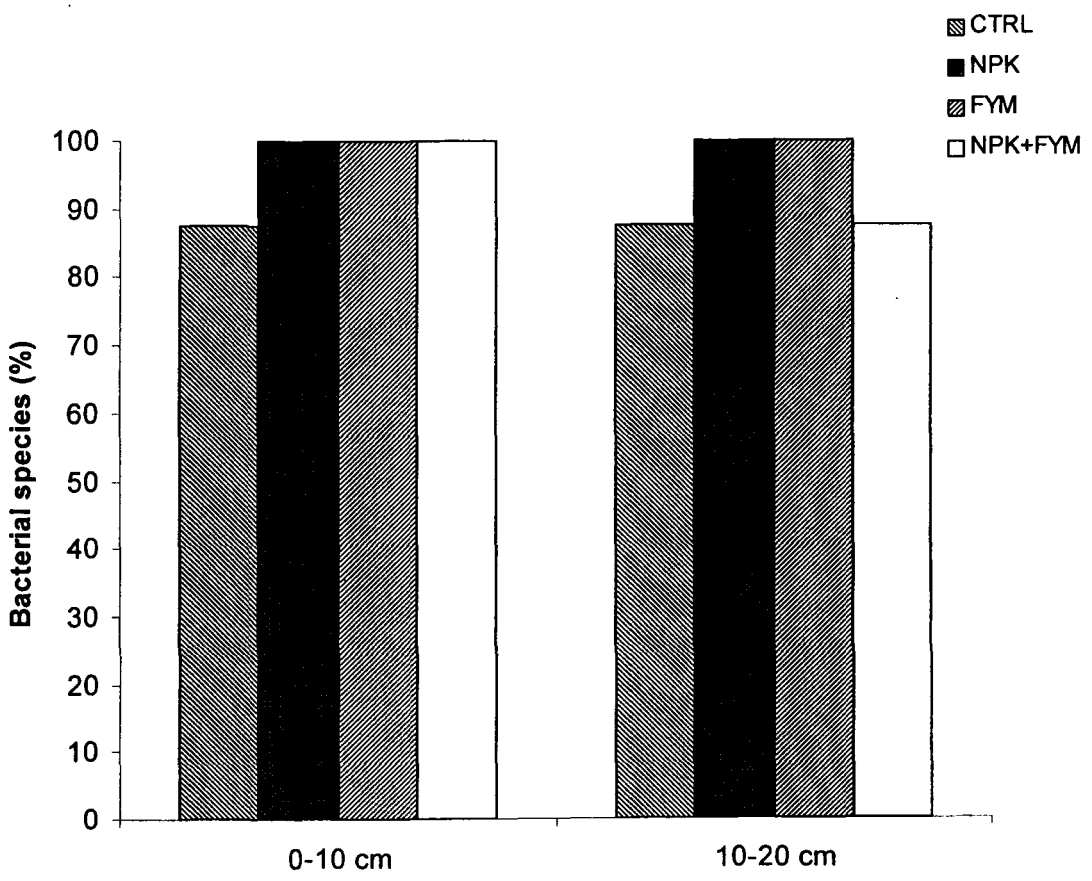


Fig. 2.3.10. Distribution of bacterial species (%) in different plots at 0-10 and 10-20 cm soil depths.

Table 2.3.10. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in control (CTRL) groundnut field at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative abundance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	0.132 (24.009)	0.336 (5.357)	0.124 (25.055)	0.42 (18.75)	9.195 (87.723)	-	0.461 (25.0)	0.372 (7.5)	1.898 (41.0)	1.629 (15.625)	0.464 (14.0)	0.464 (3.937)	0.582 (12.615)	0.258 (3.846)
2	*Bacillus cereus*	-	-	0.064 (7.501)	0.140 (6.25)	-	-	-	-	-	-	-	-	-	0.258 (3.486)
3	*Bacillus subtilis*	0.154 (28.809)	0.808 (12.857)	0.235 (27.53)	1.22 (50.0)	0.344 (3.289)	6.308 (62.015)	0.527 (28.571)	0.807 (16.25)	-	-	1.326 (40.0)	3.004 (31.25)	0.971 (21.026)	0.839 (12.5)
4	*Bacillus sp.*	0.088 (16.086)	3.706 (58.93)	0.128 (15.0)	0.420 (18.75)	0.344 (3.289)	3.187 (31.372)	0.461 (25.0)	0.993 (20.0)	0.521 (11.27)	5.345 (51.25)	1.193 (36.0)	5.674 (59.027)	2.72 (58.873)	3.875 (57.692)
5	*Micrococcus sp.*	0.088 (16.086)	0.134 (2.142)	0.064 (7.501)	0.07 (3.125)	0.551 (5.203)	0.132 (1.307)	0.065 (3.571)	0.559 (11.25)	1.356 (29.296)	-	-	0.066 (0.694)	-	0.193 (2.884)
6	*Pseudomonas sp.*	-	0.808 (12.857)	-	-	-	-	-	-	-	1.760 (16.875)	0.198 (6.0)	0.222 (2.319)	0.194 (4.205)	1.033 (15.384)
7	*Rhizobium sp.*	0.088 (16.086)	0.539 (8.571)	0.150 (17.554)	0.07 (3.125)	-	0.597 (5.882)	0.329 (17.857)	2.236 (45.0)	0.834 (18.027)	1.694 (16.25)	0.132 (4.0)	0.267 (2.77)	0.129 (2.803)	0.258 (3.486)

Table 2.3.11. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in $N_{20}P_{60}K_{40}$ kg/ha (NPK) groundnut field at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	0.065 (10.341)	0.332 (3.713)	0.628 (21.431)	0.633 (24.549)	8.579 (87.671)	2.624 (23.214)	0.088 (10.052)	0.880 (18.108)	0.707 (8.504)	1.953 (19.736)	0.133 (1.785)	0.134 (1.63)	0.91 (13.461)	0.382 (8.823)
2	*Azotobacter sp.*	-	-	0.062 (2.143)	-	-	-	-	-	0.386 (4.638)	-	-	-	-	-
3	*Bacillus cereus*	-	-	0.879 (30.004)	0.136 (5.455)	-	-	-	-	0.45 (5.412)	-	-	-	0.195 (2.889)	0.127 (2.941)
4	*Bacillus subtilis*	0.238 (37.952)	0.797 (8.911)	0.942 (32.117)	0.752 (30.0)	0.536 (5.479)	7.402 (65.476)	0.464 (52.513)	0.398 (8.197)	1.737 (20.875)	-	2.0 (26.785)	2.815 (34.238)	1.30 (19.23)	0.765 (17.647)
5	*Bacillus sp.*	0.130 (20.682)	5.186 (57.995)	0.439 (15.001)	0.82 (32.733)	0.201 (2.054)	1.009 (8.928)	0.198 (22.505)	2.398 (49.133)	4.526 (54.383)	4.817 (48.680)	5.133 (68.75)	4.577 (55.433)	3.706 (54.807)	2.997 (69.117)
6	*Micrococcus sp.*	0.065 (10.341)	0.132 (1.485)	-	0.068 (2.727)	0.469 (4.794)	0.067 (0.595)	-	-	-	-	-	-	-	-
7	*Pseudomonas sp.*	-	2.393 (26.733)	-	-	-	-	-	0.314 (6.455)	0.514 (6.185)	1.432 (14.473)	0.20 (2.678)	0.67 (8.151)	0.52 (7.692)	-
8	*Rhizobium sp.*	0.130 (20.682)	0.132 (1.485)	-	0.136 (5.455)	-	0.201 (1.785)	0.132 (15.003)	0.880 (18.108)	-	1.692 (17.105)	-	-	0.13 (1.923)	0.063 (1.47)

Table 2.3.12. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in farmyard manure 10 t/ha (FYM) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002							
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	-	2.208 (35.869)	0.507 (37.123)	1.057 (57.692)	7.534 (82.502)	2.043 (15.306)	0.227 (15.909)	0.254 (3.125)	2.59 (42.252)	2.023 (29.061)	3.628 (20.835)	2.343 (15.058)	0.536 (4.958)	0.573 (9.245)
2	*Azotobacter sp.*	-	-	-	-	-	-	-	-	0.194 (3.168)	-	-	-	-	-
3	*Bacillus cereus*	-	0.133 (2.173)	-	0.211 (11.538)	-	-	-	-	-	-	-	-	-	0.425 (6.852)
4	*Bacillus subtilis*	0.242 (6.401)	0.233 (3.63)	0.331 (24.201)	-	0.479 (5.25)	5.449 (40.816)	2.728 (47.619)	1.335 (16.406)	1.943 (31.689)	-	4.897 (28.125)	1.768 (22.728)	3.825 (35.329)	1.042 (16.783)
5	*Bacillus sp.*	0.110 (2.912)	2.275 (36.956)	0.397 (29.041)	0.211 (11.358)	0.205 (2.25)	4.904 (36.774)	0.386 (27.00)	2.735 (33.593)	0.647 (10.563)	3.133 (44.998)	0.353 (25.0)	2.586 (33.236)	5.637 (52.063)	2.678 (43.147)
6	*Micrococcus sp.*	-	0.20 (3.26)	-	0.352 (19.23)	0.684 (7.5)	0.34 (2.551)	0.091 (6.380)	0.699 (8.593)	-	-	0.453 (2.605)	0.84 (10.797)	0.134 (1.239)	0.446 (7.191)
7	*Pseudomonas sp.*	-	1.048 (17.032)	-	-	0.205 (2.25)	-	-	0.636 (7.812)	0.561 (9.158)	1.762 (25.471)	1.383 (7.945)	0.84 (10.797)	0.134 (1.239)	0.637 (10.273)
8	*Rhizobium sp.*	3.434 (90.702)	0.066 (1.086)	0.132 (9.68)	-	-	0.681 (5.102)	0.068 (4.761)	2.48 (30.468)	0.194 (3.168)	-	2.676 (15.367)	0.508 (6.536)	0.536 (4.958)	0.404 (6.513)

Table 2.3.13. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in $N_{10}P_{30}K_{20}$ kg/ha + farmyard manure 5 t/ha (NPK+FYM) groundnut field soil at 0-10 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001						2002							
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	0.067 (7.142)	2.732 (28.211)	0.197 (31.055)	0.852 (23.378)	7.938 (87.249)	1.172 (13.393)	0.023 (2.3170	0.063 (1.048)	0.533 (10.425)	0.776 (17.306)	0.686 (9.315)	1.621 (15.789)	0.578 (14.948)	0.502 (6.575)
2	*Azotobacter sp.*	-	-	-	-	-	-	0.033 (2.317)	-	-	-	-	-	-	-
3	*Bacillus cereus*	-	0.409 (3.781)	-	-	-	-		-	-	-	-	-	0.289 (7.482)	0.125 (1.643)
4	*Bacillus subtilis*	0.405 (42.857)	1.024 (9.454)	0.131 (20.703)	1.065 (29.222)	0.139 (1.53)	10.273 (80.36)	0.469 (45.49)	-	1.044 (20.425)	-	2.257 (30.63)	2.162 (21.052)	0.622 (16.103)	1.570 (20.547)
5	*Bacillus sp.*	0.27 (28.571)	2.049 (18.908)	0.263 (41.407)	1.420 (38.963)	0.208 (2.296)	0.410 (3.214)	0.346 (34.106)	0.252 (4.195)	2.259 (44.175)	1.940 (43.265)	1.527 (20.720)	5.878 (57.236)	1.60 (41.379)	4.501 (58.905)
6	*Micrococcus sp.*	0.067 (7.142)	0.683 (6.302)	-	0.355 (9.74)	0.696 (7.653)	0.136 (1.071)	0.138 (13.633)	4.993 (82.86)	-	0.388 (8.653)	0.774 (10.513)	-	-	0.314 (4.109)
7	*Pseudomonas sp.*	-	3.688 (34.035)	-	-	-	-	-	0.469 (9.175)	0.469 (9.175)	0.452 (10.096)	0.752 (10.216)	0.608 (5.921)	0.466 (12.068)	0.565 (7.397)
8	*Rhizobium sp.*	0.135 (14.285)	0.136 (1.26)	0.044 (6.928)	-	0.139 (1.53)	0.205 (1.607)	0.023 (2.317)	0.789 (15.425)	0.789 (15.425)	0.905 (20.190)	1.350 (18.324)	-	0.311 (8.051)	0.062 (0.821)

Table 2.3.14. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in control (CTRL) groundnut field soil at 10-20 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	0.154 (58.50)	0.196 (3.688)	0.126 (21.436)	0.134 (22.230)	6.316 (89.068)	-	0.432 (67.0)	1.183 (24.175)	1.709 (42.556)	0.830 (28.672)	0.128 (5.824)	0.414 (7.925)	-	0.585 (26.994)
2	*Bacillus cereus*	-	-	0.063 (10.718)	0.045 (7.450)	-	-	-	-	-	-	-	-	-	-
3	*Bacillus subtilis*	0.044 (16.750)	0.262 (4.898)	0.189 (32.154)	0.045 (7.450)	0.332 (4.687)	4.339 (54.778)	-	0.979 (20.0)	1.068 (26.599)	-	0.643 (29.120)	0.873 (16.675)	0.107 (11.928)	-
4	*Bacillus sp.*	-	4.478 (84.028)	0.126 (21.436)	0.314 (51.890)	-	2.670 (33.709)	-	1.591 (32.50)	0.748 (18.621)	1.596 (55.138)	1.180 (53.407)	3.229 (61.675)	0.343 (38.142)	1.584 (73.005)
5	*Micrococcus sp.*	-	0.131 (2.458)	-	-	0.443 (6.253)	0.066 (0.842)	-	-	-	-	-	-	-	-
6	*Pseudomonas sp.*	-	0.065 (1.229)	-	-	-	-	-	-	-	0.255 (8.822)	0.257 (11.648)	0.414 (7.925)	0.407 (45.285)	-
7	*Rhizobium sp.*	0.066 (25.0)	0.196 (3.688)	0.084 (14.362)	0.067 (11.120)	-	0.801 (10.112)	0.021 (34.00)	1.142 (23.340)	0.491 (12.238)	0.191 (6.616)	-	0.284 (5.425)	0.064 (7.142)	-

Table 2.3.15. Monthly variation in the population of bacterial species per gram dry soil X 10^5 in $N_{20}P_{60}K_{40}$ kg/ha (NPK) groundnut field soil at 10-20 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	0.022 (6.80)	-	0.335 (45.797)	0.202 (17.647)	3.509 (77.941)	0.662 (8.721)	-	0.765 (19.563)	1.688 (32.925)	1.067 (17.859)	-	0.911 (16.934)	0.194 (14.285)	0.239 (13.107)
2	*Azotobacter sp.*	-	-	0.042 (5.746)	-	-	-	-	-	-	-	-	-	-	-
3	*Bacillus cereus*	-	-	-	0.067 (5.882)	-	-	-	-	-	-	-	-	-	-
4	*Bacillus subtilis*	0.173 (53.4)	0.789 (9.474)	0.188 (25.728)	0.269 (23.529)	0.331 (7.352)	3.973 (52.328)	-	0.318 (8.151)	-	-	1.423 (30.55)	1.041 (19.354)	0.216 (15.904)	0.065 (36.964)
5	*Bacillus sp.*	0.108 (33.40)	4.605 (55.266)	0.125 (17.152)	0..539 (47.058)	0.066 (1.470)	2.516 (33.141)	0.043 (50.375)	2.126 (54.352)	1.837 (35.837)	1.707 (28.572)	3.234 (69.44)	3.125 (58.062)	0.714 (52.380)	0.160 (41.678)
6	*Micrococcus sp.*	-	0.394 (4.737)	-	0.067 (5.882)	0.596 (13.235)	0.264 (3.488)	-	-	-	1.024 (17.141)	-	-	-	-
7	*Pseudomonas sp.*	-	2.302 (27.633)	-	-	-	-	-	0.127 (3.260)	1.602 (31.250)	1.110 (18.577)	-	0.309 (5.648)	0.108 (7.592)	0.282 (15.50)
8	*Rhizobium sp.*	0.022 (6.80)	0.219 (2.636)	0.042 (5.746)	-	-	0.132 (1.744)	0.043 (50.375)	0.573 (14.672)	-	1.067 (17.859)	-	-	0.129 (9.523)	-

Table 2.3.16. Monthly variation in the population of bacterial species per gram dry soil X 10^5in farmyard manure 10 t/ha (FYM) groundnut field soil at 10-20 cm depth during the periods April – October 2001 and 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	-	1.322 (27.273)	0.213 (32.340)	0.069 (10.341)	4.535 (84.240)	0.485 (11.351)	0.220 (40.009)	0.724 (12.886)	0.371 (21.259)	1.915 (33.34)	-	0.152 (8.161)	-	0.258 (12.243)
2	*Azotobacter sp.*	-	-	-	-	-	0.132 (3.092)	-	-	-	-	-	-	-	-
3	*Bacillus cereus*	-	-	-	0.023 (3.519)	-	-	-	-	-	-	-	-	0.178 (7.628)	0.064 (3.06)
4	*Bacillus subtilis*	-	0.330 (6.818)	0.255 (38.722)	0.233 (34.575)	0.290 (5.402)	2.998 (70.120)	-	-	-	-	0.718 (12.889)	0.544 (29.089)	0.845 (36.20)	0.129 (6.121)
5	*Bacillus sp.*	0.064 (30.03)	1.874 (38.647)	0.085 (12.971)	0.186 (27.639)	0.178 (3.323)	0.551 (12.898)	0.154 (28.091)	3.278 (58.340)	0.065 (3.749)	2.110 (36.75)	2.894 (51.956)	0.957 (51.168)	1.09 (46.685)	1.141 (54.086)
6	*Micrococcus sp.*	-	0.198 (4.091)	0.106 (16.170)	0.046 (6.935)	0.313 (5.813)	-	0.066 (12.004)	0.532 (9.477)	1.158 (66.253)	-	-	0.109 (5.824)	-	0.258 (12.243)
7	*Pseudomonas sp.*	-	0.992 (20.455)	-	-	-	-	-	0.532 (9.477)	0.109 (6.261)	-	0.913 (16.404)	-	-	0.258 (12.243)
8	*Rhizobium sp.*	0.151 (70.270)	0.132 (2.727)	-	0.116 (17.287)	0.067 (1.244)	0.132 (3.093)	0.110 (20.048)	0.532 (9.477)	0.043 (2.512)	1.719 (29.931)	1.044 (18.748)	0.109 (5.824)	0.222 (9.542)	-

Table 2.3.17. Monthly variation in the population of Bacterial species per gram dry soil X 10^5 in $N_{10}P_{30}K_{20}$ kg/ha + farmyard manure 5 t/ha (NPK+FYM) groundnut field at 10-20 cm depth for the period from April – October 2001 and April – October 2002. Values in the parentheses are percentage relative dominance.

Sl. No	Bacterial Species	2001							2002						
		A	M	J	J	A	S	O	A	M	J	J	A	S	O
1	*Arthrobacter sp.*	-	1.677 (25.685)	0.129 (23.094)	0.138 (37.523)	6.721 (86.473)	0.531 (10.909)	-	0.063 (1.704)	-	0.75 (14.587)	-	0.130 (9.229)	0.242 (9.742)	0.364 (11.190)
2	*Bacillus cereus*	-	0.358 (5.486)	0.087 (15.473)	-	-	-	-	-	-	-	-	-	0.220 (8.866)	0.385 (11.841)
3	*Bacillus subtilis*	0.246 (78.755)	0.313 (4.798)	0.108 (19.284)	0.069 (18.761)	0.229 (2.947)	3.036 (62.280)	0.044 (25.093)	-	-	-	1.619 (33.33)	0.195 (13.844)	0.441 (17.706)	0.578 (17.761)
4	*Bacillus sp.*	0.067 (21.459)	1.610 (24.658)	0.151 (27.02)	0.162 (43.902)	0.137 (1.764)	0.997 (20.455)	0.022 (12.734)	1.357 (36.372)	2.016 (81.044)	3.474 (67.50)	1.705 (35.12)	0.805 (56.945)	1.08 (43.376)	1.071 (32.899)
5	*Micrococcus sp.*	-	0.358 (5.486)	-	-	0.617 (7.941)	-	0.022 (12.734)	1.887 (50.570)	-	-	0.799 (16.453)	-	-	0.407 (12.512)
6	*Pseudomonas sp.*	-	2.147 (32.877)	-	-	-	-	-	0.127 (3.408)	0.236 (9.490)	0.429 (8.337)	-	0.283 (20.027)	0.242 (9.742)	0.428 (13.163)
7	*Rhizobium sp.*	-	0.112 (1.715)	0.087 (15.473)	-	0.068 (0.882)	0.310 (3.368)	0.089 (50.187)	0.297 (7.959)	0.236 (9.490)	0.493 (9.587)	0.734 (15.120)	-	0.264 (10.618)	-

Table 2.3.18. List of bacteria isolated from control (CTRL), $N_{20}P_{60}K_{40}$ kg/ha, FYM 10 t/ha and $N_{10}P_{30}K_{20}$ kg/ha +FYM 5 t/ha soils of groundnut field at 0-10 cm and 10-20 cm depths during the study period April – October (2001- 2002)

Sl. No	Bacterial species	Soil treatments							
		CTRL		NPK		FYM		NPK+FYM	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
1	*Arthrobacter sp.*	+	+	+	+	+	+	+	+
2	*Azotobacter sp.*	-	-	+	+	+	+	+	-
3	*Bacillus cereus*	+	+	+	+	+	+	+	+
4	*Bacillus subtilis*	+	+	+	+	+	+	+	+
5	*Bacillus sp.*	+	+	+	+	+	+	+	+
6	*Micrococcus sp.*	+	+	+	+	+	+	+	+
7	*Pseudomonas sp.*	+	+	+	+	+	+	+	+
8	*Rhizobium sp.*	+	+	+	+	+	+	+	+

2.4. Discussion

2.4.1. Effect of organic and inorganic fertilizers on soil fungal population

The result which showed an increased in fungal population from pre-fertilizer treatment to post treatment could be due to the increased of soil nutrients. Agricultural practice particularly input of manure and cover crops could have large impact on the size and activity of soil microbial communities (Kirchner *et al.,* 1993) and application of fertilizer increased the soil fertility level and also the number of microorganisms. Tilak *et al.,* (1995) observed that various agricultural management practices such as cropping systems, fertilizer application, cultivation practices, soil organic amendments and fertilizer application can lead to the alteration of microbial dynamic in the agro-ecosystem.

The maximum fungal population observed at NPK treated plot is in agreement with the studies of soil fungal population made by Upadhayay and Rai (1979), which could be attributed that higher fertility and aeration of soil favored wider spectrum of fungal genera and species. In comparison to other treatments the maximum fungal population found in the NPK treated soil could be due to the highest amount of N, P & K and organic carbon of the soil.

The result that showed inconsistent distribution of fungal population within treatments could be due to the retention of fertilizers (which was already applied in the field since from many years back for other experimental purposes). Sarathchandra *et al.,* (1988), Perrott *et al.,* (1992) and Bardgett and Leemans (1994) stated that ceassation of fertilizer application from meadow for 6 years had no effect on the soil microbial community. The same result is also observed by Sarathchandra *et al.,* (1988) and Bardgett and Leemans (1994), they suggested that this lack of

effects of removing fertilizers in the short term is due in part to the long history of fertilization and accumulation of nutrient reserves in the soil before the various experiment began. It was also known that fertilizers adversely affect production of fungal fruit bodies in soil (Garbaye and Le Tacon, 1982). In the present study, the reduced fungal population in fertilized soil may also have been a reflection of shift in the species composition of the fungal community (Bardgett *et al.,* 1993).

The result, which showed the inconsistent fungal population peak, could also be due to the product of transformation of the fertilizers, which might have accumulated, became toxic to fungal populations during some months. There are various reports that fertilizers reduce the fungal population (Broadbent and Nakashima, 1971 and Bagyaraj and Rangaswami, 1976). They reported that fertilizers like urea and ammonium sulphate increase the rate of mineralization of organic nitrogen and reduce the microfungal population. Fungal population could tolerate the fertilizers application and possibly utilize them.

After the soil received fertilizers treatment, there was no significant variation between treatments except CTRL and NPK+FYM at surface soil layer. It was hypothesized that this random distribution of peak population could be due to the enrichment of soil nitrogen through biological fixation of nitrogen by the host legumes and plant composition, which affected the microbial diversity (Bardgett and Shine, 1999). Zak *et al.* (1994) also observed that the plant type affected significant differences on functional microbial diversity. It was noted that legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect (Thies *et al.,* 1995) and the observation of this published research investigation had been

confirmed the present investigation that, lower population was shown during the month of April and October which was the pre-cultivation and post harvest of groundnut respectively.

The abundance and activity of soil microorganisms are influenced by soil type, nutrient status, pH, moisture) as well as plant factors (e.g. species, age). However, shifts in microbial community structure linked to management have been attributed to changes in resource availability, particularly root exudates (Mawdsley and Bardgett, 1997). The higher fungal population could be due to the favorable soil environment viz., soil moisture, relative high temperature and better availability of organic matter and mineral nutrients. Low population may be linked to run-off losses of fungal propagules along with plant materials from the hill slope due to heavy rainfall in the study area (Kshattriya *et al.,* 1992; Maithani, 1996). The higher fungal population in the surface soil may be due to the high organic matter content, nutrient status and better aeration in the surface layer (Balasubramanium *et al.,* 1972) and moisture regime (Selvraj and Rangaswamy, 1978; Clarholm and Rosswall, 1980). The decreased in the population at 10-20 cm depth was linked to the decreased in CO_2 evolution (Tiwari *et al.,* 1986).

The Shannon-Weiner diversity index weight toward the species richness whereas Simpson was more influenced by abundance of most common species. The result showed that FYM plot at surface and subsurface soil layers contributed maximum species richness, wherein out of 56 fungal species isolated, 51 fungal species and 46 fungal species were isolated from surface and subsurface soil layers respectively. The maximum species richness in FYM plot except in 2002 at

subsurface soil layer i.e. at NPK+FYM plot could be due to the higher functional diversity of population than the mineral soil (Staddon *et al.*, 1997) and the availability of favorable condition. The high species diversity could also be due to more accumulation of nitrogen in soils through biological nitrogen fixation; this observation result also confirmed the observation made by Campbell (1976) that the N content of organic matter increased under cropping systems involving legumes.

The minimum species diversity in NPK+FYM plot could be due to the effect of physico-chemical characteristics of soil or products transformation of the fertilizers, which might have accumulated and became toxic to fungal population during later periods. Broadbent and Nakashima (1971) and Bagyaraj and Rangaswami (1976) reported that fertilizers like urea and ammonium sulphate increased the rate of mineralization of organic nitrogen and reduced the microfungal population.

Simpson diversity index showed the reverse results of Shannon diversity index during the investigation. Since this index shows only the most abundant species, the least Shannon index has higher Simpson dominance index.

The maximum similarity index of Sorensen and Jaccard were always observed at a paired treatments of organic and inorganic fertilizers i.e. FYM x NPK plots or at a combination of organic fertilizer and inorganic fertilizer i.e. FYM x NPK+FYM or NPK x NPK+FYM plots throughout the investigation. This observation implies that, some microorganisms exhibited in the soil until and unless the soil was treated with fertilizers (organic and inorganic) or it might be due to higher degree of tolerance of some species to a new soil environment. The reverse result i.e. the minimum similarity index of Sorensen and Jaccard was observed at surface soil layer at a

paired treatment of control either with organic fertilizer (CTRL x NPK+FYM) or with a combination of organic fertilizer and inorganic fertilizer (CTRL x NPK). Pugh (1963) also supported the observation of high similarity index within a treated soil that species composition and number of fungi were greatly influenced by physical and chemical properties of soil. Some fungal population could have tolerated the fertilizers and possibly utilize them.

2.4.2. Effect of organic and inorganic fertilizers on soils bacterial population

The colony form unit of soil bacteria was markedly higher than that of fungi and this result was in agreement with the finding of Staley and Konopka (1985) and Kuske *et al.* (1997) that the majority of soil microorganisms, which for bacteria can amount to 99% of the total microbiota. The increased in bacterial population after the addition of fertilizers might be due to the increased soil fertility levels and this result is agrees with the finding of Tilak *et al.* (1995) that various agricultural management practices such as cropping systems, fertilizer application, cultivation practices and soil organic amendments could leads to the alteration of microbial dynamic in the agro-ecosystem. Sarathchandra *et al.* (1993) also reported that the increased bacterial population (gram negative and rock phosphate-dissolving) was observed 2 weeks after the application of fertilizers, whereas no change in population of these bacteria was observed in unfertilized plot.

The peak in bacterial population observed at FYM and NPK+FYM treatments could be due to the increased in nutrient supply, pH, organic carbon and cation exchange capacity by farmyard manures (Bache and Heathcote, 1969; Heathcote, 1970), whereas low pH restricts legume productivity and adversely affects the

survival, growth and nitrogen fixation of rhizobia as well as legume-rhizobium symbiosis (Lie, 1981). Where Sarathchandra *et al.,* (2001) reported that the N or P treatment had no effect on total bacteria and cellulolytic microbes. The present observation result is in agreement with the findings of Kandeler and Marschner (2003), that the ratios of Gram +ve to gram –ve bacteria and of bacteria to fungi, as determined signature phospholipid fatty acids, were higher in the organic treatments than in the inorganic treatments. They also concluded that the organic amendments increased the C_{org} content of the soil whereas C_{org} content and C/N ratio significantly affected bacteria and eukaryotic community structures. Higher bacterial population at manure treatment was essentially because of the low C:N ratio of the cow dung, a condition which would be more conductive to N mineralization (Asiegbu, 1984).

From long-term manuring experiment in India, Nambiar (1994) reported that the application of farmyard manure and NPK fertilizers improved populations of *Azotobacter*, soil microorganisms, and nodulation of soybean (legume). It can be assumed that the reaction of the microbial community to the addition of manure is very similar to a rhizosphere response. The manured soils are likely to have higher levels of soluble organic C, therefore supporting higher levels of microbial activity. Kennedy (1998) describes the process by stating that many bacteria have a large rhizosphere to bulk soil ratio, indicating marked stimulation in the rhizosphere. Moreover, nonsporulating rods, *Pseudomonas* and other Gram –ve bacteria are especially competitive in the rhizosphere. Species capable of adapting to the agricultural practices will take the advantage of the situation and establish a new

microbial community. In a rich organic soil, such as one of those studied, the number of different chemical substrates will be very high. Bacteria do not specialize on a single substrate, but their diversity is the ability to use combinations of substrate under different physico chemical conditions (Brock and Madigan, 1988; Paul and Clark, 1989). This hypothesis suggests that the use of organic vs. inorganic nutrient sources results in widely diverging microbial communities with possibly different ecological functions. If the application of manures results in a rhizosphere-like response, then the microbial community in manured soils is likely to be more metabolically active, responding quickly to the input of fresh organic residue. Indeed, the use of organic nutrient sources depends on microbial activities for the mineralization of plant available nutrients. The long-term use of manure also supplied large amounts of readily available C, resulting in a more diverse and dynamic microbial system than in inorganically fertilized soil. Kirchner *et al.* (1993) showed that agricultural practices particularly in put of manure and cover crops could have large impacts on the size and activity of soil microbial communities.

Since fertilizers treatment showed positive effects on soil microorganisms after a few days of application, it was assumed that the treated plot should display higher bacterial population than control plot. But the analysis of variance showed insignificant variation on bacterial population between fertilizers treated plots. While Campbell (1978) also showed that the N content of organic matter has been shown to increase under cropping systems involving legumes. This insignificant variation of bacterial population could be due to the enrichment of soils through biological fixation of nitrogen by the host legumes (groundnut), where plant composition is

known to affect microbial diversity (Bardgett and Shine, 1999). Thies *et al.* (1995) supported the present result and they mentioned that legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect. The rhizosphere is a system exposed to environmental fluctuations due to shift on composition of root exudates, which has a marked influence on microbial communities (Lynch and Whipps, 1990).

The lower population observed during the months of April and October, which were the pre-cultivation and post harvest periods of groundnut respectively was in agreement with the observation of Lahav (Lavian) and Steinberger (2001). This is because of the fact that the bacterial functional diversity in agro-ecosystems would be affected by plant growing stages. It was also known that the abundance and activity of soil microorganisms are influenced by various environmental factors (e.g. soil type, nutrient status, pH, moisture). However, shifts in microbial community structure linked to management have been attributed to changes in resource availability, particularly root exudates (Mawdsley and Bardgett, 1997).

The reduction of bacterial population in the months of June and July in the first year may be due to the decreased in soil pH. Ayanaba and Omayuli (1975) stated that acidity significantly influences microbial abundance and it has been observed that high acidity (pH<4.2) contains the lowest population of cellulolytic microbes, *Nitrosomonas, Nitrobacter* and denitrifiers. 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 greater tolerance to

acidity and through reduced competition from other microorganisms (Alexander, 1980).

Among several factors affecting microbial population and activity, moisture and nutrient regime and soil depth are important factors. The peak bacterial population during the investigation could also be due to the favorable soil moisture, relative high temperature and better availability of organic matter and mineral nutrients. The reduction in bacterial population from surface soil layer to subsurface soil layer may be due to the high organic matter, nutrients status and better aeration in the surface layer (Balasubramanium *et al.,* 1972) and moisture regime (Selvraj and Rangaswamy, 1978; Clarholm and Rosswall, 1980). The decreased in population at 10-20 cm in the present result may be due to the decreased in oxygen, the surface soil generally showed higher values for fungal and bacterial populations and CO_2 evolution decreased with increase in depth (Tiwari *et al.,* 1986). Alexander (1977) and Bohn *et al.* (1979) reported that the amount of CO_2 in soil affects the soil pH, nutrient availability, redox potential, species composition and number of soil microbes.

The high species diversity observed during the study period, was likely influenced by the availability of host legumes plant and lower dosage of fertilizers. The result showed that except in first year, all of the maximum diversity was displayed after groundnut was sown in NPK+FYM plot. The minimum diversity of bacterial population was due to the absence or presence of the host legume plant rather than the types and doses of fertilizers treatment. This result is inconformity with the result of Bowen and Rovira (1991) and Bolton *et al.* (1992) that the variety

of organic compounds released by plants has been postulated to be a key factor influencing the diversity of microorganisms in the rhizospheres of different plant species. *Pseudomonas, Flavobacterium, Acaligenes* and *Agrobacterium* species had been stimulated particularly in the rhizosphere due to the release of exudates and lysates (Curl and Truelove, 1986).

Simpson diversity index showed the reverse results of Shannon diversity index during the investigation. Since this index shows only the most abundant species, the least Shannon index has higher Simpson dominance index.

The index of Sorensen and Jaccard, which showed a maximum similarity of bacterial species at paired treatment, was at the combination of inorganic and organic fertilizer (NPK+FYM) and other treatments as well as control plot. This observation showed that NPK+FYM treatment had a high diversity of population than the other treatments. The NPK+FYM treatment, which was the combination of 50% of the NPK and FYM treatments alone, might be the optimum dosage for some bacterial population.

Table 2.3.19. One way analysis of variance (ANOVA) of the microbial population of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) and subsurface (10-20 cm) layers ($P \leq 0.05$).

Soil properties	Source of variation	Surface layer (0-10 cm)		Subsurface layer (10-20 cm)	
		F-ratio	P-level	F-ratio	P-level
Fungal population	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK		-	-	-
	CTRL X FYM	4.373	0.03	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-
Bacterial population	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-

Note: Insignificant values are marked with ' – ' sign

Table 2.3.20. One way analysis of variance (ANOVA) of the microbial population of soil between surface (0-10 cm) and subsurface (10-20 cm) soil layers of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.001$).

Soil properties	Treatments	F-ratio	P-level
Fungal population	CTRL	71.5069	1×10^{-6}
	NPK	30.9592	1×10^{-6}
	FYM	41.4555	1×10^{-6}
	NPK + FYM	32.3499	1×10^{-6}
Bacterial population	CTRL	16.9029	9.3×10^{-5}
	NPK	13.1599	4.9×10^{-4}
	FYM	27.0226	1×10^{-6}
	NPK + FYM	13.8954	3.5×10^{-4}

Table 2.3.21. Correlation coefficient (r) values among microbial population in between surface (0-10 cm) and subsurface (10-20 cm) soil of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Treatments (0-10 X 10-20 cm)	Fungal population	Bacterial population
CTRL	0.5267^{c}	0.7114^{c}
NPK	0.6404^{c}	0.8437^{c}
FYM	0.3607^{a}	0.5511^{c}
NPK+FYM	0.5209^{c}	0.5411^{c}

Note: Values marked with a and c are significant at $P \leq 0.05$ and $P \leq 0.001$ respectively

Table 2.3.22. Correlation coefficient (r) values among microbial population with various biological, biochemical and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) soil layer ($P \leq 0.05$).

Treatments	Soil properties	BP	AT	ST	MC	pH	OC	TN	AP	K	SR	C_{mic}	DHA	URA	PA	RF
CTRL	FP	-	0.4935^{c}	-	-	-0.4732^{b}	-	0.5195^{c}	0.3907^{a}	-0.5189^{c}	-	0.3524^{a}	-	-	-	-
	BP		-	-	-	-	-	-	-	-	-	0.5841^{c}	-0.3101^{a}	-	-	0.3688^{a}
NPK	FP	-	-	-	-	-0.4255^{b}	0.5901^{c}	-	-	-	-	0.4254^{b}	0.3070^{a}	-	-	-
	BP		-	-	-	-	-	-	-	-	-	-	-	-	-	0.3286^{a}
FYM	FP	-	0.3306^{a}	-	-	-	-	0.3207^{a}	-	-	0.4294^{b}	0.4135^{b}	-	-	-	-
	BP		-	-	-	-	-	-0.3557^{a}	0.3666^{a}	-	-	-	-0.3223^{a}	-	-	-
NPK+FYM	FP	-	0.4054^{b}	-	-	-0.3716^{a}	-	0.3842^{a}	0.5390^{c}	-	-	0.5004^{c}	-	-	-	-
	BP		-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.3.23. Correlation coefficient (r) values among microbial population with various biological, biochemical and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at subsurface (10-20 cm) soil layer ($P \leq 0.05$).

Treatments	Soil properties	BP	AT	ST	MC	pH	OC	TN	AP	K	SR	C_{mic}	DHA	URA	PA	RF
CTRL	FP	-	-	0.3628^{c}	-	-	-	0.3546^{a}	-	-0.3929^{b}	-	-	0.7592^{c}	-	-	-
	BP		-	-	-	-	0.4990^{c}	-	-0.5871^{c}	0.3766^{a}	-	-	-	-	-	-
NPK	FP	-	-	-	-	-	0.3213^{a}	0.3322^{a}	-	-	0.3335^{a}	0.4022^{b}	0.6342^{c}	-	-0.3203^{a}	-
	BP		-	-	-	0.4483^{b}	0.3240^{a}	-	-	-	-	0.3062^{a}	-	0.3067^{a}	-	0.3112^{a}
FYM	FP	-	-	-	-	-	-	-	-	-	-	-	0.4796^{c}	-	-	-
	BP		-	-	-	-	-	-0.4110^{b}	-	-	-	-	-	-	-	0.4860^{c}
NPK+FYM	FP	-	-	-	-	-	-	-	0.5964^{c}	-	0.4117^{b}	0.3139^{a}	0.3177^{a}	-	-	-
	BP		-	-	-	-	-	-	-	-	-	0.3321^{a}	-	-	-	0.3167^{a}

(Note: FP=fungal population, BP=bacterial population, AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available hosphorus, K=exchangeable potassium, SR=soil respiration, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity, RF=rainfall)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Chapter-3

Soil microbial biomass carbon (C_{mic}) and soil respiration in agro-ecosystem

3.1. Introduction

The assessment and quantification of microbial biomass carbon and soil respiration (CO_2 evolution) in agro-ecosystem can be used as sensitive indicator for the status and changes in the agro-ecosystem and soil fertility levels, and it can also predict the future soil quality and ecosystem functioning. In addition, biomass measurement have been used to give an early indication of changes in the organic matter content of soils due to variation in soil management (Insam *et al.*, 1989 and Brookes, 1995). Soil microbial biomass, which represents about 1-4% of total soil organic C, is more sensitive indicator of changing soil conditions than direct analysis of the organic C content.

Soil microorganisms are important in the cycling of almost all the major plant nutrients (Smith and Paul, 1990), particularly so in natural and agriculture ecosystems with low inputs. A number of soil microbiological parameters, notably microbial biomass carbon and basal respiration (Doran and Parkin, 1994; Sparling, 1997), have been suggested as possible indicators of soil quality and have been employed in national and international monitoring programs. Soil microbial biomass can be 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; Insam *et al.*, 1991; Pankhurst *et al.,* 1995).

Microbial biomass carbon is considered to be a transformation agent of soil organic materials and a labile reservoir of nutrients such as C, N, P and S (Jenkinson and Ladd, 1981). The quantity and composition of microbial biomass is sensitive to changes in the soil chemical and physical environments (Wolters and Joergensen, 1991; Wardle, 1992; Bauhus and Khanna, 1994; Beck *et al.,* 1995).

Carbon dioxide evolution, the major product of aerobic catabolic processes in the C cycle, is also commonly measured and indicates the total C turnover. The metabolic quotient, i.e. the ratio of basal respiration to microbial biomass, is inversely related to the efficiency with which the microbial biomass uses the indigenous substrates (Anderson and Domsch, 1990) and can be related to soil development and ecological succession (Insam and Domsch, 1988). Soil respiration is the evolution of CO_2 from soil surface as a result of microbial and root respiration (Schlenther and Cleve, 1985; Wagai *et al.*, 1998) and its measurement can be utilized to assess relative productivity and fertility of soils (Upadhyaya *et al.*, 1997). Soil respiration is considered as one of the indices of microbial activity in soil (Anderson and Domsch, 1975 and Tiwari *et al.*, 1989) and biological activity. Carbon dioxide evolution has been used as an index of microbial activity of agricultural and forest soils (Julia and Pedziwik, 1985).

Soil surface CO_2 flux is a major transfer of carbon from terrestrial ecosystem to the atmosphere and land use practices, vegetation type, organic matter content, pool fractions, fine root biomass and biodiversity in both plant and

microbial communities significantly affect CO_2 flux (Wagai *et al.,* 1998). Keith *et al.* (1997) reported that the nutrient availability in soil and nutritional quality of litter influenced microbial utilization efficiency of organic compounds. The changes in nutrient availability in soil can also cause changes in the composition of microbial population, and thus alter soil CO_2 efflux.

3.2. Methodology

3.2.1. 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 25^0 C. Weighted another 10 g of each sample for un-fumigated extraction (ct_2). The sample was then kept in a watertight extraction bottle (125 ml) and extracted directly without fumigation with 50 ml of 0.5 M K_2SO_4 and was shaken for 30 minutes. After 5 days the fumigated soil (ct_1) sample was extracted like the un-fumigated 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 150^0C for 30 minutes. Two blanks were prepared i.e. one preheated at 150^0C 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 K_2SO_4 solution was added in place of sample filtrate solution.

The microbial biomass C was calculated as follows:

Organic C (%) = {(A x M x 0.003)/g} X (E/S) X 100

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

$A = (Ml_{HB} - Ml_{sample}) X \{(Ml_{UB} - Ml_{HB})/Ml_{UB}\} + (Ml_{HB} - Ml_{sample})$

G = Dry soil mass (g)

E = Extraction volume (ml)

S = Digest sample volume (ml)

Microbial biomass C = (Extracted ct_1 *– Extracted* ct_2*) X 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.

3.2.2. Soil respiration

Soil respiration was measured by the method of McFadyen (1970). One kg of soil from each sample was placed in a glass jar. 100 ml glass beaker containing 20 ml of 0.1N potassium hydroxide (KOH) solution was kept inside of each jar. The lid of the jar was then sealed by grease to make it air tight and kept for 24 hours. The jar lid was open and carbon dioxide fixed by potassium hydroxide was estimated by titrating the same with 0.1N hydrochloric acid (HCl) solution using phenolphthalein as an indicator. While for the subtraction of atmospheric carbon

dioxide, a control was run by using sterilized sand instead of soil sample. Replicates were maintained for each sample. The soil respiration was expressed as CO_2 evolved in terms of mg CO_2 evolved/kg/24 hours on dry weight basis.

Calculation

$$CO_2\ (mg) = (B\text{-}V)\ N\ X\ E$$

Where, B = Volume of acid titrate without the sample

V = Volume of acid titrate with soil sample

N = Normality of the acid

E = Equivalent weight of CO_2 (E=22)

3.3. Results

3.3.1. Microbial biomass carbon (C_{mic})

Soil microbial biomass carbon (C_{mic}) increased from pre-fertilizers treatment to post fertilizers treatment. The peak microbial biomass carbon was observed at NPK and NPK+FYM plots, whereas the minimum was observed at CTRL and FYM plots. The CTRL plot showed decreased in C_{mic} from September to October (Fig. 3.3.1).

In the first year at the surface soil layer, C_{mic} ranged between 42.46 and 1061.17 μg C g^{-1} dry soil in FYM plot in the months of August and in NPK+FYM plot in the month of May respectively. At the sub-surface soil layer, it ranged from 16.17 to 817.67 μg C g^{-1} dry soil in FYM plot in the month of April and in NPK+FYM plot in the month of May respectively. In the second year at the surface soil layer, C_{mic} ranged between 50.733 and 416.581 μg C g^{-1} dry soil in CTRL plot in the month of October and in NPK plot in the month of July respectively. While at

the subsurface soil layer, it ranged between 31.692 and 414.35 μg C g^{-1} dry soil in the months of October and July in NPK plot respectively.

The analysis of variance showed insignificance variation ($P \leq 0.05$) on C_{mic} among the treatments at surface and subsurface soil layers (Table 3.3.1). The ANOVA also showed the significant variation ($P \leq 0.001$) on microbial biomass carbon between surface and subsurface soil layers except in NPK+FYM plot (Table 3.3.2) and C_{mic} at surface soil layer was positively correlated ($P \leq 0.001$) with C_{mic} at subsurface soil layer (Table 3.3.3).

In CTRL plot at surface layer, C_{mic} was positively correlated with ambient temperature, fungal population, bacterial population and rainfall. At subsurface soil layer it was positively correlated with ambient temperature and rainfall (Tables 3.3.4 and 3.3.5).

In NPK plot at surface layer, C_{mic} was positively correlated with organic carbon, fungal population, dehydrogenase activity and urease activity and at subsurface layer it was positively correlated with soil pH, fungal population, bacterial population and dehydrogenase activity (Tables 3.3.4 and 3.3.5).

In FYM plot at surface layer, C_{mic} was positively correlated with total nitrogen, available phosphorus, fungal population and dehydrogenase activity and at subsurface layer, it was positively correlated with soil respiration, ambient temperature, soil pH, organic carbon, available phosphorus and rainfall (Tables 3.3.4 and 3.3.5).

In NPK+FYM plot at surface layer, C_{mic} was positively correlated with soil temperature, moisture content, organic carbon, total nitrogen, fungal population,

dehydrogenase activity and acid phosphatase activity and at subsurface layer it was positively correlated with soil temperature, organic carbon, fungal population, bacterial population and dehydrogenase activity (Tables 3.3.4 and 3.3.5).

3.3.2. Soil respiration

The maximum soil respiration displayed in FYM plot in the month of July throughout the investigation. Unlike microbial biomass carbon, the result showed that soil respiration decreased from pre-fertilizers treatment to post treatment except in NPK and NPK+FYM plots at subsurface layer in 2002 and the soil respiration was dropped at post harvest (Fig. 3.3.2).

In the first year at surface soil layer, soil respiration ranged between 2.739 and 6.645 mg CO_2 100 g^{-1} soil $24h^{-1}$ in NPK plot in the month of October and FYM plot in the month of July respectively, whereas at subsurface soil layer, it ranged from 1.503 to 5.945 mg CO_2 100 g^{-1} soil $24h^{-1}$ in NPK plot in the month of October and in FYM plot in the month of July respectively.

In the second year at surface layer, soil respiration ranged from 2.676 to 6.363 mg CO_2 100 g^{-1} soil $24h^{-1}$ in the month of October and in the month of July in FYM plots respectively, whereas at subsurface layer, it ranged from 1.33 to 4.064 mg CO_2 100 g^{-1} soil $24h^{-1}$ in CTRL plot in the month of June and FYM plot in the month of July respectively.

The analysis of variance (ANOVA) showed significant variation ($P \leq 0.05$) of soil respiration between NPK and FYM treatments at 0-10 cm soil layer, whereas at 10-20 cm soil layer, significant variation among the treatments except in between CTRL and NPK plots (Table 3.3.1). The result also showed that

significant variation ($P \leq 0.001$) of soil respiration between surface and subsurface soil layers (Table 3.3.2) and soil respiration at surface layer was positively correlated ($P \leq 0.001$) with soil respiration at subsurface soil layer (Table 3.3.3).

The correlation coefficient values in CTRL plot in surface layer showed that the soil respiration was positively correlated with ambient temperature and moisture content. While at subsurface soil layer it was, positively correlated with ambient temperature, moisture content, total nitrogen and available phosphorus (Tables 3.3.4 and 3.3.5).

In NPK plot at surface soil layer, soil respiration was positively correlated with ambient temperature and moisture content and at subsurface soil layer it was positively correlated with ambient temperature, moisture content, total nitrogen, fungal population and dehydrogenase activity (Tables 3.3.4 and 3.3.5).

In FYM plot at surface soil layer, soil respiration was positively correlated with ambient temperature, moisture content, available phosphorus and fungal population. While at subsurface soil layer, it was positively correlated with ambient temperature, moisture content, total nitrogen and available phosphorus (Tables 3.3.4 and 3.3.5).

In NPK+FYM plot at surface soil layer, soil respiration was positively correlated with ambient temperature, moisture content and total nitrogen. While at subsurface soil layer, it was positively correlated with ambient temperature, moisture content, total nitrogen, available phosphorus and fungal population (Tables 3.3.4 and 3.3.5).

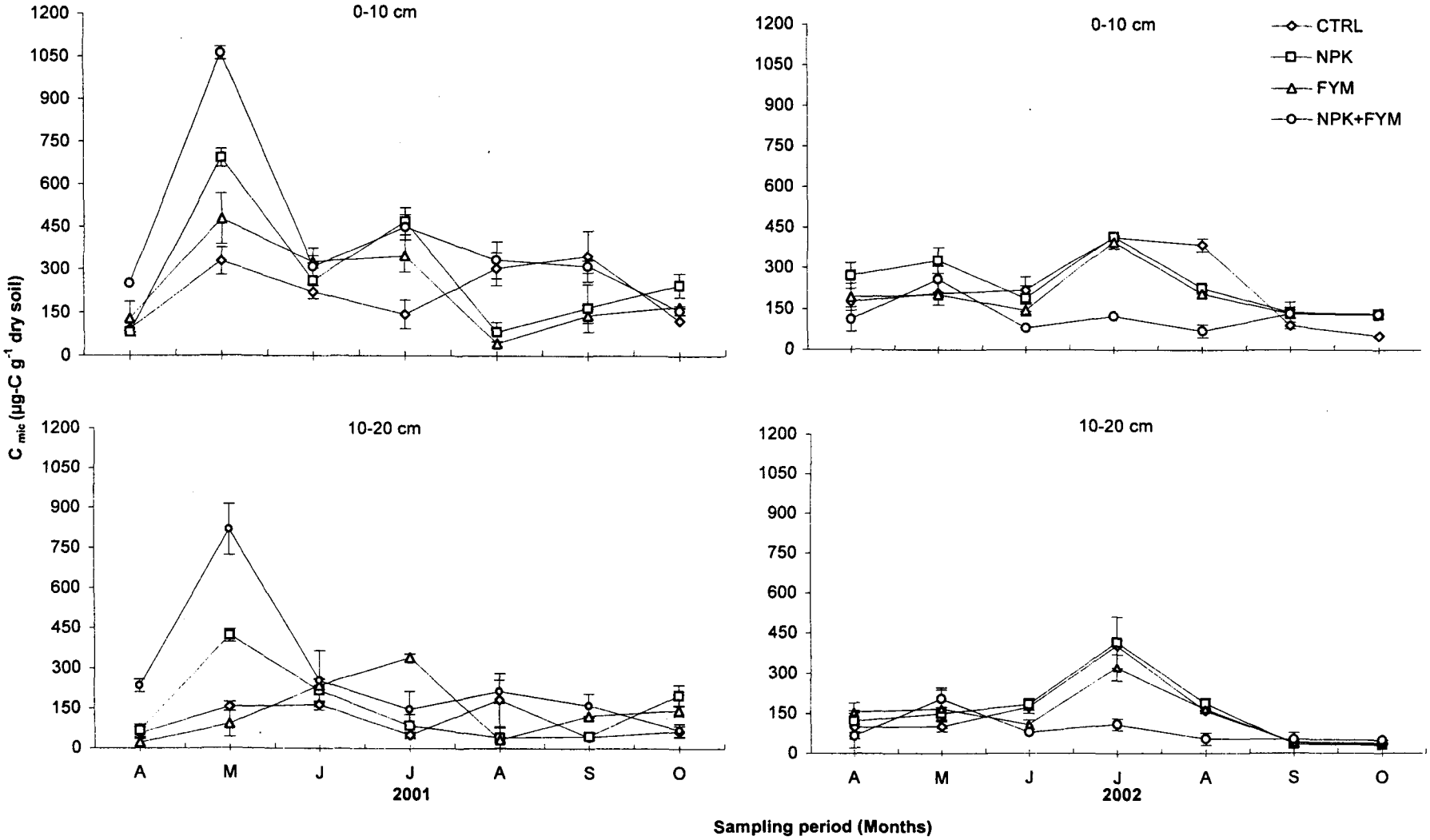


Fig. 3.3.1. Microbial biomass carbon (C_{mic}) in groundnut field soil at 0-10 cm and 10-20 cm depths.

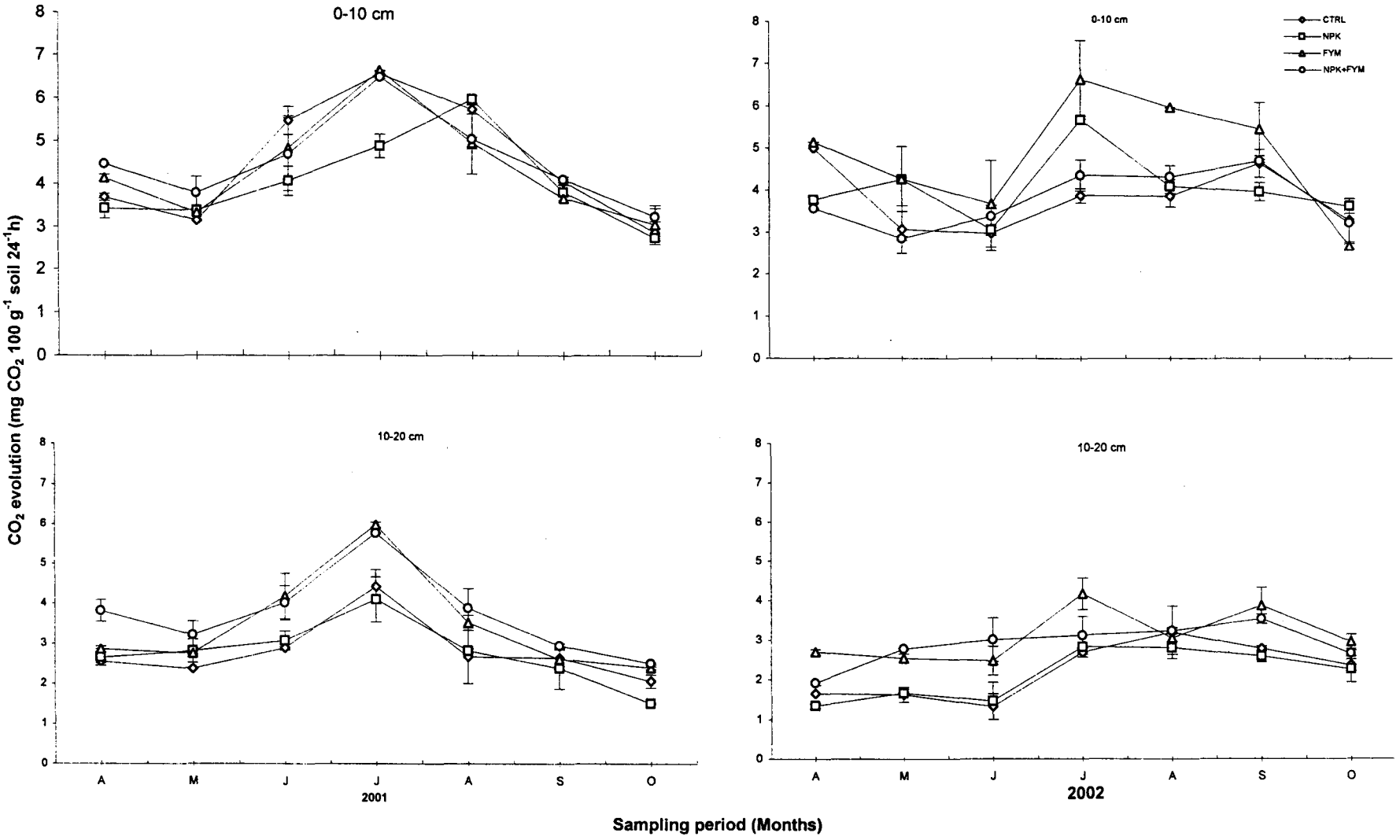


Fig. 3.3.2. Carbondioxide (CO_2) evolution in groundnut field soil at 0-10 cm and 10-20 cm depths.

3.4. Discussion

3.4.1. Effects of organic and inorganic fertilizers on the distribution of soil microbial biomass C

Microbial biomass carbon (C_{mic}) increased shortly after the application of fertilizers throughout the investigation and this result could be due to the increased in soil microbial populations (fungi and bacteria) and the effect of root exudation. Jordan *et al.* (1995) reported that the main components of soil microbial biomass are fungi and bacteria. The present result is in agreement with the observation of Polyanskaya *et al.* (1997), that microbial biomass carbon measures the total biomass C (fungi + bacteria) and the specific studies have indicated that fungi are dominant component of the total soil microbial biomass accounting for up to 90% of total. It was also known that plant root exudates can influence the presence and growth of soil microbial population, since the host plant was leguminous plant, it was expected to support the soil microbial population especially those of symbiotic nitrogen fixing bacteria i.e. *Rhizobium* sp. Perfect *et al.* (1990) reported that higher C_{mic} values are commonly found in crops with intensive root growth and root density. In addition, it was noted that there were differences in rhizosphere population because of the variations in the concentrations and types of organic compounds released by the roots of different plants (Lynch and Bragg, 1985).

The result that showed maximum amount of C_{mic} in fertilized plots might be due to the higher accumulation of organic carbon. It was noted that manure applications typically result in increased soluble organic C in soil (Bhogal and Shepard, 1997; Gregorich *et al.,* 1998; Liang *et al.,* 1998). Goyal *et al.* (1992) reported that the effects of inorganic fertilizer and organic amendments on organic

matter-microbial biomass relationships in field experiments under tropical conditions have shown that soil microbial biomass C and N increased with balanced fertilization. They also found that addition of the organic amendments increased microbial biomass even when the organic C content of the soil did not increase. Wardle (1992) reported that soil microbial biomass is usually resource limited and thus microbial C and N concentrations are generally related to amount of soil C and N. It was also known that soil management practice i.e. manuring increased carbon input to the soil (Ritz *et al.,* 1997) and therefore the ratio of microbial C to soil organic carbon has thus been used as an indicator for C availability (Insam and Domsch, 1988).

Since inorganic fertilizer reduced soil microbial biomass carbon (Biederbeck *et al.,* 1984; McAndrew and Malhi, 1992; Ladd *et al.*, 1994), the control and FYM plots were expected to show higher amount of microbial biomass carbon rather than those inorganic (NPK) treated plot during the investigation (Sakamoto and Oba, 1994; Lovell *et al.,* 1995 and, Hopkins and Shiel, 1996). But it was observed that C_{mic} showed inconsistent distribution i.e. within sampling period higher C_{mic} was also noted in NPK (inorganic) or NPK+FYM plots. So, it can be hypothesized that this inconsistent distribution could be due to the retention of fertilizers which was already applied to this field since from some few years back for other experimental purposes. The hypothesis is in agreement with the observation of Bardgett and McAlister (1999) that the neither the cessation of fertilizer application nor changes in cutting and grazing management significantly affected soil microbial biomass or the fungal:bacterial biomass ratio and they suggested that

the lack of effects on the soil microbial community may be related to high residual fertility caused by retention of fertilizer N in the soil. The analysis of variance result also revealed that fertilizers treatment (inorganic or organic) showed insignificant variation ($P \leq 0.05$) on microbial biomass carbon as compared to control plot.

Studies on the effect of inorganic fertilizer application on soil microbial biomass have shown contradictory results. Some workers have reported increase in the size of microbial biomass (Fraser *et al.*, 1994; Omay *et al.,* 1997), whereas others have shown the opposite i.e. the C_{mic} was less in agricultural soil as compared to the forest soil which is in conformity with our finding (Biederbeck *et al.,* 1984; Luizao *et al.*, 1992; McAndrew and Malhi, 1992; Wardle, 1992; Srivastava, 1992; Singh and Singh, 1993; Henrot and Robertson, 1994 and Ladd *et al.,* 1994). Blah (1999) also reported that the C_{mic} in the forest soil was markedly higher than that of the agricultural soils of the same study region. The reduction in C_{mic} under fertilizers treatment might be due to the high level of mineral N availability. These reductions in C_{mic} in fertilized soil have been discussed by Lovell *et al.* (1995) and have been attributed to changes in substrate quality and root growth (Ennik *et al.,* 1980; Hassink, 1992; Lovell *et al.,* 1995), changes in microbial competition and community structure, repression of enzyme activity and the build-up of recalcitrant and toxic compounds (Fog, 1988). Reductions in microbial biomass in fertilized soil have also been attributed to the acidifying effect of nitrogenous fertilizers (microbial production of nitric oxide) in soil (Christie and Beattie, 1989). On the basis of the present investigation result it is suggest that fertilizers application could have lowered the amount of soil microbial biomass

carbon. Ananyeva *et al.* (1999) also observed that long-term soil management practices (primarily tillage and fertilizers application) led to decrease in total microbial biomass.

Higher accumulation of microbial biomass carbon at the surface soil layer could be due to higher microbial population (fungi and bacteria) and due to more accumulation of organic carbon than that at the subsurface soil layer. The analysis of variance showed significant declined ($P \leq 0.01$) of C_{mic} from surface to sub-surface layers (Table 3.3.2). Lavahun *et al.* (1996) also found significant decline in the microbial biomass C with increasing soil depth. Maithani *et al.* (1996) also reported that microbial biomass C at the surface soil layer of disturbed sub-tropical humid forests was significantly ($P \leq 0.01$) greater than that of the subsurface soil layer. The reason for this higher microbial biomass at the surface soil layer was attributed to the greater accumulation of litter and fine root biomass and presence of relatively dense growth of plants in the forests.

From the result, it can be concluded that the insignificant variation of soil microbial biomass carbon and its inconsistent distribution within treatments may be due to the effects of host legumes root exudation, retention of fertilizers, environmental factors and microbial efficiency (Wardle and Ghani, 1995).

3.4.2. Effects of organic and inorganic fertilizers on soil respiration

The result that showed maximum soil respiration in the month of July at FYM plot, could be due to the release of high amount of root exudates, coinciding with groundnut plant attained 60 days old in this month and it was supposed to perform more metabolic activities. Franzluebbers *et al.* (1995) reported that mean soil CO_2 evolution was greater during the growing season than during fallow in all crops, and legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect (Thies *et al.,* 1995). Kursar (1989) stated that soil respiration includes root exudation, microbial decomposition of litter and dead roots as well as respiration by root symbionts. It has also been well documented that soil CO_2 evolution was a function of root biomass (Behera *et al.*, 1990), soil temperature and moisture (Peterjohn *et al.*, 1994), and fungal population (Rygiewicz and Anderson, 1994; Vose *et al.,* 1995).

The maximum soil respiration in FYM plot might be due to the enrichment of soil nutrients through the addition of high organic carbon content or the availability of active organic carbon of farmyard manure. It can be hypothesized that the maximum soil respiration in the month of July rather than at the time of initial stage of fertilizers application, might be due to the lower availability of organic carbon, where FYM was supposed to provide higher amount of organic carbon. This hypothesis confirmed the observation result of Lovell and Jarvis (1996). They reported that, after 12 weeks the labile carbon substrates from the dung were likely to have become depleted, leaving large amount of dead microbial materials as a possible energy source for other microorganisms. Fungi that were usually

slower to respond to substrate inputs (Cheng-Sheng Tsai *et al.,* 1997) may then have capitalized on this situation. This differs from the effects of regular fertilizers input which tend to produce a sustained increase in plant turnover and lead to increased microbial activity (Fauci and Dick, 1994).

It can also be hypothesized that high rainfall, optimum temperature and high soil moisture contents in month of July influenced FYM fertilizer to enable more plant growth, high root respiration as well as high CO_2 evolution of soil microbes through root environment. The manure soils likely have higher levels of soluble organic C, therefore supporting higher levels of microbial activity. It has been proved that the total soil respiration in ecosystem could provide an estimate of the turnover of soil organic matter (Parker *et al.,* 1983). Other soil factors potentially influencing rate of soil respiration *in situ* includes the availability of C substrates for microorganisms (Seto and Yanagiya, 1983), plant root densities and activities (Ben-Asher *et al.,* 1994), soil organism levels (Rai and Srivastava, 1981), soil physical and chemical properties (Boudot *et al.,* 1986). Jones *et al.* (2003) observed that manure application has significantly increased CO_2 evolution as compared to control. From long-term manuring experiment in India, Nambiar (1994) reported that the application of farmyard manure and NPK fertilizer improved population of *Azotobacter*, soil microorganisms and nodulation of soybean (legume). It can be assumed that the reaction of the microbial community to the addition of manure is very similar to a rhizosphere response. The manured soils were likely to have higher levels of soluble organic C, therefore supporting higher levels of microbial activity.

The result which showed strong positive correlation of soil respiration with temperature and moisture contents, were in agreement with the findings of Kursar (1989), Raich and Nadelhoffer (1989), Cavelier and Penuela (1990), Maggs and Hewett (1990) and Jurik *et al.* (1991). The maximum rainfall and optimum temperature in this month coincided with the highest rate of CO_2 evolution (Rout and Gupta, 1989). Raich and Potter (1995) also stated that seasonal changes in soil microclimate play an important role in defining seasonal differences in soil CO_2 evolution within the site. The inconsistent trend of soil respiration might be due to the influence of environment i.e. temperature, rainfall, soil moisture content. Carlyle and Than (1988) also stated that, rates of soil respiration largely depended upon soil temperature and moisture condition. Soil respiration drastically dropped at post harvest (October), and this observation result could be due to the ceased root respiration, lesser microbial population, and or lower availability of organic matter. This observation is supported by Silvola *et al.* (1996) that the CO_2 released in soil respiration was formed from organic matter which differs in age and stability, ranging from soluble root exudates to more persistent plant remains.

The analysis of variance, which showed the significant variation ($P \leq 0.005$) of soil respiration within treatments at subsurface soil layer, could be due to more influence of fertilizers on CO_2 evolution as compared to surface soil layer. It can be hypothesized that subsurface soil regions were occupied by small amount of groundnut roots and organic matter which mean less root respiration. Therefore, at the subsurface soil layer, soil organisms contributed higher amount of CO_2 evolution rather than root respiration. This finding is in agreement with the reports of Linn and

Doran (1984) that greater soil respiration in surface soil layer could be due to surface accumulation of organic matter.

The analysis of variance that showed the significant variation ($P \leq 0.005$) of soil respiration between 0-10 cm and 10-20 cm layers were due to the higher soil microbial population in the surface layer or it might be due to the high accumulation of nutrients, availability of higher level of oxygen, occurrence of larger amount of host roots. Tiwari *et al.* (1986) also observed that surface soil generally showed higher values for fungal and bacterial populations and CO_2 evolution decreased with increase in soil depth.

It can be concluded that soil respiration was strongly influenced by temperature, soil moisture content, rainfall, and age of plant and fertilizers treatment. Among the fertilizers, FYM had more beneficial effects on soil respiration but only on when organic carbon was in the state of depletion to provide energy for the other soil microorganisms, which in turn increased soil respiration. Treatment of soil with fertilizers did not result in significant changes on soil respiration as compared to control plot. It was also observed that soil respiration at subsurface soil was much more dependent on fertilizers rather than the plant effects.

Table 3.3.1 One way analysis of variance (ANOVA) of the microbial biomass carbon (C_{mic}) and soil respiration (SR) of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) and subsurface (10-20 cm) layers ($P \leq 0.05$).

Soil properties	Source of variation	Surface layer (0-10 cm)		Subsurface layer (10-20 cm)	
		F-ratio	P-level	F-ratio	P-level
C_{mic}	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-		-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-
SR	CTRL X NPK X FYM X NPK+FYM	-	-	12.4297	1×10^{-6}
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	15.8199	1.4×10^{-4}
	CTRL X NPK+FYM	-	-	18.3974	4.9×10^{-5}
	NPK X FYM	4.9848	0.0282	18.7697	4.2×10^{-5}
	NPK X NPK+FYM	-	-	21.7522	1.2×10^{-5}
	FYM X NPK+FYM	-	-	-	-

Note: Insignificant values are marked with ' – ' sign

Table 3.3.2 One way analysis of variance (ANOVA) of the microbial biomass carbon (C_{mic}) and soil respiration (SR) of soil between surface (0-10 cm) and subsurface (10-20 cm) soil layers of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.001$).

Soil properties	Treatments	F-ratio	P-level
C_{mic}	CTRL	17.3848	7.5×10^{-5}
	NPK	10.8026	1.4×10^{-3}
	FYM	9.3436	3×10^{-3}
	NPK + FYM	-	-
SR	CTRL	57.8895	1×10^{-6}
	NPK	75.8939	1×10^{-6}
	FYM	27.1080	1×10^{-6}
	NPK + FYM	17.1540	8.3×10^{-5}

Note: Insignificant values are marked with ' – ' sign

Table 3.3.3 Correlation coefficient (r) values among microbial biomass carbon (C_{mic}) and soil respiration (SR) between surface (0-10 cm) and subsurface (10-20 cm) soil of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Treatments (0-10 X 10-20 cm)	C_{mic}	SR
CTRL	0.6409^c	0.6057^c
NPK	0.7461^c	0.51825^c
FYM	0.6211^c	0.7100^c
NPK+FYM	0.9350^c	0.8006^c

Note: Values marked with c are significant at $P \leq 0.001$

Table 3.3.4. Correlation coefficient (r) values among microbial biomass carbon (C_{mic}) and soil respiration with microbial population, biochemical and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) soil layer ($P \leq 0.05$).

Treatments	Soil properties	SR	AT	ST	MC	pH	OC	TN	AP	K	FP	BP	DHA	URA	PA	RF
CTRL	C_{mic}	-	0.4932^{c}	-	-	-	-	-	-	-	0.3524^{a}	0.5841^{c}	-	-	-	0.3298^{a}
	SR		0.447^{b}	-	0.3508^{a}	-	-	-	-	-	-	-	-	-0.3073^{a}	-0.5633^{c}	-
NPK	C_{mic}	-	-	-	-	-	0.5750^{c}	-	-	-	0.4254^{b}	-	0.4490^{b}	0.3158^{a}	-	-
	SR		0.6084^{c}	-	0.3332^{a}	-0.4156^{b}	-0.3247^{a}	-	-	-	-	-	-	-	-0.3840^{a}	-
FYM	C_{mic}	-	-	-	-	-	-	0.5123^{c}	0.5769^{c}	-	0.4135^{b}	-	0.3915^{b}	-	-	-
	SR		0.6100^{c}	-0.4775^{c}	0.4019^{b}	-	-0.4707^{b}	-	0.6092^{c}	-	0.4294^{b}	-	-0.3197^{a}	-	-	-
NPK+FYM	C_{mic}	-	-	0.3471^{a}	0.3959^{b}	-	0.6043^{c}	0.4786^{c}	-	-0.4945^{c}	0.5004^{c}	-	0.8092^{c}	-	0.3299^{a}	-
	SR		0.6645^{c}	-	0.5915^{c}	-	-	0.4433^{b}	-	-0.4757^{c}	-	-	-	-	-	-

Table 3.3.5 Correlation coefficient (r) values among biomass carbon (C_{mic}) and soil respiration with microbial population, biochemical and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) soil layer ($P \leq 0.05$).

Treatments	Soil properties	SR	AT	ST	MC	pH	OC	TN	AP	K	FP	BP	DHA	URA	PA	RF
CTRL	C_{mic}	-	0.3988^{b}	-	-	-	-	-	-	-	-	-	-	-	-	0.3567^{a}
	SR		0.6222^{c}	-	0.5004^{c}	-	-	0.3318^{a}	0.3917^{b}	-0.3169^{a}	-	-	-	-0.3951^{b}	-	-
NPK	C_{mic}	-	-	-	-	0.4368^{b}	-	-	-	-	0.4022^{b}	0.3062^{a}	0.4551^{b}	-	-	-
	SR		0.6656^{c}	-	0.5277^{c}	-0.3702^{a}	-	0.4746^{c}	-	-0.3292^{a}	0.3335^{a}	-	0.4237^{b}	-0.3929^{b}	-	-
FYM	C_{mic}	0.5817^{c}	0.3935^{b}	-	-	0.3955^{a}	0.3853^{a}	-	0.7385^{c}	-	-	-	-	-	-	0.3931^{b}
	SR		0.6001^{c}	-	0.5717^{c}	-	-	0.5719^{c}	0.7600^{c}	-	-	-	-	-	-	-
NPK+FYM	C_{mic}	-	-	0.4388^{b}	-	-	0.6127^{c}	-	-	-	0.3139^{a}	0.3321^{a}	0.8906^{c}	-	-	-
	SR		0.6657^{c}	-	0.6533^{c}	-0.5009^{c}	-	0.5851^{c}	0.5357^{c}	-0.3603^{a}	0.4117^{b}	-	-	-0.3075^{a}	-0.3926^{b}	-

(Note: C_{mic}=microbial biomass carbon, SR=soil respiration, AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, FP=fungal population, BP=bacterial population, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity, RF=rainfall)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Chapter- 4

Estimation of soil enzymes (dehydrogenase, urease and phosphatase) in agro-ecosystem

4.1. Introduction

Soil enzyme activities are very sensitive to both natural and anthropogenic disturbances, and show a quick response to the induced changes (Dick, 1997). The analysis of soil enzymes could be useful to identify positive or negative effects of residue management, soil compaction, tillage, crop rotation and soil contamination during reasonable time period. Enzyme activities have been found to be very responsive to different agricultural soil conservation practices such as non-tillage (Dick, 1992; Bergstrom *et al.*, 1998), organic amendments (Dick, 1992; Perucci, 1992; Miller and Dick, 1995; Banerjee *et al.*, 1997), crop rotation (Dick, 1992; Miller and Dick, 1995), and organic cultivation (Beyer *et al.*, 1992).

Among different types of enzymes studied from various objectives of investigations, dehydrogenase, urease and phosphatase are thoroughly studied enzymes due to their specific importance in organic matter transformation processes and phosphorus cycle in agricultural practices. The measurement of biochemical activity in soil i.e. soil enzyme assays has been done for various reasons particularly, as a measure of soil fertility or productivity (Tiwari *et al.*, 1988), as a measure of microbial biomass (Klose and Tabatabai, 1999), as indicators of effects of pollutants and to conduct biogeochemical cycling, total microbial activity (Tiwari *et al.*, 1988), as a predictor of bioremediation and

potential success (Dick *et al.*, 1998), to understand rhizosphere effect (Boero and Thien, 1979), as a potential indicator of soil quality (Palma *et al.*, 2000 and Pascula *et al.*, 2000).

Soil dehydrogenase is an extra-cellular enzyme which is considered to be a good tool to measure microbial oxidative activity (Ross, 1971) as an indicator of any disruption caused by pesticide application, trace element discharge and soil management practices (Reddy and Faza, 1989), as a measure of microbial biomass (Ladd, 1978) and measure of soil respiration. Dehydrogenase plays an important role in the initial stages of the oxidation of soil organic matter by transferring hydrogen or electron from substrates to acceptors (Ross, 1971). Because of its importance in the organic matter transformation processes and its potential to indicate the available microbiological activity in the soil, dehydrogenase has been the subject of chosen biochemical tool in various fields of agricultural and soil science investigations.

Urease is a hydrolase enzyme responsible for hydrolytic conversion of the substrate, urea into carbon dioxide and ammonia. Owing to this property, it has an applied importance in the N-economy of soil. So, the enzyme assay is an important in understanding mineralization process of N element and its response to the application of inorganic fertilizers and soil management systems particularly its relationship to the agricultural practices led to the extensive research assay and has become an important and routine practice in agricultural systems.

Urease activity is also an important factor for survival of ammonium fertilizer oxidizers in forest and agricultural soils (Swenson and Bakken, 1998). Studies also

showed that fertilization and cropping practices have significant effects on its activity in soils (Bolton *et al.*, 1985; Deng and Tabatabai, 1996a; Burket and Dick, 1998).

Phosphatase enzyme mediates the release of inorganic phosphorous from organically bound phosphorous to soil as litter and other organic debris and the intensity of phosphatase is important as it affects the rate of phosphorous cycling. So, phosphatase activity is essential for conversion of organic substrates containing phosphorus into organic form through hydrolysis in the soil. Phosphatase can be inhibited by inorganic phosphate, which produces a feedback inhibition of this enzyme (Nannipieri *et al.*, 1979). Acid and alkaline phosphatase activity assays have been used to understand the phosphorus cycling which is related to the organic matter and its turnover in soil (Trasar-Cepeda and Gill Sotres, 1987).

4.2. Methodology

4.2.1. Dehydrogenase

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 30^0 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.

4.2.2. Urease

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 37^0C for 3 hours in an incubator. Whereas in control, 10 ml of distilled water was added 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.

4.2.3. Phosphatase

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 37^0 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. I. 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.

4.3. Results

4.3.1 Dehydrogenase

Dehydrogenase activity increased from pretreatment to post treatment throughout the investigation. It was also observed that the enzyme activity in NPK+FYM plot was not dropped at post harvest. In the first year, the enzyme activity dropped remarkable from May to June onward, whereas such activity was not observed in the second year (Fig. 4.3.1).

At the surface soil layer in the first year, dehydrogenase activity ranged from 0.304 to 1.329 mg TPF g^{-1} dry soil $24h^{-1}$ in NPK and NPK+FYM plots in the month of September and May respectively. In the second year, it ranged between 0.065 and 0.63 mg TPF g^{-1} dry soil $24h^{-1}$in NPK+FYM and FYM plots in the months of April and August respectively.

At the subsurface soil layer in the first year, dehydrogenase activity ranged from 0.071 to 1.283 mg TPF g^{-1} dry soil $24h^{-1}$ in NPK and NPK+FYM plots in the month of September and May and respectively. In the second year, it ranged between 0.015 and 0.33 mg TPF g^{-1} dry soil $24h^{-1}$ in NPK+FYM and FYM plots in the month of April and May respectively.

The one-way analysis of variance (ANOVA) showed insignificant variation ($P \leq 0.05$) of dehydrogenase activity among treatments at two soil depths (Table 4.3.1), and a significant variation ($P \leq 0.001$) of enzyme activity between surface

and subsurface soil layers was observed except in NPK+FYM plot (Table 4.3.2). Correlation coefficient values ($P \leq 0.001$) showed that the enzyme activity at surface soil layer was positively correlated with enzyme activity at subsurface soil layer (Table 4.3.3).

In CTRL plot at surface soil layer, dehydrogenase activity was positively correlated with soil temperature, moisture content, organic carbon and total nitrogen. At subsurface soil layers it was positively correlated with soil temperature, organic carbon, total nitrogen and fungal population (Tables 4.3.4 and 4.3.5).

In NPK plot at surface soil layer, dehydrogenase activity was positively correlated with soil temperature, organic carbon, total nitrogen, fungal population and microbial biomass carbon. At subsurface soil layer, it was positively correlated with soil temperature, organic carbon, total nitrogen, soil respiration, fungal population and microbial biomass carbon (Tables 4.3.4 and 4.3.5).

At FYM plot at surface soil layer, dehydrogenase activity was positively correlated with soil temperature, moisture content, organic carbon, total nitrogen and microbial biomass carbon. At subsurface soil layer it was positively correlated with soil temperature, moisture content, pH, organic carbon and fungal population (Tables 4.3.4 and 4.3.5).

At NPK+FYM plot at surface soil layer, dehydrogenase activity was positively correlated with phosphatase activity, soil temperature, moisture content, pH, organic carbon, total nitrogen and microbial biomass carbon. At subsurface soil layer it was positively correlated with soil temperature, moisture content,

organic carbon, total nitrogen, fungal population and microbial biomass carbon (Tables 4.3.4 and 4.3.5).

4.3.2 Urease

The urease activity showed consistent trends of distribution within sampling month in the first and second years. It was observed that the enzyme activity increased from pre-treatment to post treatment and the activity dropped in the month of June and at post harvest period. Maximum enzyme activity was displayed in NPK plot in the month of May during the study periods (Fig. 4.3.2).

In the first year at surface soil layer, urease activity ranged between 0.018 and 0.074 NH^{+}_{4}-N g^{-1} dry soil $3h^{-1}$ in CTRL and NPK plots in the months of June and May respectively. At subsurface soil layer, enzyme activity ranged from 0.013 to 0.07 NH^{+}_{4}-N g^{-1} dry soil $3h^{-1}$ in NPK plot in the months of May and June.

In the second year at surface soil layer, the enzyme activity ranged between 0.036 and 0.11 NH^{+}_{4}-N g^{-1} dry soil $3h^{-1}$ in NPK+FYM and NPK in the months of October and May respectively. At subsurface soil layer, the enzyme activity ranged between 0.035 and 0.104 and NH^{+}_{4}-N g^{-1} dry soil $3h^{-1}$ in NPK+FYM and NPK in the month of October and May respectively.

The one-way analysis of variance (ANOVA) showed insignificant variation ($P \leq 0.05$) of urease activity among treatments (Table 4.3.1) and between surface and subsurface soil layers (Table 4.3.2). Correlation coefficient values ($P \leq 0.001$) showed that the enzyme activity at surface soil layer was positively correlated with enzyme activity at subsurface soil layer (Table 4.3.3).

In CTRL plot at surface soil layer, urease activity was positively correlated with pH and potassium. At subsurface soil layer, enzyme activity was positively correlated with pH and potassium (Tables 4.3.4 and 4.3.5).

In NPK plot at surface soil layer, urease activity was positively correlated with phosphorus, potassium and microbial biomass carbon. At subsurface soil layer, enzyme activity was positively correlated with phosphorus and potassium (Tables 4.3.4 and 4.3.5).

In FYM and NPK+FYM plots at surface and subsurface soil layers, urease activity was positively correlated with potassium (Tables 4.3.4 and 4.3.5).

4.3.3 Phosphatase

Phosphatase activity increased from pre-fertilizers treatment to post treatment and the enzyme activity was not decline at post harvest. A remarkable increase in activity was observed from August to September. Generally, higher enzyme activity was observed at surface soil than the subsurface soil layer (Fig. 4.3.3).

In the first year at surface soil layer, phosphatase activity ranged between 104.96 and 501.80 μg PNP released g^{-1} dry soil h^{-1} in NPK and FYM plots in the months of August and September respectively. At subsurface soil layer, it ranged between 62.20 and 480.0 μg PNP released g^{-1} dry soil h^{-1} in NPK and NPK+FYM plots in the months of August and September respectively.

In second year at surface soil layer, the enzyme activity ranged between 160.06 and 442.0 μg PNP released g^{-1} dry soil h^{-1} in NPK+FYM in the months of April and July respectively. At subsurface soil layer, it ranged between 128.46 and

385.73 μg PNP released g^{-1} dry soil h^{-1} in CTRL and NPK+FYM plots in the months of April and September respectively.

The one-way analysis of variance showed significant variation ($P \leq 0.05$) of phosphatase activity between CTRL and FYM plots at surface layer, whereas at subsurface soil layer, it was observed between CTRL and NPK+FYM plots (Table 4.3.1). Correlation coefficient values ($P \leq 0.001$) showed that the enzyme activity at surface soil layer was positively correlated with enzyme activity at subsurface soil layer (Table 4.3.3).

At surface soil layer in CTRL plot, phosphatase activity was positively correlated with soil temperature and potassium. In NPK plot, it was positively correlated with soil temperature, pH and potassium. In FYM plot, it was positively correlated with soil temperature and organic carbon and in NPK+FYM plot, it was positively correlated with soil temperature and microbial biomass carbon (Table 4.3.4).

At subsurface soil layer in CTRL and NPK+FYM plots, phosphatase activity was positively correlated with soil temperature (Table 4.3.5).

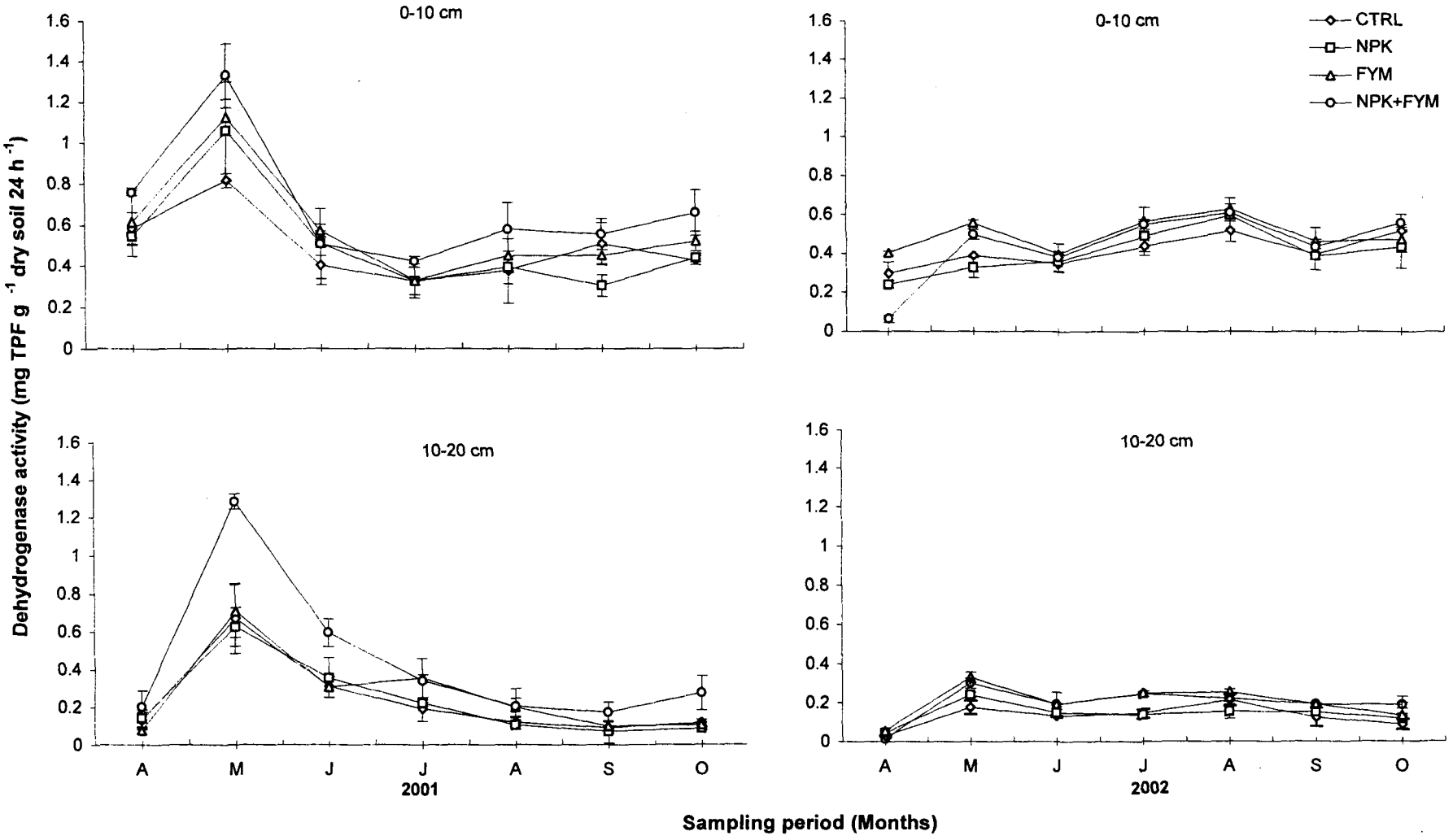


Fig. 4.3.1. Dehydrogenase activity in groundnut field soil at 0-10 cm and 10-20 cm depths.

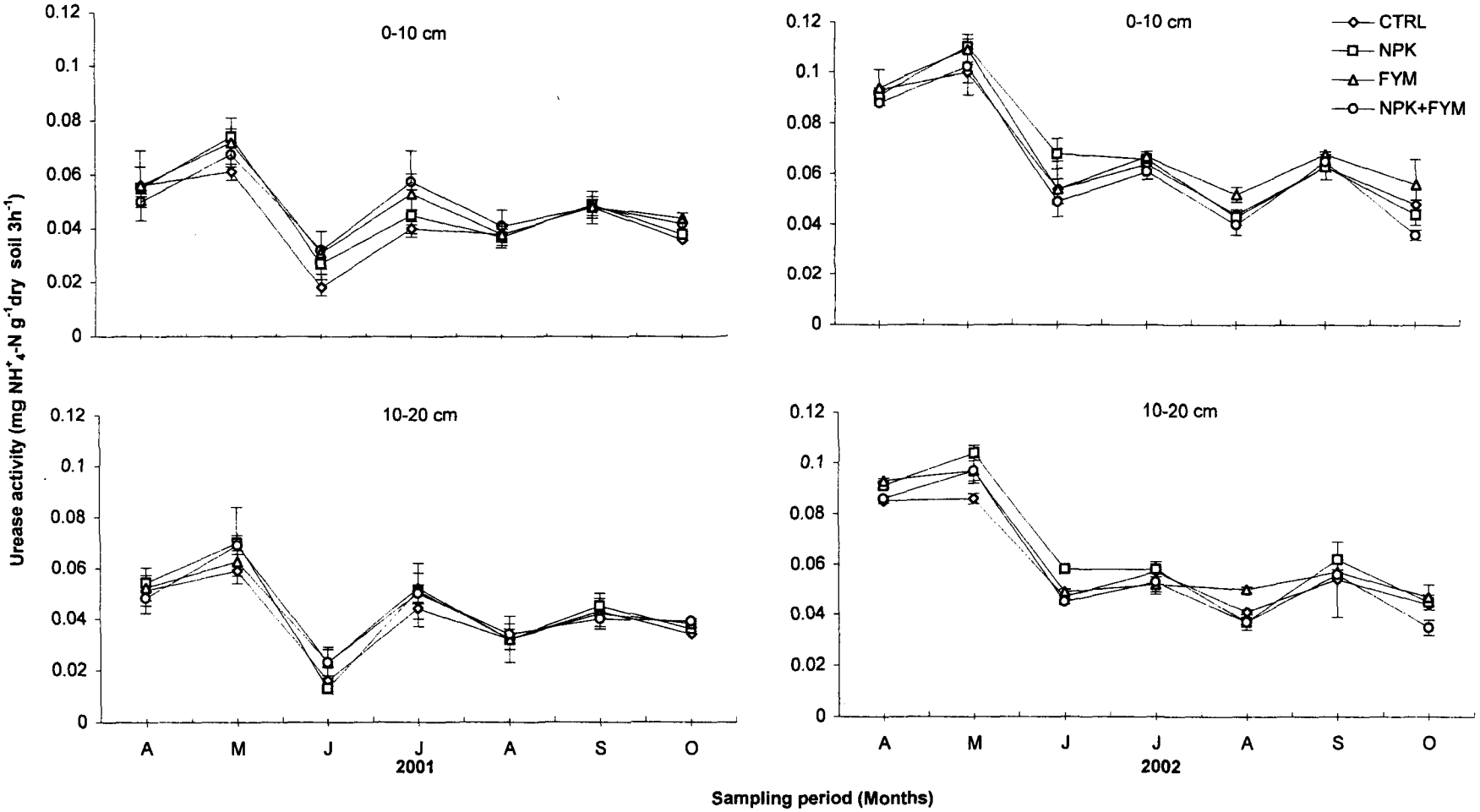


Fig. 4.3.2. Urease activity in groundnut field soil at 0-10 cm and 10-20 cm depths.

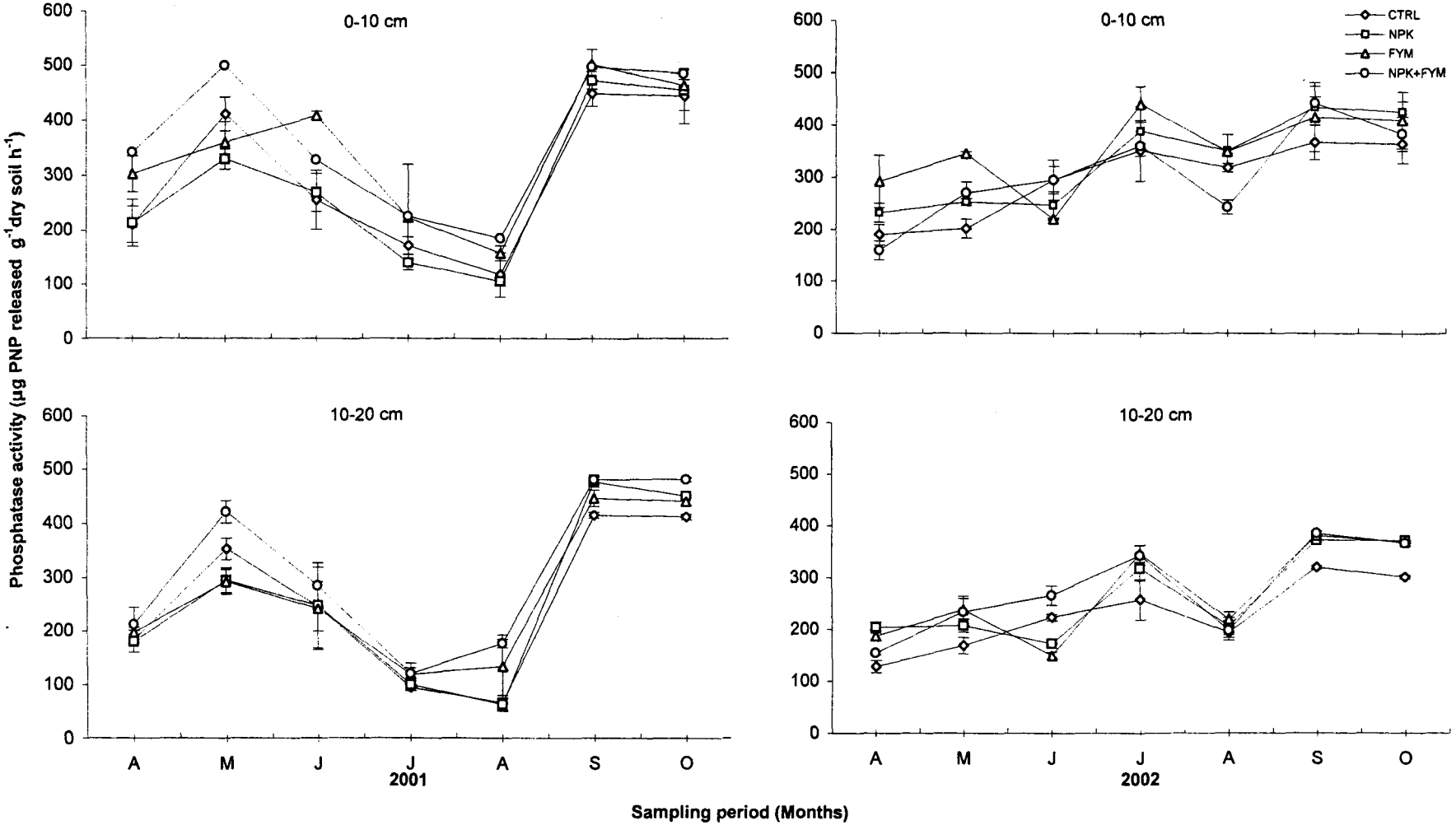


Fig. 4.3.3. Phosphatase activity in groundnut field soil at 0-10 cm and 10-20 cm depths.

4.4. Discussion

4.4.1. Effect of organic and inorganic fertilizers on dehydrogenase enzyme activity

Dehydrogenase activity that showed increased from pre-fertilizers treatment to post fertilizers treatment could be due to the increase in soil microbial population or due to the effects of soil management practices i.e. fertilization and plowing of soil for seedbed preparation. The same result was observed by Ross (1970) who stated that dehydrogenase activity appeared to be more dependent on the biological activity of microbial population than on any free enzyme present in the soils. Jenkinson and Powlson (1976) and Batra *et al.* (1997) also stated that, soil management practices and seasonal conditions affect the soil enzymatic activities. So the activity of soil microorganisms and soil management (fertilization and tillage) were strongly linked to the activity of soil enzyme (Miller and Dick, 1995; Deng and Tabatabai, 1997; Klose *et al.*, 1999). Therefore, it can be concluded that the result that showed dissimilar activity of dehydrogenase in the first year and second year could be due to the effect of soil microbial population.

The result that showed maximum dehydrogenase activity in FYM and NPK+FYM plots coincided with the observation of Simek *et al.* (1999), that dehydrogenase activity was lower in soil that had received the largest amount of fertilizers; this suggests that dehydrogenase activity was highly sensitive to the inhibitory effects associated with large amount of fertilizer additions. Another possible reason of higher enzyme activity in the manure treated plot as suggested by Parham *et al.* (2002) is that manure promoted biological and microbial activities, which accelerated the breakdown of organic substances in the added

manure. They also reported that within each sampling period, the highest dehydrogenase activity was in soil treated with animal manure, while lowest was in the CTRL or NP-treated plots. So, the addition of FYM and NPK+FYM enhanced and promoted dehydrogenase enzyme activity. Ross (1971) also reported that increased dehydrogenase activity due to NPK+OM (organic manure), OM and NPK treatments appeared to be linked with increased microbial population associated with organic manure substrate.

It can be hypothesized that FYM treatment was expected to influence more on the activity of dehydrogenase than that of NPK+FYM treatment. This hypothesis agreed with the result of James *et al.* (1996) that the addition of manure saturated soil's capacity to retain manure-P and the soil P status might also influence microbial growth directly, through its effect on plant root growth and consequently influence the amount of C released by roots (Perrott and Sarathchandra *et al.*, 1989). So that any management practice that increase total C accumulation should also increase the size and activities of soil microbial biomass (Buchanan, 1990) and this result has strongly confirmed the result of our findings, which showed that dehydrogenase activity significantly correlated ($P \leq 0.05$) with soil microbial biomass carbon (C_{mic}) except at CTRL at 0-10 cm and CTRL and FYM at 10-20 cm. The organic carbon also significantly correlated with dehydrogenase activity during the study period; this observation confirmed with the result of Leiros *et al.* (2000), that dehydrogenase activity was strongly correlated with soil organic carbon. Manure has been reported to improve soil

properties (Sommerfeldt and Chang, 1985), Parham *et al.* (2002) also observed that dehydrogenase was significantly higher in the soil treated with cattle manure.

Since soil microbial population control the soil dehydrogenase activity, the fertilizers treatment that affect on the microbial population was believed to be more effective on the dehydrogenase activity rather than plant factors (Asiegbu, 1984). Tiwari (1996a) also observed the significant dehydrogenase activity ($P \leq 0.05$) in plots treated with organic manure or with N and P or a combination of both than in the control plots.

The result that showed insignificant variation of dehydrogenase activity within treatments coincided with the finding of Tiwari (1996) that no significant impact of individual treatments of the fertilizers on the dehydrogenase activity. It was well documented that some soil microbial activity was affected by plant through root exudation, but the present result showed that the plant factors might not influence dehydrogenase activity, because it was observed that the enzyme activity in FYM and NPK+FYM plots was not dropped even after post harvest.

The analysis of variance that showed a significant variation of dehydrogenase activity between surface and sub-surface layers could be due to the differences in soil microbial population and environmental factors at these layers. Das (1980), Baruah and Mishra (1984) and Tiwari *et al.* (1987b) also reported that higher dehydrogenase activity in the surface soil layer was due to presence of higher bacterial population, organic carbon content, favorable moisture content and temperature.

It can be concluded that addition of fertilizers i.e. FYM (organic fertilizers) and NPK+FYM (combination of inorganic and organic) as well as soil management practices could have impact on the size and activity of soil dehydrogenase enzyme. The fertilizers treatment could have been a large impact on soil dehydrogenase activity rather than plant factors and the removal of plant from the plot does not show significant effect on enzyme activity. It was also suggested that the organic carbon and soil temperature have a strong positive correlation with the enzyme. The surface soil layer showed a higher enzyme activity than the subsurface soil layer.

4.4.2. Effect of organic and inorganic fertilizers on urease enzyme activity

The result which showed increased urease activity from pre-fertilizers treatment to post treatment might be due to the increased in soil microbial population. During our investigation, the result also showed an increased microbial population from pre-treatment to post fertilizers treatment. It has been well documented that urease activity could originate from plant materials or microorganisms (Tiwari *et al.*, 1988). Zantua and Bremner (1977) also reported that soil urease are microbial products that could accumulate in cell free form in the soil because of they are highly resistant to environmental degradation, they occur in agricultural soils with a variety of cultural histories.

In general, greater urease activity was observed at a fertilizers treated plots than the control plot. This observation result was in agreement with the finding of Garcia-Gil *et al.* (2000) that mineral fertilization plot had the greatest urease activity than unfertilized plot. Tiwari (1996a) also reported that urease activity was

considerably greater in NPK+OM (organic matter), OM and NPK than control plots. So, the increased activity of enzyme in treated plot could be due to higher organic matter and N content in these plots or because of the presence of higher soil microbial population in treated plots (Asiegbu, 1984). Beri *et al.* (1978) and Tiwari *et al.* (1989) also reported that urease activity was principally associated with the organic matter content of the soils. Studies from long-term field experiments have shown that a high portion of legumes in the rotation led to greater contents of organic C and N in soils (Bolton *et al.*, 1985) and thus contributed to higher microbial activities.

The result showed consistent distribution of urease activity within sampling period i.e. the enzyme activity drastically dropped in the month of June. This observation result coincided with the reports of Schiner *et al.* (1980), that compound fertilization inhibited urease activity after six weeks of application. Long-term N fertilizer application and products formed from microbial assimilation of NH_4^+ and NO_3^- in C-amended soils could suppress the urease activity (Dick *et al.*, 1988; McCarty *et al.*, 1992).

Within each sampling months, urease enzyme showed a fluctuation activity among treated and untreated plots, where the observation result was expected to show higher enzyme activity only at treated plots. It was observed that in some months, CTRL plot exhibited higher activity than fertilized plot and the enzyme activity dropped at post harvest. So, the result that showed fluctuation in the enzyme activity could be due the effects of groundnut plant through its rhizosphere effect (Burns, 1978) and due to the retention of fertilizers. Lloyd and Sheaffe

(1973) also reported that due to increment in ureolytic bacteria in soils, the urease activity might be increased. It has also been reported that variation in urease activity was caused by changes in organic matter content of soils (Bremner and Mulvaney, 1978) and legumes rotation led to greater contents of organic C and N in soils (Bolton *et al.*, 1985).

The analysis of variance (ANOVA), which showed the insignificance variation ($P \leq 0.005$) of soil urease activity between treatments, at both 0-10 cm and 10-20 cm may be due to the fluctuation in enzyme activity, which was led by the retention of fertilizers and the effect of plant.

It can be concluded that the application of fertilizer as well as retention of fertilizers and host legume plant could affect the soil urease activity and its activity was higher in NPK treated plot during the entire investigation.

4.4.3. Effects of organic and inorganic fertilizers on phosphatase enzyme activity

The result that showed increased phosphatase activity from pre-fertilizers treatment to post treatment could be due to increase in microbial population. This observation result coincided with the report of Speir and Ross (1990), that phosphatase activity is originated from microorganisms, wherein the present investigation result also showed an increased fungal and bacterial population in the month of May.

A consistent trend in distribution of phosphatase activity i.e. higher enzyme activity in NPK+FYM and FYM treated plots and maximum enzyme activity in NPK+FYM plot in the month of May was observed. This result is in agreement with

the findings of Spiers and McGill (1979) that greater phosphatase activity in NPK+OM (organic manure); NPK and OM plots were due to mainly higher organic matter contents and microbial population (Nilson and Eiland, 1980). Tiwari (1996) also reported significant greater ($P \leq 0.05$) activities of acid phosphatase in plots treated with organic manure or with N and P or a combination of both than in the control plot.

The soil treated with NPK+FYM and FYM fertilizers, which were highly bound unavailable form of organic P likely exhibited more enzyme activity. Parham *et al.* (2002) also reported that phosphatase activity was significantly higher in the soil treated with cattle manure than P, NP, NPK and NPK plus lime. So, it can be hypothesized that the phosphatase activity was activated when there was low P availability in soils. It can also be concluded that plants may take up some form of organic P from soils (Islam *et al.*, 1979); however, most organic P must first undergo an enzymatic hydrolysis to inorganic P to become available for plants. Soil microorganisms and plant could utilize soil organic P by means of phosphatase enzyme (Pant *et al.*, 1994).

It was also observed that the phosphatase activity of soils increased significantly with a combination of inorganic fertilizers and organic amendments. This result indicated that soil organic matter level and soil microbial activities vital for the nutrients turnover and long-term productivity of the soil were enhanced by use of organic amendments along with inorganic fertilizers (Goyal *et al.*, 1999). This enhancement of biological activities in the manure treated soil was evidenced by relatively high phosphatase activity (Parham *et al.*, 2002) and they also

suggested that the possible reason of higher enzyme activity in a manure treatment was that manure promoted biological and microbial activities, which accelerated the breakdown of organic substances in the added manure.

The maximum phosphatase activity was displayed in the month of September within the entire experiment, where it markedly increased from the months of August to September. So, it can be hypothesized that the result, which showed maximum enzyme activity in the month of September, wherein the groundnut plant attained its maximum growth (120 DAS) could be due to the rhizosphere effect (Burns, 1978). It was well documented that the root exudation of plant enhanced the microbial population and the activity of soil microorganisms was strongly linked to the activity of enzymes (Miller and Dick, 1995; Deng and Tabatabai, 1997; Klose *et al.*, 1999). Thies *et al.* (1995) also reported that legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect. The decreased enzyme activity from September towards post harvest (October) could be due to the removal of plant, which in turn affects the soil microbial population.

The correlation coefficient value that showed a positive correlation of phosphatase activity with temperature was in agreement with the finding of Sinsabaugh *et al.* (1991) that temperature is a controlling factor of the enzyme activity and it effects the enzyme activity indirectly through influencing microbial proliferation, and also directly, by modifying enzyme kinetics (Chrost, 1991).

It can be concluded that higher phosphatase enzyme activity was noted in NPK+FYM and FYM treated plots and microbial population was one of the

controlling factors for the activity. Plant has a great beneficial influence on the enzyme activity through its root exudation, where the enzyme was strongly correlated with soil temperature.

Table 4.3.1. One way analysis of variance (ANOVA) of the biochemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface (0-10 cm) and subsurface (10-20 cm) layers ($P \leq 0.05$).

Soil properties	Source of variation	Surface layer (0-10 cm)		Subsurface layer (10-20 cm)	
		F-ratio	P-level	F-ratio	P-level
Dehydrogenase	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-
Urease	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-
Phosphatase	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	5.2381	0.0246	-	-
	CTRL X NPK+FYM	-	-	5.1223	0.0262
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-

Note: Insignificant values are marked with ' – ' sign

Table 4.3.2. One way analysis of variance (ANOVA) of the biochemical properties of soil between surface (0-10 cm) and subsurface (10-20 cm) soil layers of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.001$).

Soil properties	Treatments	F-ratio	P-level
Dehydrogenase	CTRL	8.8000	3.9×10^{-3}
	NPK	8.2864	5×10^{-3}
	FYM	7.2065	8.7×10^{-3}
	NPK + FYM	-	-
Urease	CTRL	-	-
	NPK	-	-
	FYM	-	-
	NPK + FYM	-	-
Phosphatase	CTRL	6.0132	1.6×10^{-2}
	NPK	-	-
	FYM	11.8992	8.9×10^{-4}
	NPK + FYM	-	-

Note: Insignificant values are marked with ' – ' sign

Table 4.3.3. Correlation coefficient (r) values among the biochemical properties of soil between surface and subsurface soil layers of control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Treatments (0-10 X 10-20 cm)	Dehydrogenase	Urease	Phosphatase
CTRL	0.7757^{c}	0.9270^{c}	0.9142^{c}
NPK	0.9040^{c}	0.9152^{c}	0.9176^{c}
FYM	0.7403^{c}	0.9269^{c}	0.8462^{c}
NPK+FYM	0.8430^{c}	0.6901^{c}	0.9275^{c}

Note: Values marked with c are significant at $P \leq 0.001$

Table 4.3.4. Correlation coefficient (r) values among biochemical properties of soil with various microbial population, biological and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface soil layer ($P \leq 0.05$).

Treatments	Soil properties	URA	PA	AT	ST	MC	pH	OC	TN	AP	K	SR	FP	BP	C_{mic}	RF
CTRL	DHA	-0.3302^{a}	-	-	0.4858^{c}	0.4607^{b}	-0.3703^{a}	0.3735^{a}	0.3757^{b}	-0.4511^{b}	-0.4074^{b}	-	-	-0.3101^{a}	-	-
	URA		-	-0.4590^{c}	-0.3520^{a}	-0.5282^{c}	0.4674^{b}	-	-0.5641^{c}	-	0.4003^{b}	-0.3073^{a}	-	-	-	-
	PA			-	0.4984^{c}	-	-	-	-	-	0.3385^{a}	-0.5633^{c}	-	-	-	-
NPK	DHA	-	-	-	0.4031^{b}	-	-	0.7997^{c}	0.3746^{a}	-0.4544^{b}	-0.4810^{c}	-	0.3070^{a}	-	0.4490^{b}	-
	URA		-	-0.4179^{b}	-	-	-	-	-0.3144^{a}	0.4045^{b}	0.7213^{c}	-	-	-	0.3158^{a}	-
	PA			-	0.4237^{b}	-	0.5761^{c}	-	-	-	0.4204^{b}	-0.3840^{a}	-	-	-	-0.3427^{a}
FYM	DHA	-	-	-	0.4569^{b}	0.3592^{a}	-	0.5350^{c}	0.6157^{c}	-	-0.5520^{c}	-0.3197^{a}	-	-0.3223^{a}	0.3915^{b}	-
	URA		-	-0.4544^{b}	-	-0.4501^{b}	-	-	-	-	0.6952^{c}	-	-	-	-	-
	PA			-	0.5201^{c}	-	-	0.3165^{a}	-	-	-	-	-	-	-	-0.3730^{a}
NPK+FYM	DHA	-	0.4728^{b}	-	0.4616^{b}	0.6011^{c}	0.3191^{a}	0.7969^{c}	0.6163^{c}	-0.4306^{b}	-0.7205^{c}	-	-	-	0.8092^{c}	-
	URA		-	-	-	-	-	-	-0.3865^{a}	-	0.4455^{b}	-	-	-	-	-
	PA			-	0.6483^{c}	-	-	-	-	-	-0.4139^{b}	-	-	-	0.3299^{a}	-

(Note: C_{mic}=microbial biomass carbon, SR=soil respiration, AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, FP=fungal population, BP=bacterial population, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity, RF=rainfall)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 4.3.5. Correlation coefficient (r) values among biochemical properties of soil with various microbial population, biological and physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at subsurface soil layer ($P \leq 0.05$).

Treatments	Soil properties	URA	PA	AT	ST	MC	pH	OC	TN	AP	K	SR	FP	BP	C_{mic}	RF
CTRL	DHA	-	-	-	0.5754^{c}	-	-	0.4715^{b}	0.4540^{b}	-	-0.3654^{a}	-	0.7592^{c}	-	-	-
	URA		-	-0.4713^{b}	-0.3259^{a}	-0.3115^{a}	0.4563^{b}	-	-0.4827^{c}	-	0.3526^{a}	-0.3951^{b}	-	-	-	-
	PA	-		-	0.4794^{c}	-	-	-	-	-	-	-	-	-	-	-
NPK	DHA	-	-	-	0.5385^{c}	-	-	0.3163^{a}	0.6586^{c}	-	-0.3227^{a}	0.4237^{b}	0.6342^{c}	-	0.4551^{b}	-
	URA		-	-0.4588^{b}	-0.3195^{a}	-	-	-	-0.4711^{b}	0.3901^{a}	0.5380^{c}	-0.3929^{b}	-	0.3067^{a}	-	-
	PA	-		-0.3349^{a}	-	-	-	-	-	-	-	-	-0.3203^{a}	-	-	-
FYM	DHA	-	-	-	0.5317^{c}	0.3180^{a}	0.3214^{a}	0.5019^{c}	-	-	-	-	0.4796^{c}	-	-	-
	URA		-	-0.4830^{c}	-0.3932^{b}	-	-	-	-0.6097^{c}	-	0.6608^{c}	-	-	-	-	-
	PA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.3785^{a}
NPK+FYM	DHA	-	-	-	0.5960^{c}	0.3827^{a}	-	0.6793^{c}	0.4157^{b}	-	-0.4038^{b}	-	0.3177^{a}	-	0.8906^{c}	-
	URA		-	-0.4183^{b}	-	-	-	-	-0.5402^{c}	-	0.3659^{c}	-0.3075^{a}	-	-	-	-
	PA	-		-	0.4567^{b}	-	-	-	-	-	-0.3931^{b}	-0.3926^{b}	-	-	-	-

(Note: C_{mic}=microbial biomass carbon, SR=soil respiration, AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, FP=fungal population, BP=bacterial population, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity, RF=rainfall)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Chapter-5

Physico-chemical characteristics of soil in agro-ecosystem

5.1. Introduction

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). These physical properties of soil are considered as important factors, which affect the growth and activity of soil microorganisms (Frankenberger and Dick, 1983). 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).

The present experimental plots were treated with different fertilizers influencing greatly the soil physico-chemical properties and soil fertility levels. The organic materials most commonly used to improve soil conditions and fertility include farmyard manure, animal wastes, crop residues, urban organic wastes, green manures, biogas spend slurry, microbial preparations, vermicompost, and biodynamic preparations (Verma and Thampan, 1995). Goyal *et al.* (1999) indicated that the amount of soil organic matter and mineralizable C increased with the application of inorganic fertilizers, however, there were greater increase of these parameters when farmyard manure, wheat straw or green was applied along

with inorganic fertilizers. Application of fertilizer to legume crops not only reduce biological N_2 fixation (Caroll and Mathews, 1990) but also decreased the genetic diversity among native Rhizobium strains (Cabarello-Mellado and Martinez-Romero, 1999).

It was observed that application of dairy manure over a 5-year period resulted in significant increase in C, N and soil microbial biomass, as well as changes in microbial community structure (Peacock *et al.*, 2001). Whereas long-term fertilization resulted in decreased total organic C (TOC) and basic cation contents, and had an acidifying effect on soil. The decreased in TOC was greater in simple fertilizer treatments (N, P, or K) whereas basic cation contents and pH declined more in balanced fertilizer treatments (NPK) (Belay *et al.*, 2002).

The magnitude of change in soil pH following the application of urea to soil is affected by factors such as temperature, soil moisture and urease enzyme activity (Singh and Yadav, 1981). Sierra (1997) examined the combined effect of temperature and soil moisture on net N mineralization using undisturbed soil samples. He found that net N mineralization was more responsive to temperature than it was to moisture.

5.2. Methodology

5.2.1. Soil temperature

Soil temperature was measured by using soil thermometer. The soil temperature was taken at monthly interval at surface and subsurface soil layers.

5.2.2. 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.

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

Where, W_1 = *initial weight*

W_2 = *final weight*

5.2.3. 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.

5.2.4. 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 labelled 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.

$$Organic\ carbon\ (\%) = \frac{(K\,X\,0.1)}{(W\,X\,0.74)}$$

Where, *W= Weight of soil.*

5.2.5. 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 kjeltablet was added and then the soil sample was digested in a block digestor 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 distillated was then collected in a beaker with 5 ml of boric acid indicator till the pink colour turned greenish. The distillated was then titrated against N/140 hydrochloric acid. The titration was stop when the colour turned pink.

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

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.

5.2.6. Available phosphorous

The available phosphorous was measured by following molybdenum blue method (Allen *et al.*, 1974). Weighed 5 g 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.

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

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 [$(NH_4)_6Mo_7O_{24}.4H_2O$] 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.

5.2.7. Exchangeable potassium

Exchangeable potassium was measured by using the method of Allen *et al.* (1974). 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.

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

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.

5.3. Results

5.3.1. Soil temperature

Soil temperature was generally higher in the first year than in the second year and the surface soil displayed higher temperature than the subsurface soil layer. In the first year maximum soil temperatures of 33.1^0 C and 29.26 ^{0}C were observed in the months of June and September at surface and subsurface soil layers respectively. In the second year, the maximum soil temperatures 30.7^0 C and 25.5 ^{0}C were observed in the months of October and July at surface and subsurface soil layers respectively (Fig. 5.3.1).

In CTRL plot at surface soil layer, soil temperature was positively correlated with nitrogen, dehydrogenase activity and phosphatase activity. At subsurface soil layer, it was positively correlated with moisture content, organic carbon, nitrogen, fungal population, dehydrogenase and phosphatase activities (Tables 5.3.4 and 5.3.8).

In NPK plot at surface soil layer, soil temperature was positively correlated with organic carbon, nitrogen and dehydrogenase. At subsurface soil layer, it was positively correlated with nitrogen and dehydrogenase activity (Tables 5.3.5 and 5.3.9).

In FYM plot at surface soil layer, soil temperature was positively correlated with organic carbon, dehydrogenase and phosphatase. At subsurface soil layer, it was positively correlated with moisture content, pH, organic carbon, nitrogen and dehydrogenase (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at surface soil layer, soil temperature was positively correlated with organic carbon, microbial biomass carbon, and dehydrogenase

and phosphatase activities. At subsurface soil layer, it was positively correlated with pH, organic carbon, nitrogen, microbial biomass carbon, and dehydrogenase and phosphatase activities (Tables 5.3.7 and 5.3.11).

5.3.2. Soil moisture content

The maximum soil moisture content was observed in the month of July and a closed relationship of moisture content between surface and subsurface soil layers was observed during the entire investigation (Fig. 5.3.2).

In the first year at surface soil layer, moisture content ranged between 20.033 and 29.067% in NPK and FYM plots in the month of June and July respectively. At subsurface soil layer, it ranged from 20.3 to 28.5 % in NPK and FYM plots in the month of June and July respectively.

In the second year at surface soil layer, moisture content ranged between 19.407 and 26.533 % in CTRL and FYM plots in the month of April and July respectively. At subsurface soil layer, it ranged from 18.3 to 25.067 % in CTRL and FYM in the months of April and September respectively.

The analysis of variance (ANOVA) showed a significance variation ($P \leq 0.05$) of soil moisture content between CTRL X NPK X FYM X NPK+FYM, NPK X FYM and NPK X NPK+FYM treated plots at surface layer, whereas at subsurface layer the significant variation was observed between CTRL X FYM, CTRL X NPK+FYM, NPK X FYM and NPK X NPK+FYM (Table 5.3.1). The ANOVA also showed a significance variation of soil moisture content between surface and subsurface soil layers except at NPK+FYM plot (Table 5.3.2).

The correlation coefficient values of soil moisture content showed a positive correlation between surface layer and subsurface soil layer at $P \leq 0.001$ level in treated and untreated plots (Table 5.3.3).

In CTRL plot at surface soil layer, soil moisture content was positively correlated with ambient temperature, nitrogen, soil respiration and dehydrogenase. At subsurface soil layer, it was positively correlated with ambient temperature and soil respiration (Tables 5.3.4 and 5.3.8)

In NPK plot at surface soil layer, soil moisture content was positively correlated with ambient temperature and soil respiration. At subsurface soil layer, it was positively correlated with ambient temperature, nitrogen and soil respiration (Tables 5.3.5 and 5.3.9).

In FYM plot at surface soil layer, soil moisture content was positively correlated with ambient temperature, nitrogen, soil respiration and dehydrogenase. At subsurface soil layer, it was positively correlated with ambient temperature, organic carbon, nitrogen, soil respiration and dehydrogenase (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at surface soil layer, soil moisture content was positively correlated with ambient temperature, organic carbon, nitrogen, soil respiration, microbial biomass carbon and dehydrogenase activity. At subsurface soil layer, it was positively correlated with ambient temperature, organic carbon, nitrogen, soil respiration and dehydrogenase (Tables 5.3.7 and 5.3.11).

5.3.3. Soil pH

The surface soil pH was generally higher than the subsurface soil layer i.e. subsurface soil was more acidic than surface soil. In the first year at surface soil layer, soil pH was ranged between 5.0 and 6.0 in NPK and CTRL plots in the month of July and April respectively. At subsurface soil layer, it ranged between 4.9 and 5.7 in CTRL and NPK+FYM plots in the month of April and October respectively.

In the second year at surface soil layer, soil pH ranged between 5.23 and 6.0 in FYM and NPK+FYM plots in the months of September and April respectively. At subsurface soil layer, it ranged between 5.02 and 5.81 in NPK and NPK+FYM plots in the month of September and April respectively (Fig. 5.3.3).

The one way analysis of variance showed a significant variation ($P \leq 0.05$) of soil pH between treated plots viz. CTRL X NPK X FYM X NPK+FYM, CTRL X FYM, NPK X FYM and NPK x NPK+FYM at surface and subsurface soil layers, whereas significant variation between treated plots viz. CTRL X NPK+FYM, FYM X NPK+FYM were observed only at subsurface layer (Table 5.3.1). The ANOVA also showed a significant variation ($P \leq 0.001$) of soil pH between surface and subsurface soil layers except at NPK+FYM plot (Table 5.3.2).

The correlation coefficient values ($P \leq 0.001$) of soil moisture content showed a positive correlation between surface and subsurface soil layers in CTRL and NPK+FYM plots (Table 5.3.3).

In CTRL plot at surface soil layer, the pH was positively correlated with potassium and urease. At subsurface soil layer, it was positively correlated with potassium, rainfall and urease (Tables 5.3.4 and 5.3.8).

In NPK plot at surface soil layer, the pH was positively correlated with, phosphatase. At subsurface soil layer, it was positively correlated with rainfall, bacterial population and microbial biomass carbon (Tables 5.3.5 and 5.3.9).

In FYM plot at subsurface soil layer, the pH was positively correlated with soil temperature, organic carbon, potassium, rainfall, microbial biomass carbon and dehydrogenase (Table 5.3.10).

In NPK+FYM plot at surface soil layer, the pH was positively correlated with organic carbon and dehydrogenase. At subsurface soil layer, it was positively correlated with temperature and organic carbon (Tables 5.3.7 and 5.3.11).

5.3.4. Soil organic carbon

The soil organic carbon in FYM and NPK+FYM plots showed increased percentage from pre-fertilizers treatment to post treatment (Fig. 5.3.4). The result showed that generally within each sampling month, the percentage organic carbon was higher in FYM and NPK+FYM plots, whereas CTRL and NPK plots displayed a lower percentage value of organic carbon. The surface soil organic carbon was higher than subsurface soil layer during the entire investigation.

In the first year at surface soil layer, soil organic carbon ranged between 1.81% and 2.75% in FYM and NPK+FYM plots in the months of July and May respectively. At subsurface soil layer, it ranged between 1.48% and 2.53% in CTRL and NPK+FYM plots in the month of April and May respectively.

In the second year, soil organic carbon ranged between 1.59% and 2.29% in NPK and NPK+FYM plots in the months of June and May respectively. At subsurface soil layer, it ranged between 0.99% and 1.83% in CTRL and NPK+FYM plots in the months of October and May respectively.

The one way analysis of variance showed a significant variation ($P \leq 0.05$) of soil organic carbon between treatments except in CTRL X NPK and FYM X NPK+FYM plots at surface and subsurface soil layers (Table 5.3.1). The ANOVA also showed a significant ($P \leq 0.001$) variation of soil organic carbon between surface and subsurface soil layers in all the treatments (Table 5.3.2).

The correlation coefficient values ($P \leq 0.01$) of soil organic carbon also showed a positive correlation between surface soil layer and subsurface soil layer in CTRL and NPK+FYM plots (Table 5.3.3).

In CTRL plot at the surface layer, soil organic carbon was positively correlated with dehydrogenase. At subsurface soil layer, it was positively correlated with soil temperature, nitrogen, rainfall, bacterial population and dehydrogenase (Tables 5.3.4 and 5.3.8).

In NPK plot at the surface soil layer, organic carbon was positively correlated with soil temperature, nitrogen, fungal population, microbial biomass carbon and dehydrogenase. At the subsurface soil layer, it was positively correlated with fungal population, bacterial population and dehydrogenase (Tables 5.3.5 and 5.3.9).

In FYM plot at the surface soil layer, organic carbon was positively correlated with soil temperature, dehydrogenase and phosphatase. At the

subsurface soil layer, it was positively correlated with soil temperature, moisture content, pH, nitrogen, rainfall, microbial biomass carbon and dehydrogenase (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at the surface soil layer, soil organic carbon was positively correlated with soil temperature, moisture content, pH, nitrogen, microbial biomass carbon and dehydrogenase. At the subsurface soil layer, it was positively correlated with soil temperature, moisture content, pH, nitrogen, microbial biomass carbon and dehydrogenase (Tables 5.3.7 and 5.3.11).

5.3.5. Total nitrogen

The result indicated that at surface soil layer, total nitrogen increased from pre-fertilizers treatment to post treatment in all the plots, whereas at subsurface soil layer, It increased in all treated plots except in FYM plot. The percentage of total nitrogen was more in the first year than in the second year at both surface and subsurface soil layers. The result showed that generally soil nitrogen reduced at post harvest and the inconsistent peak distribution of soil nitrogen within each sampling month was observed.

In the first year at surface soil layer, total soil nitrogen ranged from 0.130% to 0.312% in NPK plot in the months of April and June. At subsurface soil layer, it ranged from 0.041% to 0.22% in CTRL and NPK plots in the months of April and May respectively.

In the second year at surface soil layer, the total soil nitrogen ranged from 0.063% to 0.322% in CTRL and NPK in the months of April and June respectively.

At subsurface soil layer, it ranged from 0.04% to 0.133% in NPK+FYM and NPK plots in the month of April and August respectively (Fig. 5.3.5).

The one way analysis of variance showed a significant variation ($P \leq 0.05$) of total soil nitrogen between CTRL X NPK plots at subsurface soil layer (Table 5.3.1) and a significant ($P \leq 0.001$) variation of total soil nitrogen between surface and subsurface soil layers in all treated plots (Table 5.3.2).

The correlation coefficient ($P \leq 0.05$) values also showed a positive correlation of total soil nitrogen content between surface and subsurface soil layers (Table 5.3.3).

In CTRL plot at the surface soil layer, total soil nitrogen was positively correlated ($P \leq 0.05$) with ambient temperature, soil temperature, moisture content, fungal population and dehydrogenase. At the subsurface soil layer, it was positively correlated with ambient temperature, soil temperature, organic carbon, rainfall, soil respiration, fungal population and dehydrogenase (Tables 5.3.4 and 5.3.8).

In NPK plot at the surface soil layer, total soil nitrogen was positively correlated with ambient temperature, soil temperature, organic carbon, rainfall and dehydrogenase. At the subsurface soil layer, it was positively correlated with ambient temperature, soil temperature, moisture content, soil respiration, fungal population and dehydrogenase (Tables 5.3.5 and 5.3.9).

In FYM plot at the surface soil layer, total soil nitrogen was positively correlated with moisture content, fungal population, microbial biomass carbon and dehydrogenase. At the subsurface soil layer, it was positively correlated with

ambient temperature, soil temperature, moisture content, organic carbon, phosphorus and soil respiration (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at the surface soil layer, total soil nitrogen was positively correlated with ambient temperature, moisture content, organic carbon, soil respiration, fungal population, microbial biomass carbon and dehydrogenase. At the subsurface soil layer, it was positively correlated with ambient temperature, soil temperature, moisture content, organic carbon, rainfall, soil respiration and dehydrogenase (Tables 5.3.7 and 5.3.11).

5.3.6. Available phosphorous

The result showed that soil available phosphorus increased from pre-fertilizers treatment to post treatment. The maximum phosphorus content displayed in FYM plot in the month of July and it was also observed that peak phosphorus showed inconsistent distribution (Fig. 5.3.6).

In the first year at surface soil layer, soil phosphorus content ranged between 5.33 and 44.39 $\mu g\ g^{-1}$ dry soil in NPK+FYM and FYM plots in the months of September and July respectively. At subsurface soil layer it ranged between 3.4 and 38.0 $\mu g\ g^{-1}$ dry soil in CTRL and FYM plots in the month of September and July respectively.

In the second year at surface soil layer, soil phosphorus content ranged between 16.73 and 68.0 and $\mu g\ g^{-1}$ dry soil in FYM and NPK+FYM plots in the months of April and July respectively. At subsurface soil layer, it ranged between 4.7 and 43.63 $\mu g\ g^{-1}$ dry soil in NPK and FYM plots in the months of August and July respectively.

The one way analysis of variance showed a significant variation ($P \leq 0.05$) of phosphorus between NPK X NPK+FYM plots at surface soil layer (Table 5.3.1) and between surface soil layer and subsurface soil layers (Tables 5.3.2 and 5.3.3).

The correlation coefficient values ($P \leq 0.001$) of soil phosphorus also showed a positive correlation between surface soil layer and subsurface soil layers (Table 5.3.3).

In CTRL plot at surface layer, soil phosphorus content was positively correlated with ambient temperature and fungal population. At subsurface soil layer, it was positively correlated with soil respiration (Tables 5.3.4 and 5.3.8).

In NPK plot at surfacel layer, soil phosphorus was positively correlated with potassium and urease. At subsurface soil layer, it was positively correlated with potassium and urease (Tables 5.3.5 and 5.3.9).

In FYM plot at surface layer, soil phosphorus was positively correlated with ambient temperature, soil respiration, bacterial population and microbial biomass carbon. At subsurface soil layer, it was positively correlated 'with ambient temperature, nitrogen, rainfall, soil respiration and microbial biomass carbon (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at surface layer, soil phosphorus was positively correlated with fungal population. At subsurface soil layer, it was positively correlated with ambient temperature, soil respiration and fungal population (Tables 5.3.7 and 5.3.11).

5.3.7. Exchangeable potassium

The result indicated that the potassium increased from pre-fertilizers treatment to post treatment in a fertilizer treated plot viz. NPK and NPK+FYM plots. Inconsistent trend of peak potassium distribution within each sampling month and maximum potassium displayed in NPK plot was observed and the potassium was dropped at post harvest in treatments. Generally, soil potassium content was higher in the second year in the surface soil layer than the subsurface soil layer (Table 5.3.7).

In the first year at surface soil layer, soil potassium content ranged between 0.011% and 0.021% in NPK+FYM and NPK plots in the months of April and May respectively. At subsurface, it ranged between 0.006% and 0.017% in NPK plot in the month of October and May respectively.

In the second year at surface soil layer, soil potassium content ranged between 0.015% and 0.027% in FYM and NPK plots in the month of October and May respectively. At subsurface soil layer, it ranged between 0.011% and 0.022% in FYM and NPK plots in the months of October and May respectively.

The one-way analysis of variance showed a significant variation ($P \leq 0.05$) of potassium between CTRL X NPK and CTRL X NPK+FYM plots at surface soil layer (Table 5.3.1) and the result also indicated a significant ($P \leq 0.001$) variation of potassium between surface soil layer and subsurface soil layer (Table 5.3.2).

The correlation coefficient values ($P \leq 0.001$) of soil potassium also showed a positive correlation between surface soil layer and subsurface soil layer level (Table 5.3.3).

In CTRL plot at surface soil layer, soil potassium was positively correlated with pH, urease and phosphatase. At the subsurface soil layer, it was positively correlated with pH, bacterial population and urease (Tables 5.3.4 and 5.3.8).

In NPK plot at surface soil layer, soil potassium was positively correlated with phosphorus, urease and phosphatase. At the subsurface soil layer, it was positively correlated with phosphorus, soil respiration and urease (Tables 5.3.5 and 5.3.9).

In FYM plot at surface soil layer, soil potassium was positively correlated with urease. At the subsurface soil layer, it was positively correlated with pH, rainfall and urease (Tables 5.3.6 and 5.3.10).

In NPK+FYM plot at surface soil layer, soil phosphorus was positively correlated with urease. At the subsurface soil layer, it was positively correlated with urease (Tables 5.3.7 and 5.3.11).

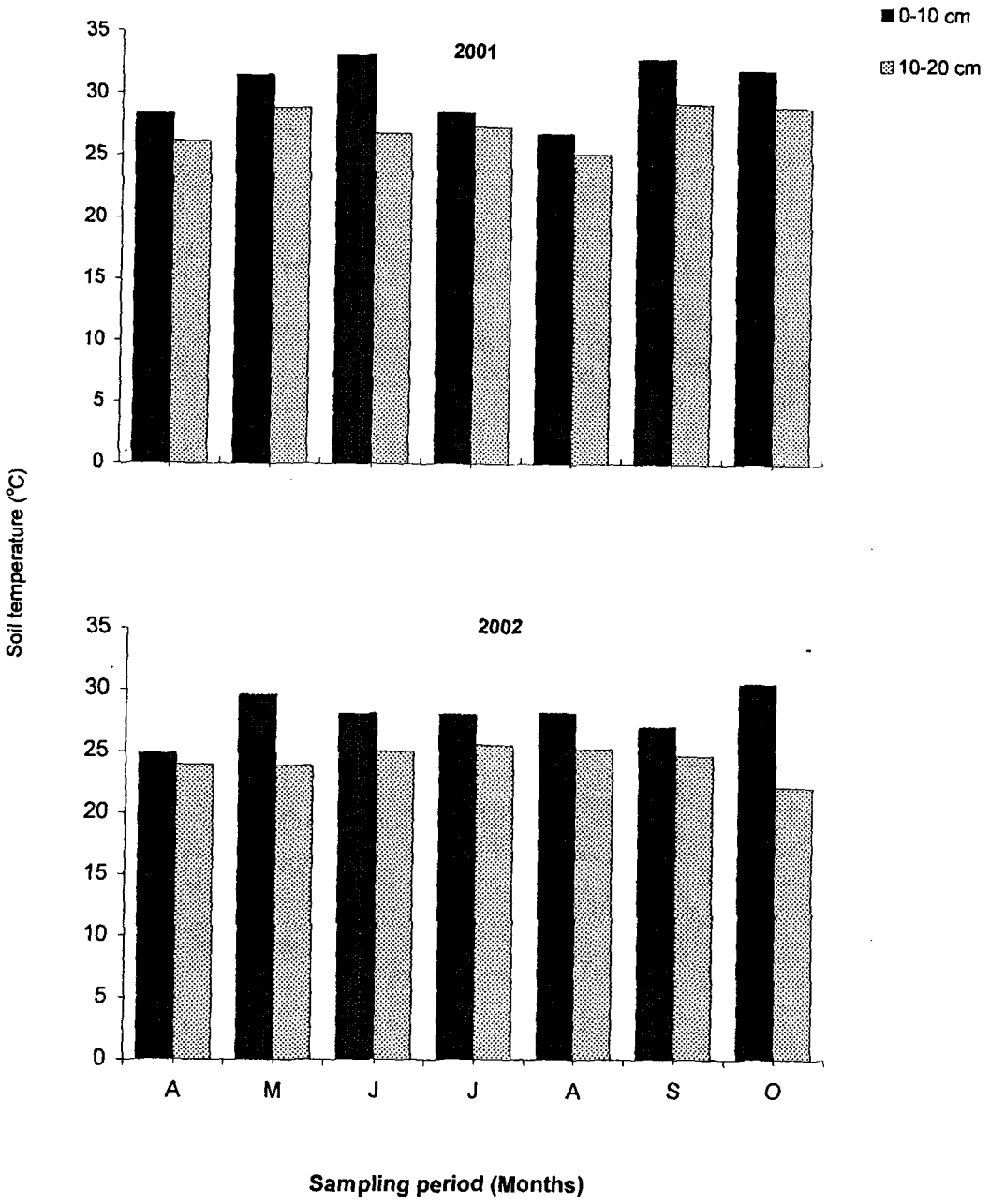


Fig. 5.3.1. Soil temperature in groundnut field soils at 0-10 cm and 10-20 cm depths.

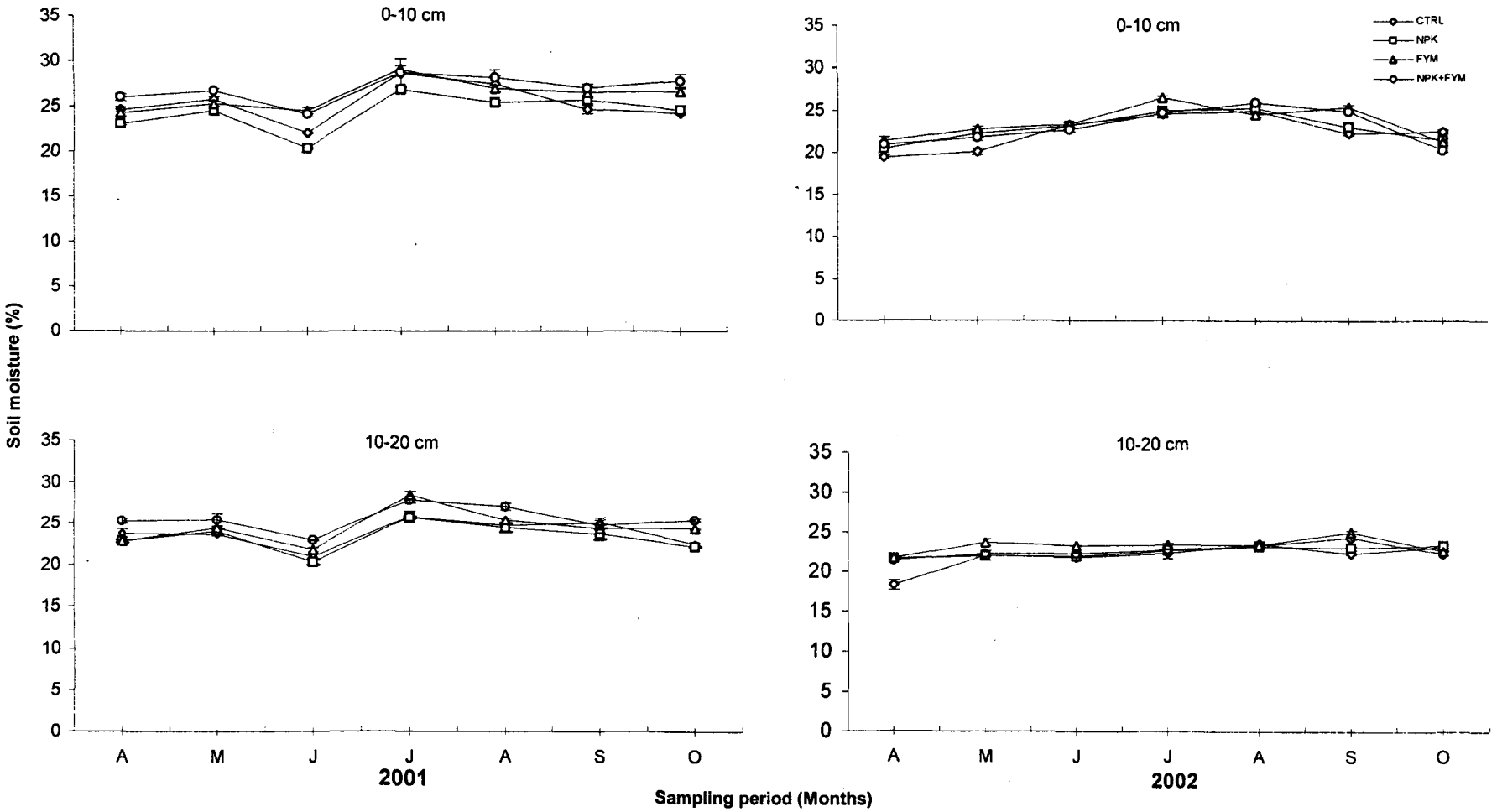


Fig. 5.3.2. Moisture content in groundnut field soil at 0-10 cm and 10-20 cm depths.

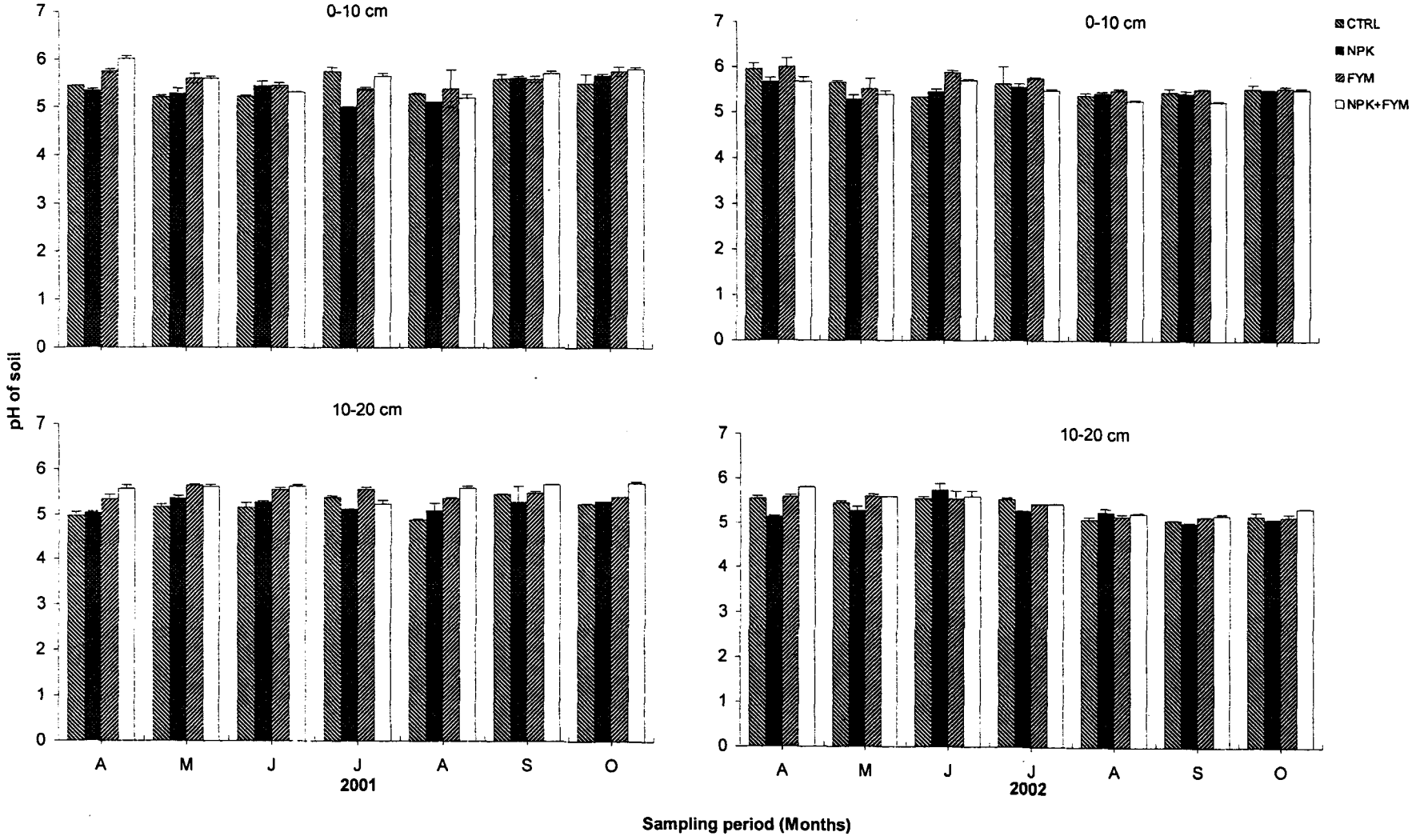


Fig. 5.3.3. Distribution of soil pH in groundnut field soil at 0-10 cm and 10-20 cm depths.

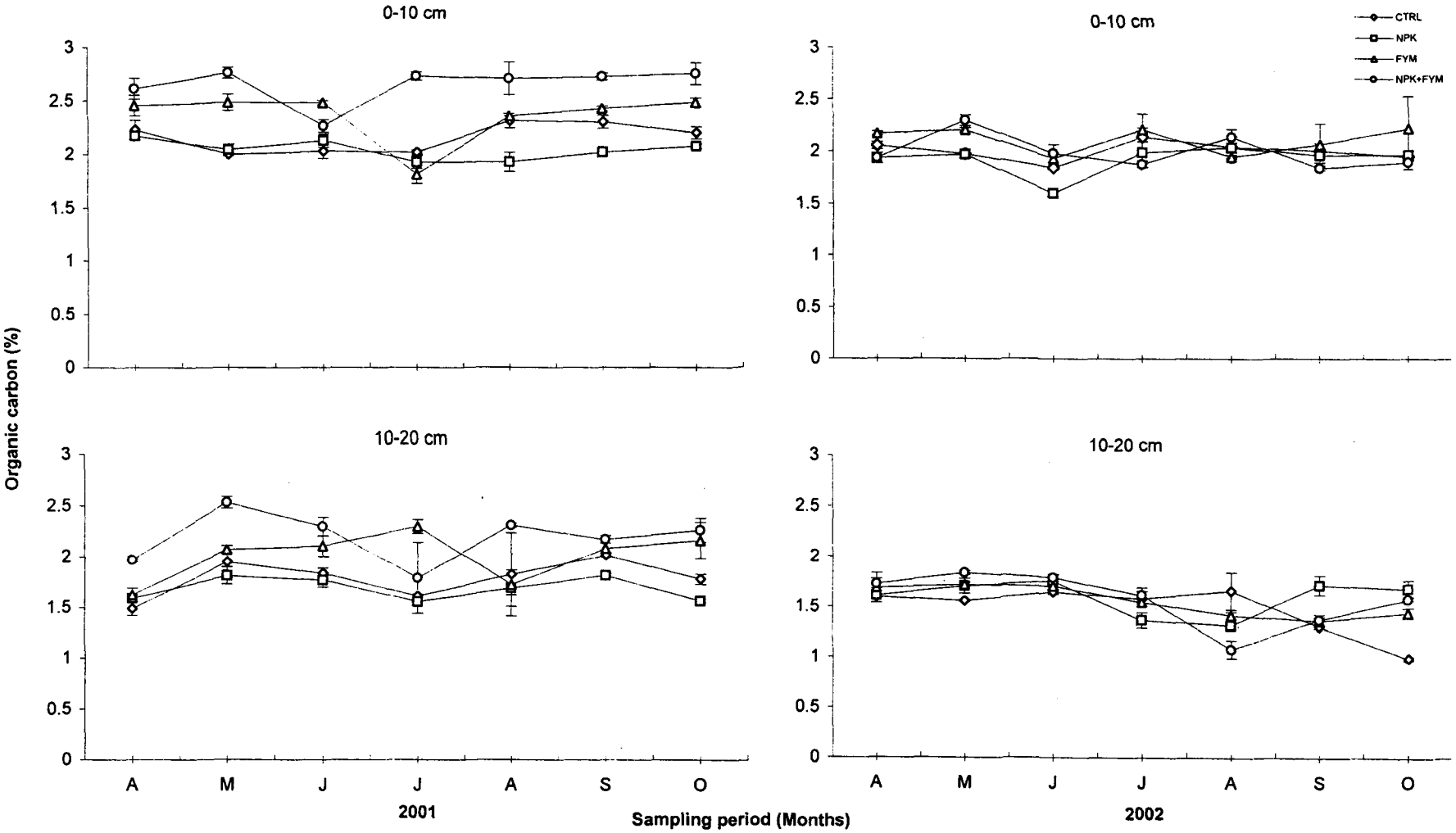


Fig. 5.3.4. Distribution of organic carbon in groundnut field soil at 0-10 cm and 10-20 cm depths.

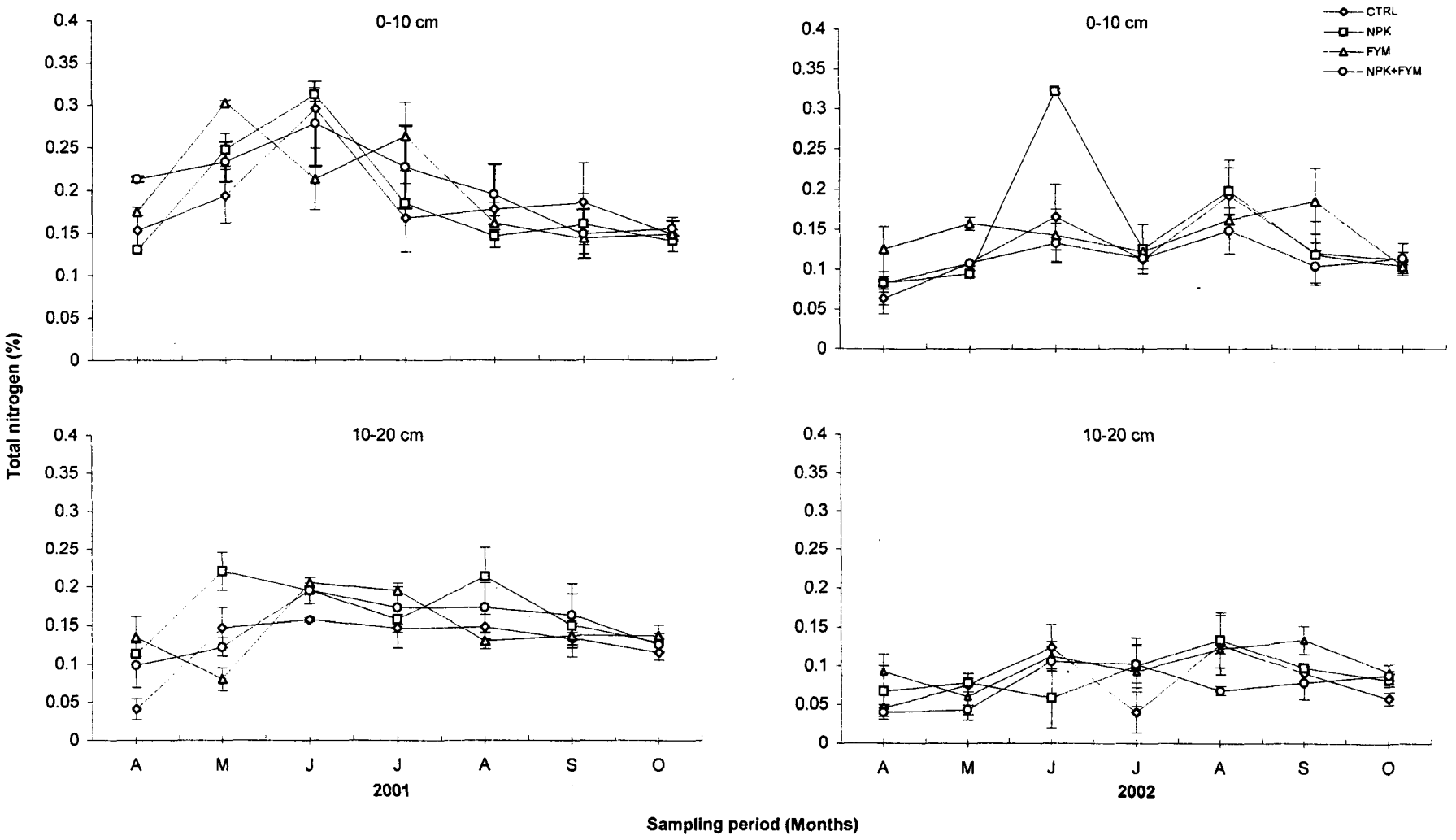


Fig. 5.3.5. Distribution of total nitrogen in groundnut field soil at 0-10 cm and 10-20 cm depths.

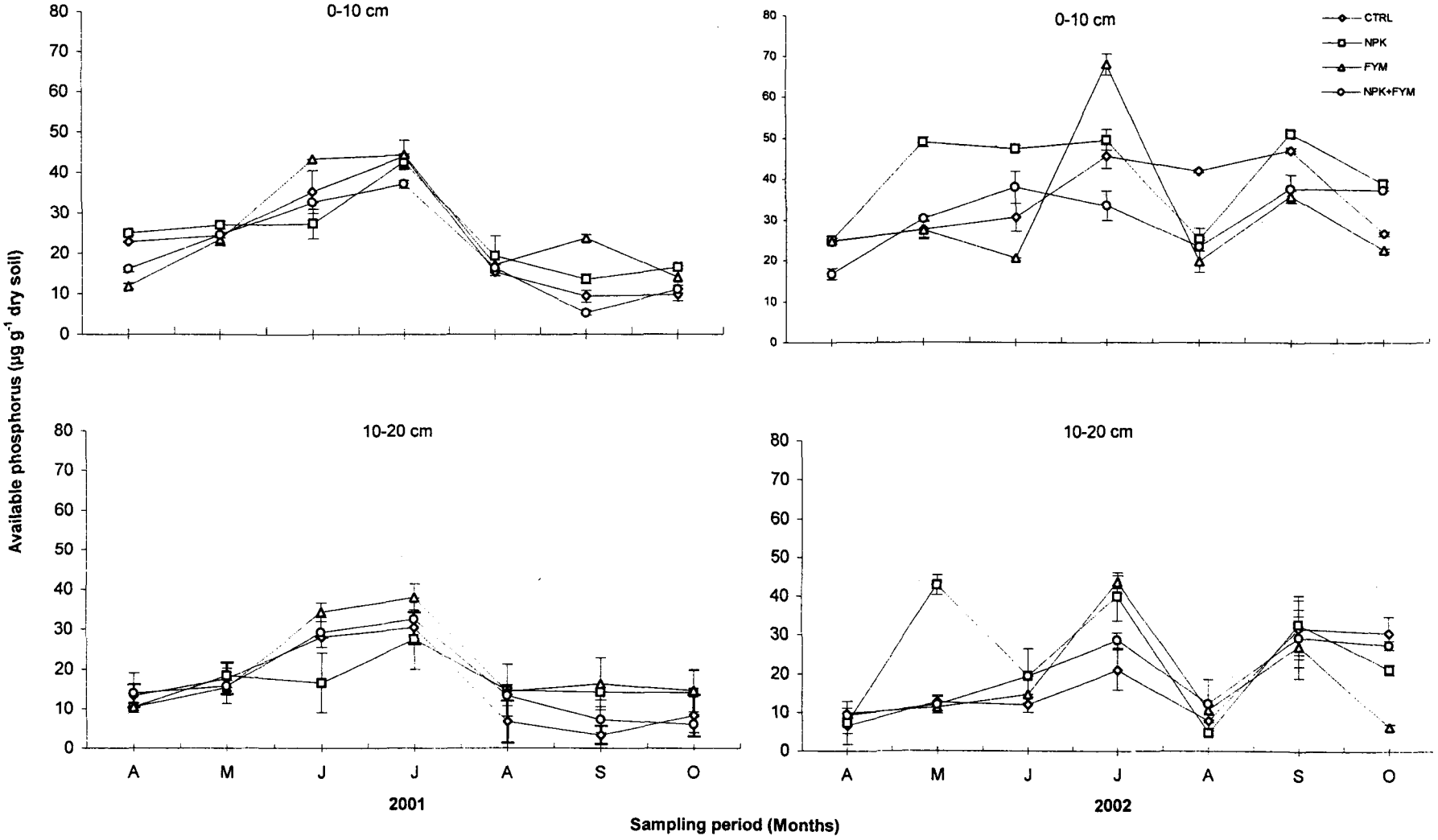


Fig. 5.3.6. Distribution of available phosphorus in groundnut field soil at 0-10 cm and 10-20 cm depths.

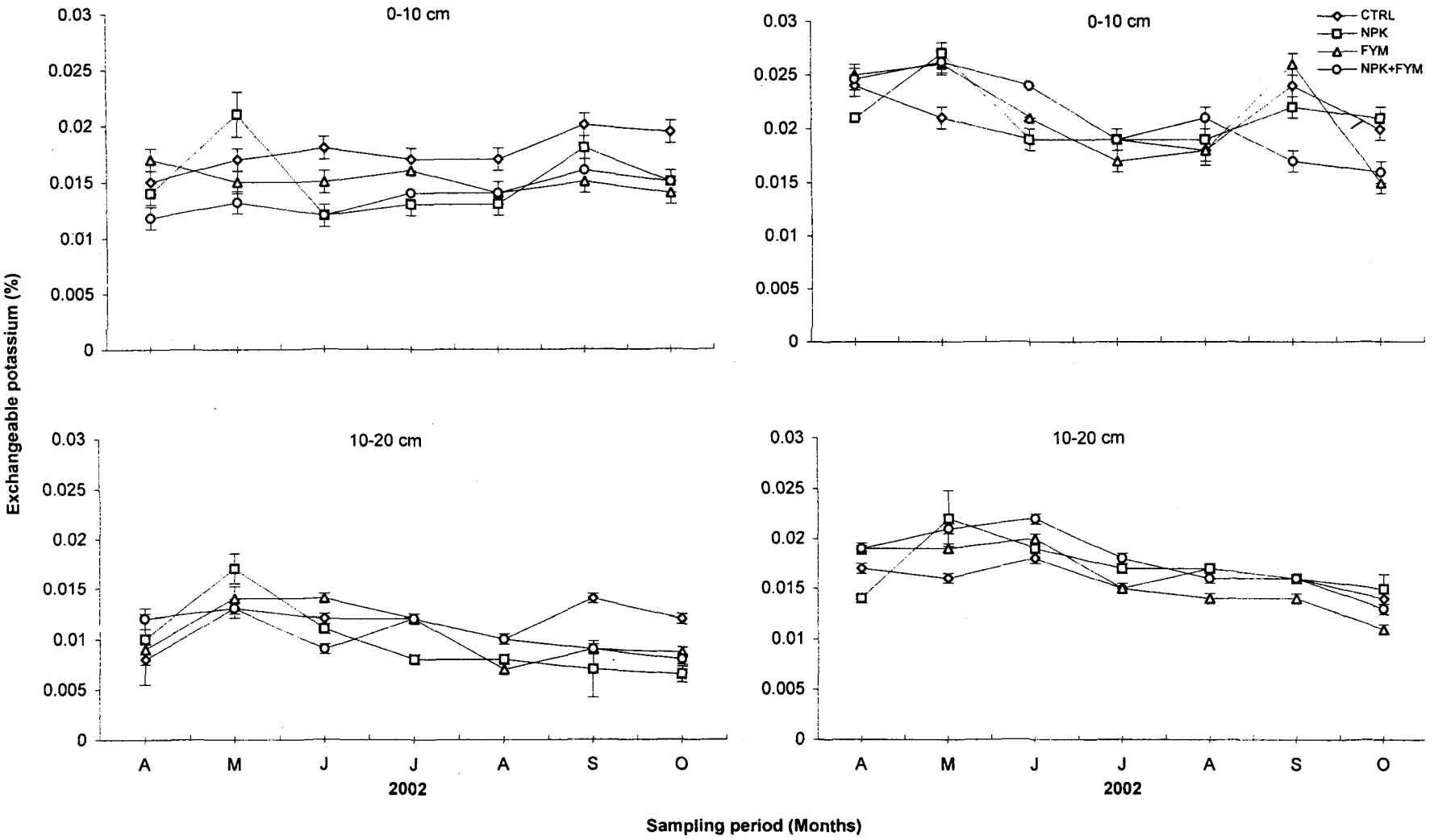


Fig. 5.3.7. Distribution of exchangeable potassium in groundnut field soil at 0-10 cm and 10-20 cm sepths.

5.4. Discussion

5.4.1. Soil temperature and soil moisture content in agro-ecosystem

The result that showed higher soil temperature at surface soil layer than subsurface soil layer could be due to the heating up of surface soil by solar radiation and also due to the higher moisture content in the deeper soil layer. The result that showed a positive correlation of soil enzymes with soil temperature is in agreement with the findings of Sinsabaugh *et al.* (1991) that temperature has been controlling factors of the enzyme activities in upland soils. Chrost (1991) also reported that, soil temperature affects the enzyme activity indirectly through influencing microbial proliferation, and also directly, by modifying enzyme kinetics

The moisture content significantly ($P \leq 0.05$) varied among the treatment in the 0-10 cm, where the greater moisture content was noted at FYM plot, this result could be due to the greater water retention capacity of farmyard manure. Mogaddeghi *et al.* (2000) also reported that application of farmyard manure at the rate of 50 Mg ha^{-1} increased soil wetness trafficability range, thus reducing soil compactibility.

5.4.2. Effects of organic and inorganic fertilizers on soil pH

The result indicated that soil pH in the surface layer decreased after it was treated with fertilizers and sowing of groundnut. This result is in conformity with Simek *et al.* (1999) that soil pH decreased by the addition of organic manure plus inorganic fertilizers in the absence of liming. Yan *et al.* (1996) reported that during cultivation of legumes, soil is acidified due to proton release from roots and they further mentioned that soil pH significantly decreased by field legumes (beans)

from 6.00 to 5.64 in a cultivation period of 45 days. It was also observed that within each monthly sampling, the soil pH showed inconsistent trend among plots in the surface and subsurface soil layers. This unreliable result could be due to the retention of fertilizers and types of the fertilizers (organic or inorganic), which were applied in earlier experiment to this field. Colting, (1997) stated that all the plots that were continuously applied with pure organic fertilizer showed slight increase in soil pH and soil organic matter content. Conversely, the continuous application of pure inorganic fertilizer resulted in a decreasing trend in soil pH.

5.4.3 Effects of organic and inorganic fertilizers on soil organic carbon

The higher soil organic carbon observed in FYM and NPK+FYM plots might be due to the higher organic matter content in farmyard manure. Saviozzi *et al.* (1999) reported that FYM treated plot showed higher amount of total organic matter (TOC). Soil organic matter levels and soil microbial activities, vital for the nutrient turnover and long-term productivity of the soil, were enhanced by use of organic amendments along with inorganic fertilizers (Goyal *et al.*, 1999).

The peak organic carbon which noted in the month of May in NPK+FYM plot in the surface and subsurface soil layers could be due to the supplies of large amounts of readily available C, resulting in a more diverse and dynamic microbial system than inorganically fertilized soil (Peacock *et al.*, 2001). The same result is also reported by Agbenin and Goladi (1997) that the combination of farmyard manure with N+P and N+P+K fertilization could enable soil carbon to be maintained equal to, or greater than the native site soil. In contrast, continuous

inorganic fertilization was deleterious to soil quality because of depletion of organic matter, the reservoir of plant available N and P in weathered, tropical soils (Agbenin and Goladi, 1997). The higher organic carbon in NPK+FYM plot even at the subsurface soil layer could also be due the significant increase soluble organic carbon in a soil treated with manure (Liang *et al.*, 1998) and the downward movement of soluble carbon in the soil profile (Bhogal and Shepard, 1997).

5.4.4. Effects of organic and inorganic fertilizers on soil total nitrogen

Groundnut is a leguminous crop; it can easily fix atmospheric nitrogen through its nodules present in the root system. Since the result showed peak soil nitrogen content in NPK plot and minimum in pre-fertilizers treatment, within each monthly sampling NPK and NPK+FYM plots were expected to display higher amount of soil N. Omay *et al.* (1997) and Simek *et al.* (1999) also observed that the soil N contents were greater for all fertilized treatments as compared to the control. But it was observed that CTRL and FYM plots showed higher range of soil N in some months, this inconsistent result could be due to the higher accumulation of soil N through biological N fixation by the leguminous groundnut plant and the effects of retention of fertilizers. It was also observed that total soil N dropped after the plant was removed (October). This result suggested that nitrogen fertilizer (urea) was not the only controlling factor on the distribution of soil N, whereas it was highly controlled by availability of N through biological nitrogen fixation.

There are lots of reports on the higher soil N content in FYM treated soil. (Saviozzi *et al.*, 1999). However, combination of farmyard manure with N+P+K

fertilization enabled N to be maintained equal to, or greater than the native site soil (Agbenin and Goladi, 1997).

5.4.5. Effects of organic and inorganic fertilizers on soil available phosphorus

The result that showed increased soil P from pre-fertilizers treatment to post treatment could be due to the availability of inorganic P through the addition of P fertilizer (single super phosphate). This result is supported by the observation of Ishaq *et al.* (2002) and Agbenin and Goladi (1998) that the P fertilizer application significantly increased soil P concentration. Scholefield and Stone (1995) also reported that little of the P fertilizer added in their experiments could be detected in the bicarbonate-extractable fraction a few days after addition.

The result that showed maximum phosphorus in FYM plot could be due to the highly bound unavailable form of organic P in manures. Though the maximum P was observed in FYM plot, the manure P was relatively more mobile but less available for plants than inorganic fertilizer P and long-term application of cattle manure promoted microbiological activities and P cycling, but did not result in P accumulation to levels close to those in inorganic P fertilizer-treated soils (Parham *et al.*, 2002).

The soil P distribution within each monthly sampling showed inconsistent distribution, where treated plot was expected to display higher amount of soil P. So, the inconsistent distribution might be due to the effect of fertilizers retention.

5.4.6. Effects of organic and inorganic fertilizers on soil exchangeable potassium

The NPK and NPK+FYM treated plots displayed increased soil exchangeable potassium after the addition of fertilizers. Simek *et al.* (1999) also reported that the soil concentrations of all the inorganic nutrients (NPK) measured were greater following fertilizer applications as compared to the unfertilized plots, and this effect was most marked for K in soils from plot that had received the largest amounts of these nutrients as fertilizers. But the present result indicated that the CTRL and FYM plots in 2001 at surface and subsurface soil layers displayed greater amount of K than NPK+FYM in the month of May and inconsistent peak K distribution within each monthly sampling. It was hypothesized that this inconsistent result might be due to the effects of K retention, which was applied few years back for other experimental purposes. The result that showed insignificant variation ($P \leq 0.05$) of K among different treatments also confirmed this hypothesis.

The result showed that the percentage of soil K dropped in post harvest and it was hypothesized that, since the uptake of K by groundnut plant was more in the month of September and so the K content in soil was likely to be reduced in the post harvest. The analysis of K content in plant tissue (Fig. 6.3.5) also showed higher K in the month of September as compared to other months.

It can be concluded that due to more solar radiation and higher moisture content at the subsurface soil layer, the soil temperature was higher at surface

layer. FYM plot has greater soil moisture content due to its higher retention of water. The addition of fertilizer especially organic and inorganic reduced the soil pH as well as the legume and the retention of fertilizers have also affected the distribution of soil pH. It was also concluded that due to increase in soluble organic carbon in treated manure soil, higher soil organic carbon was noted only at FYM or NPK+FYM plots during the investigation. It was observed that not only inorganic fertilizers but also the leguminous plant (groundnut) has a great influenced on the distribution of soil N. Soil P content was markedly higher in presence of FYM during the entire investigation. The soil K distribution was also affected by the application of inorganic fertilizers and its retention in soil.

Table 5.3.1. One way analysis of variance (ANOVA) of the physico-chemical properties of soil in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farmyard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) at surface and subsurface soil layers ($P \leq 0.05$).

Soil properties	Source of variation	Surface layer (0-10 cm)		Subsurface layer (10-20 cm)	
		F-ratio	P-level	F-ratio	P-level
Moisture content	CTRL X NPK X FYM X NPK+FYM	3.5272	1.6×10^{-2}	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	5.5537	2.08×10^{-2}
	CTRL X NPK+FYM	-	-	7.2615	8.5×10^{-3}
	NPK X FYM	7.6102	7.1×10^{-3}	8.8268	3.8×10^{-3}
	NPK X NPK+FYM	6.7879	1.08×10^{-2}	10.900	1.4×10^{-3}
	FYM X NPK+FYM	-	-	-	-
pH	CTRL X NPK X FYM X NPK+FYM	6.8629	2.2×10^{-4}	18.2769	1×10^{-7}
	CTRL X NPK	-	-	-	-
	CTRL X FYM	6.3514	1.3×10^{-2}	14.1120	3.2×10^{-4}
	CTRL X NPK+FYM	-	-	29.3418	1×10^{-6}
	NPK X FYM	22.4657	9×10^{-6}	21.5622	1.3×10^{-5}
	NPK X NPK+FYM	7.6748	6.9×10^{-3}	40.2295	1×10^{-7}
	FYM X NPK+FYM	-	-	4.1024	4.6×10^{-2}
Organic carbon	CTRL X NPK X FYM X NPK+FYM	9.5051	8×10^{-6}	6.2945	4.5×10^{-4}
	CTRL X NPK	-	-	-	-
	CTRL X FYM	11.6380	1×10^{-3}	5.5866	2.04×10^{-2}
	CTRL X NPK+FYM	15.5078	1.7×10^{-4}	10.7411	1.5×10^{-3}
	NPK X FYM	10.9970	1.3×10^{-3}	5.6785	1.9×10^{-2}
	NPK X NPK+FYM	15.1144	2.05×10^{-4}	11.1830	1.2×10^{-3}
	FYM X NPK+FYM	-	-	-	-
Total nitrogen	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	4.4294	3.8×10^{-2}
	CTRL X FYM	-	-	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-
Available phosphorus	CTRL X NPK X FYM X NPK+FYM	-	-	-	-
	CTRL X NPK	-	-	-	-
	CTRL X FYM	-	-	-	-
	CTRL X NPK+FYM	-	-	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	6.9170	1.01×10^{-2}	-	-
	FYM X NPK+FYM	-	-	-	-
Exchangeable potassium	CTRL X NPK X FYM X NPK+FYM			-	-
	CTRL X NPK	4.9847	2.8×10^{-2}	-	-
	CTRL X FYM			-	-
	CTRL X NPK+FYM	6.0631	1.5×10^{-2}	-	-
	NPK X FYM	-	-	-	-
	NPK X NPK+FYM	-	-	-	-
	FYM X NPK+FYM	-	-	-	-

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

Table 5.3.2. One way analysis of variance (ANOVA) of physico-chemical properties of soil between surface and subsurface soil layers in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farmyard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.001$).

Soil properties	Treatments	F-ratio	P-level
Moisture content	CTRL	4.1355	4.5×10^{-2}
	NPK	4.2597	4.2×10^{-2}
	FYM	5.6784	1.9×10^{-2}
	NPK + FYM	-	-
pH	CTRL	20.1577	2.3×10^{-5}
	NPK	12.6418	6.3×10^{-4}
	FYM	17.7427	6.4×10^{-5}
	NPK + FYM	-	-
Organic carbon	CTRL	82.4566	1×10^{-7}
	NPK	100.4127	1×10^{-7}
	FYM	53.4808	1×10^{-7}
	NPK + FYM	26.8032	2×10^{-6}
Total nitrogen	CTRL	16.0254	1.3×10^{-4}
	NPK	7.7105	6.8×10^{-3}
	FYM	18.2308	5.2×10^{-5}
	NPK + FYM	14.1975	3.09×10^{-4}
Available phosphorus	CTRL	23.3004	6×10^{-6}
	NPK	19.4739	3.1×10^{-5}
	FYM	6.1697	3.2×10^{-3}
	NPK + FYM	8.9944	3.5×10^{-3}
Exchangeable potassium	CTRL	71.4232	1×10^{-7}
	NPK	24.0683	5×10^{-5}
	FYM	25.1293	3×10^{-6}
	NPK + FYM	8.0804	5.6×10^{-3}

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

Table 5.3.3. Correlation coefficient values among physico-chemical properties of soil between surface and subsurface soil layers in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farmyard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Treatments (0-10 X 10-20 cm)	Moisture content	pH	Organic carbon	Total nitrogen	Available phosphorus	Exchangeable potassium
CTRL	0.5345^{c}	0.6968^{c}	0.4114^{b}	0.4730^{b}	0.5779^{c}	0.7252^{c}
NPK	-	0.7668^{c}	-	0.3211^{a}	0.7198^{c}	0.7418^{c}
FYM	-	0.7766^{c}	-	0.3050^{a}	0.8949^{c}	0.6924^{c}
NPK+FYM	0.3891^{a}	0.8818^{c}	0.6871^{c}	0.6492^{c}	0.7925^{c}	0.8759^{c}

Note: Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; Insignificant values are marked with ' – ' sign.

Table 5.3.4. Correlation coefficient values among physico-chemical properties of soil with various microbial population, **biological and biochemical properties of soil in control** (CTRL) at surface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
CTRL	AT	-	0.6536^{c}	-0.3146^{a}	-	0.3910^{b}	0.4440^{c}	-0.3600^{b}	0.3341^{a}	0.4470^{b}	0.4935^{c}	-	0.4932^{c}	-	-0.4590^{b}	-
	ST		-	-0.3054^{a}	-	0.3967^{b}	-	-	-	-	-	-	-	0.4858^{c}	-0.3520^{a}	0.4984^{c}
	MC			-	-	0.3184^{a}	-	-0.5512^{c}	-	0.3508^{a}	-	-	-	0.4607^{b}	-0.5282^{c}	-
	pH				-	-0.4965^{c}	-	0.4810^{c}	-	-	-0.4732^{b}	-	-	-0.3703^{a}	0.4674^{b}	-
	OC					-	-0.4865^{c}	-	-	-	-	-	-	0.3735^{a}	-	-
	TN						-	-0.3562^{a}	-	-	0.5195^{c}	-	-	0.3757^{b}	-0.5641^{c}	-
	AP							-	-	-	0.3907^{a}	-	-	-0.4511^{b}	-	-
	K								-	-	-0.5189^{c}	-	-	-0.4074^{b}	0.4003^{b}	0.3385^{a}
	RF									-	-	0.3688^{a}	0.3298^{a}	-	-	-

Table 5.3.5. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in $N_{20}P_{60}K_{40}$ kg/h (NPK) at surface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
NPK	AT	-	0.6295^{c}	-0.5128^{c}	-	0.3636^{b}	-	-0.3998^{b}	0.3341^{a}	0.6084c	-	-	-	-	-0.4179^{b}	-
	ST		-	-	0.3550^{a}	0.3420^{a}	-	-	-	-	-	-	-	0.4031^{b}	-	-
	MC			-0.3612^{a}	-	-	-	-0.3109^{a}	-	0.3332^{a}	-	-	-	-	-	-
	pH				-	-	-	-	-	-0.4156^{b}	-0.4255^{b}	-	-	-	-	0.5761^{c}
	OC					0.3379^{a}	-	-	-	-0.3247^{a}	0.5901^{c}	-	0.5750^{c}	0.7997^{c}	-	-
	TN						-	-0.3341^{a}	0.5813^{c}	-	-	-	-	0.3746^{a}	-0.3144^{a}	-
	AP							0.4959^{c}	-	-	-	-	-	-0.4544^{b}	0.4045^{b}	-
	K								-	-	-	-	-	-0.4810^{c}	0.7213^{c}	0.4204^{b}
	RF									-	-	0.3286^{a}	-	-	-	-0.3427^{a}

(Note: AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rainfall, SR=soil respiration, FP=fungal population, BP=bacterial population, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 5.3.6. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in farmyard manure 10 t/h (FYM) at surface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
FYM	AT	-	0.6836^{c}	-0.4989^{c}	-0.3495^{a}	-	0.4071^{b}	-	0.3341^{a}	0.6100^{c}	0.3306^{a}	-	-	-	-0.4544^{b}	-
	ST		-	-	0.3809^{a}	-	-	-0.5066^{c}	-	-0.4775^{c}	-	-	-	0.4569^{b}	-	0.5201^{c}
	MC			-0.3916^{b}	-	0.4067^{c}	-	-0.4331^{b}	-	0.4019^{b}	-	-	-	0.3592^{a}	-0.4501^{b}	-
	pH				-	-0.3318^{a}	-	-0.3056^{a}	-	-	-	-	-	-	-	-
	OC					-	-	-0.3836^{a}	-	-0.4707^{b}	-	-	-	0.5350^{c}	-	0.3165^{a}
	TN						-	-	-	-	0.3207^{a}	-0.3577^{a}	0.5123^{c}	0.6157^{c}	-	-
	AP							-	-	0.6092^{c}	-	0.3666^{a}	0.5769^{c}	-	-	-
	K								-	-	-	-	-	-0.5520^{c}	0.6952^{c}	-
	RF									-	-	-	-	-	-	-0.3730^{a}

Table 5.3.7. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in $N_{10}P_{30}K_{20}$ kg/h + farmyard manure 5 t/h (NPK+FYM) at surface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
NPK+FYM	AT	-	0.5653^{c}	-0.4791^{c}	-	0.3356^{a}	-	-	0.3341^{a}	0.6645^{c}	0.4054^{b}	-	-	-	-	-
	ST		-	-	0.3800^{a}	-	-	-0.4468^{b}	-	-	-	-	0.3471^{a}	0.4616^{b}	-	0.6483^{c}
	MC			-	0.7490^{c}	0.5143^{c}	-0.3954^{b}	-0.6050^{c}	-	0.5915^{c}	-	-	0.3959^{b}	0.6011^{c}	-	-
	pH				0.3296^{a}	-	-0.3612^{a}	-	-	-	-0.3716^{a}	-	-	0.3191^{a}	-	-
	OC					0.5658^{c}	-0.5713^{c}	-0.5823^{c}	-	-	-	-	0.6043^{c}	0.7969^{c}	-	-
	TN						-	-0.7050^{c}	-	0.4433^{b}	0.3842^{a}	-	0.4786^{c}	0.6163^{c}	-0.3865^{a}	-
	AP							-	-	-	0.5390^{c}	-	-	-0.4306^{b}	-	-
	K								-	-0.4757^{c}	-	-	-0.4945^{c}	-0.7205^{c}	0.4455^{b}	-0.4139^{b}
	RF									-	-	-	-	-	-	-

(Note: AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rainfall, SR=soil respiration, FP=fungal population, BP=bacterial population, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 5.3.8. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in control (CTRL) at subsurface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
CTRL	AT	-	0.4388^{b}	-	-	0.4600^{b}	-	-	0.3341^{a}	0.6222^{c}	-	-	0.3988^{b}	-	-0.4713^{b}	-
	ST		0.3314^{a}	-	0.7104^{c}	0.4889^{c}	-	-	-	-	0.3628^{a}	-	-	0.5754c	-0.3259^{a}	0.4794^{c}
	MC			-0.3281^{a}	-	-	-	-0.3392^{a}	-	0.5004^{c}	-	-	-	-	-0.3115^{a}	-
	pH				-	-	-	0.6196^{c}	0.5254^{c}	-	-	-	-	-	0.4563^{b}	-
	OC					0.5199^{c}	-0.4701^{b}	-	0.4482^{b}	-	-	0.4990^{c}	-	0.4715^{b}	-	-
	TN						-	-	0.3889^{a}	0.3318^{a}	0.3546^{a}	-	-	0.4540^{b}	-0.4827^{c}	-
	AP							-	-	0.3917^{b}	-	-0.5871^{c}	-	-	-	-
	K								-	-0.3169^{a}	-0.3929^{b}	0.3766^{a}	-	-0.3654^{a}	0.3526^{a}	-
	RF									-	-	-	0.3567^{a}	-	-	-

Table 5.3.9. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in $N_{20}P_{60}K_{40}$ kg/h (NPK) at subsurface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
NPK	AT	-	0.3772^{a}	-	-	0.3832^{a}	-	-	0.3341^{a}	0.6656^{c}	-	-	-	-	-0.4588^{b}	-0.3349^{a}
	ST		-	-	-	0.5377^{c}	-	-0.6518^{c}	-	-	-	-	-	0.5385^{c}	-0.3195^{a}	-
	MC			-	-	0.3516^{a}	-	-0.3648^{a}	-	0.5277^{c}	-	-	-	-	-	-
	pH				-	-	-	-	0.6337^{c}	-0.3702^{a}	-	0.4483^{b}	0.4368^{b}	-	-	-
	OC					-	-	-	-	-	0.3213^{a}	0.3240^{a}	-	0.3163^{a}	-	-
	TN						-	-0.5495^{c}	-	0.4746^{c}	0.3322^{a}	-	-	0.6586^{c}	-0.4711^{b}	-
	AP							0.4056^{b}	-	-	-	-	-	-	0.3901^{a}	-
	K								-	0.3292^{a}	-	-	-	-0.3227^{a}	0.5380^{c}	-
	RF									-	0.3112^{a}	-	-	-	-	-

(Note: AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rainfall, SR=soil respiration, FP=fungal population, BP=bacterial population, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 5.3.10. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in farmyard manure 10 t/h (FYM) at subsurface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
FYM	AT	-	0.5169^{b}	-	-	0.4401^{b}	0.5107^{c}	-	0.3341^{a}	0.6001^{c}	-	-	0.3935^{b}	-	-4830^{c}	-
	ST		0.3611^{a}	0.3540^{a}	0.7465^{c}	0.3837^{a}	-	-0.3467^{a}	-	-	-	-	-	0.5317^{c}	-0.3932^{b}	-
	MC			-	0.3863^{a}	0.3155^{a}	-	-0.3296^{a}	-	0.5717^{c}	-	-	-	0.3180^{a}	-	-
	pH				0.6398^{c}	-	-	0.4535^{b}	0.5814^{c}	-	-	-	0.3955^{b}	0.3214^{a}	-	-
	OC					0.4625^{b}	-	-	0.4314^{b}	-	-	-	0.3853^{a}	0.5019^{c}	-	-
	TN						0.4332^{b}	-0.3748^{a}	-	0.5719^{c}	-	-0.4110^{b}	-	-	-0.6097^{c}	-
	AP							-	0.3376^{a}	0.7600^{c}	-	-	0.7385^{c}	-	-	-
	K								0.3356^{a}	-	-	--	-	-	0.6608^{c}	-
	RF									-	-	0.4860^{c}	0.3931^{b}	-	-	0.3785^{a}

Table 5.3.11. Correlation coefficient values among physico-chemical properties of soil with various microbial population, biological and biochemical properties of soil in $N_{10}P_{30}K_{20}$ kg/h + farmyard manure 5 t/h (NPK+FYM) at subsurface soil layer ($P \leq 0.05$).

Treatments	Soil properties	ST	MC	pH	OC	TN	AP	K	RF	SR	FP	BP	C_{mic}	DHA	URA	PA
NPK+FYM	AT	-	0.4256^{b}	-0.5282^{c}	-	0.4711^{b}	0.3682^{a}	-	0.3341^{a}	0.6657^{c}	-	-	-	-	-0.4183^{b}	-
	ST		-	0.5710^{c}	0.5803^{c}	0.5686^{c}	-	-0.6052^{c}	-	-	-	-	0.4388^{b}	0.5960^{c}	-	0.4567^{b}
	MC			-	0.3779^{a}	0.5846^{c}	-	-0.6393^{c}	-	0.6533^{c}	-	-	-	0.3827^{a}	-	-
	pH				0.6706^{c}	-	-0.6000^{c}	-	-	-0.5009^{c}	-	-	-	-	-	-
	OC					0.5468^{c}	-	-0.4882^{c}	-	-	-	-	0.6127^{c}	0.6793^{c}	-	-
	TN						-	-0.7075^{c}	0.4007^{b}	0.5851^{c}	-	-	-	0.4157^{b}	-0.5402^{c}	-
	AP							-	-	0.5357^{c}	0.5964^{c}	-	-	-	-	-
	K								-	-0.3603^{a}	-	-	-	-0.4038^{b}	0.3659^{c}	-0.3931^{b}
	RF									-	-	0.3167^{a}	-	-	-	-

(Note: AT=ambient temperature, ST=soil temperature, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rainfall, SR=soil respiration, FP=fungal population, BP=bacterial population, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity)

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Chapter-6

Performance and nutrient content of groundnut in agro-ecosystem

6.1. Introduction

Fertilizer is commonly applied to crops at or near the time of sowing, but the crop's needs are small, and there is an opportunity for N losses to occur prior to increased crop demand (Myers *et al.*, 1994). The plants themselves (N-fixing legume) can modify the patterns of nutrient release from soil. In any system, the pattern of the uptake of N into the vegetation component is closely related to the pattern of growth of the plants.

The fertilizers treatment has an influence on the groundnut plant performance (shoot length, root length, number of nodules, weight and number of pod) and yield. Addition of compost and inorganic fertilizers has a beneficial influence on soil biological and yield of crop under a cereal-legume and it was noted that crop yield was significantly correlated with activities of soil enzymes (Manna and Ganguli, 1997).

One of the characteristics of organic fertilizers is the slow release of its nitrogen component. Consequently, in order to maintain high crop yield, supplementation with chemical nitrogen fertilizers is sometimes necessary. It is known that the microorganism is the sole agent responsible for the transformation of nitrogen in the ecosystem. Through nitrification, the mobility of inorganic nitrogen increases considerably. Nitrate will then move with percolation and run-off

water into both ground water and nearby surface water and be removed from the root zone. Further, researchers have also shown that the addition of certain organic fertilizers causes a net mobilization of soil nitrogen (Murwira and Kirchmann, 1993).

Addition of manure in a peanut crop influences nutrient mobilization and root absorption activity, N and P mobilization and absorption fourfold as compared to the fertilizer plots, while K increased by twofold. These results indicate that organic residue additions could activate root function in crops grown on sandy soils, thus improving the synchrony of nutrient demand with nutrient availability. Cisse (1986) reported that the addition of manure increased rooting depth and root mass per unit area at all depths. Fertilizer plus manure plots showed higher root depth than application of fertilizer alone.

The beneficial effect of N and P may be due to its stimulating effect on the root growth that on decomposition added to the organic resources of the soil (Mathan *et al.*, 1978). Prolonged input of fertilizer N increases soil C indirectly as a result of enhanced plant growth, the effect of which may not become evident within one seasonal cycle (Hatch *et al.*, 2000).

The relationship between soil K supply, characterized by the soil solution K concentration and the soil K buffer power, and plant K status was investigated for field grown crops (Schneider *et al.*, 2003). Low level of soil K supply has early effects on plant growth leading to irreversible negative effects on grain yield (Rama Rao, 1986).

6.2. Methodology

5.2.1. Total nitrogen

The plant nitrogen content was estimated by following the method of Allen *et al.* (1974). Weighed 0.2 g of dried plant powder into a kjeldahl digestion flask and to it 3 ml of sulphuric acid was added. To this half kjel-tablet was added and then the plant sample was digested in a block digester till the colour turned 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 till the colour turned pink.

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

Where, T= Burette reading

5.2.2. Phosphorous and Potassium

Phosphorous and potassium were measured by following the method of Allen *et al.* (1974). Weighed 0.2 g of dried plant powder in a digestion tube. To this 3 ml of tri-acid was added and the plant sample was digested in a block digester till the colour turned green. The mixture was filtered through Whatman filter paper No. 1. The flask was allowed to cool and diluted with 50 ml of distilled water. The sample solution was divided into two parts- one part was used for estimation of

phosphorus by following molybdenum blue method and one part was used for estimation of potassium.

Phosphorus (molybdenum blue method)

10 ml of sample was pipette into 50 ml volumetric flask. The sample was diluted about two third of the flask. To this 2 ml 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. For the control, 10 ml of sample was replaced by 10 ml of distilled water. 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.

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

Potassium

The plant extract solution was taken directly for the determination of potassium by using to the flame photometer (Mediflame 127).

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

6.3. Results

6.3.1. Plant performance

(a) Shoot length

In the first year maximum shoot length of 63.30 cm in NPK+FYM plot and in the second year 45.67 cm in NPK plot at 120 days after sowing (DAS) observed. Within each sampling period, CTRL plot showed minimum shoot length as compared to the treated plot (Fig. 6.3.1).

Analysis of variance (ANOVA) showed insignificant variation ($P \leq 0.05$) of shoot length between the treatments (Table 6.3.1).

The correlation coefficient showed that shoot length was positively correlated with number of nodules, yield, phosphatase, rainfall and soil temperature in all treatments and urease activity except in NPK+FYM plot (Tables 6.3.2– 6.3.13).

(b) Root length

In the first year maximum root length of 23.33 cm and in the second year maximum of 18.33 cm was observed in NPK+FYM plot at 120 DAS. It was also observed that CTRL plot showed minimum root length in the first year, whereas the same was not observed in the second year (Fig. 6.3.1).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of root length between the treatments (Table 6.3.1).

The correlation coefficient showed that in CTRL plot, root length was positively correlated with number of pod, weight of pod and number of peg (Table 6.3.2) and in NPK+FYM plot, it was positively correlated with number of nodules,

root phosphorus, yield, phosphatase, pH, rainfall and soil temperature (Tables 6.3.5, 6.3.9 and 6.3.13).

(c) Number of nodules

The maximum number of nodules 543.33 in the first year and 323.33 in the second year was observed in FYM plot at 120 DAS, whereas the minimum of 333.4 in the first year and 264.4 in the second year was observed in CTRL plot at 30 DAS. It was also observed that within some sampling periods, CTRL plot showed higher number of nodules than the treated plot and generally, the number of nodules was higher in the first year than the second year (Fig. 6.3.1).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of nodules number between the treatments (Table 6.3.1).

The correlation coefficient showed that the number of root nodules was positively correlated with yield except in NPK plot, phosphatase, rainfall and soil temperature in all the treatments (Tables 6.3.2 - 6.3.13).

(d) Yield

The highest groundnut yield (sun dried) of groundnut 39.58 q h^{-1} and 31.62 q h^{-1} was observed in NPK+FYM plot in the first year and in the second year respectively whereas, CTRL plot showed lowest yield i.e. 21.34 q h^{-1} and 12.5 q h^{-1} in the first year and in the second year respectively (Fig. 6.3.2).

Analysis of variance showed significant ($P \leq 0.05$) variation of yield between CTRL x NPK x FYM x NPK+FYM, CTRL x NPK and CTRL x NPK+FYM plots (Table 6.3.1).

The correlation coefficient showed that yield was positively correlated with shoot length, number of nodules and weight of pods in all the treatments except in NPK plot and it was also positively correlated with phosphatase and soil temperature in all plots (Tables 6.3.2 - 6.3.13).

(f) Number of pods

In the first year, number of pods ranged between 10.0 in NPK+FYM at 120 DAS and 28.0 in FYM plots at 90 DAS, whereas in the second year, it ranged between 7.67 in FYM plot at 60 DAS and 16.67 in FYM plot at 90 DAS. Generally pods numbers were found to be higher in the first year than the second year (Fig. 6.3.2).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of number of pods between the treatments (Table 6.3.1).

The correlation coefficient showed that the number of pods was positively correlated with root length in CTRL plot and number of pegs in FYM plots (Fig. 6.3.2 and 6.3.4).

(g) Weight of pods

The weight of the groundnut pods was generally higher in the first year than the second year. The highest pod weight in the first year (48.04 g) and in the second year (33.38 g) was observed at 90 DAS in FYM plot. It was also observed that within some sampling periods CTRL plot showed higher pod weights than the treated plot (Fig. 6.3.2).

Analysis of variance showed insignificant (P≤ 0.05) variation of pods weight between treatments (Table 6.3.1).

The correlation coefficient showed that weight of pods was significantly (P≤ 0.05) correlated with yield, bacterial population, urease activity, potassium and rainfall in all treatments except at NPK plot (Tables 6.3.2 - 6.3.13).

6.3.2. Nutrients content

(a) Nitrogen

(i) Root nitrogen

The distribution of root nitrogen followed consistent trend, where peak nitrogen was observed twice at 30 DAS and 90 DAS. The maximum root nitrogen in the first year (2.65%) and second year (2.39%) was observed in NPK+FYM plot at 30 DAS, whereas the minimum root nitrogen in the first year (1.14%) and in the second year (1.30%) was observed at 60 DAS and 120 DAS in NPK plot respectively (Fig. 6.3.3).

Analysis of variance showed a significant (P≤ 0.05) variation of root nitrogen content between NPK and FYM plots (Table 6.3.1).

The correlation coefficient showed that, root nitrogen was positively correlated with shoot nitrogen, soil respiration, ambient temperature in all plots, fungal population except in FYM plot and moisture content except in NPK plot (Tables 6.2.2 - 6.3.13).

(ii) Shoot nitrogen

The shoot nitrogen content decreased with increase in plant age and the unfertilized plot also displayed higher shoot nitrogen. The maximum shoot nitrogen

content in the first year (2.86%) and second year (1.97%) was observed at 30 DAS in NPK+FYM plot and the minimum nitrogen in the first year (0.85%) and in the second year (0.717%) observed at 120 DAS in NPK+FYM and in CTRL plots respectively (Fig. 6.3.3).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of shoot nitrogen content between the treatments (Table 6.3.1).

The correlation coefficient showed that shoot nitrogen content was positively correlated with root nitrogen and leaf potassium (Tables 6.3.2 – 6.3.5).

In CTRL and NPK plots, shoot nitrogen content was positively correlated with root phosphorus, shoot phosphorus, leaf phosphorus and shoot potassium (Tables 6.3.2 and 6.3.3).

In FYM and NPK+FYM plots, shoot nitrogen content was positively correlated with leaf nitrogen and root potassium (Tables 6.3.4 and 6.3.5).

Shoot nitrogen content was positively correlated with biological characteristic of soils viz. soil respiration in all the plots and fungal population in the CTRL and NPK+FYM plots (Tables 6.3.5 - 6.3.9).

The result also showed that shoot nitrogen content was positively correlated with the physico-chemical properties of soil viz. ambient temperature in all the plots and moisture content in the entire plot except at NPK plot (Tables 6.3.10 - 6.3.13).

(iii) Leaf nitrogen

The maximum leaf nitrogen content in the first year (2.58%) and in the second year (2.85%) was observed at 30 DAS in NPK plot and the minimum

nitrogen in the first year (1.90%) and in the second year (2.16%) was observed at 120 DAS in NPK+FYM and FYM plots respectively. It was also observed that higher root nitrogen content was also observed in unfertilized plot (Fig. 6.3.3).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of leaf nitrogen content between the treatments (Table 6.3.1).

The correlation coefficient showed that in CTRL and NPK plots, shoot nitrogen content was positively correlated with root phosphorus, shoot phosphorus, leaf phosphorus and shoot potassium (Tables 6.3.2 - 6.3.5).

In FYM and NPK+FYM plots, leaf nitrogen content was positively correlated with root nitrogen, shoot nitrogen, soil respiration, ambient temperature and moisture content (Tables 6.3.4 - 6.3.13).

Leaf nitrogen content was positively correlated with fungal population in NPK and NPK+FYM plots (Tables 6.3.3 and 6.3.5).

(b) Phosphorus

(i) Root phosphorus

The root phosphorus content showed a peak at 90 DAS and dropped at 120 DAS. In the first year, the maximum root phosphorus content of 510.0 µg g-1 dry plant and in the second year of 881.0 µg g-1 dry plant was observed in FYM plot, whereas the minimum root phosphorus of 46.67 µg g-1 dry plant in the first year and 363.34 µg g-1 dry plant in the second year was observed in FYM plot at 30 DAS and 120 DAS respectively (Fig. 6.3.4).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of root phosphorus content between the treatments (Table 6.3.1).

The correlation coefficient showed that the root phosphorus content was positively correlated with leaf phosphorus and shoot phosphorus in all the treatments (Tables 6.3.2 – 6.3.5).

In CTRL plot, root phosphorus content was positively correlated with moisture content, soil phosphorus and ambient temperature (Table 6.3.10).

In NPK plot, root phosphorus content was positively correlated with fungal population, soil respiration, dehydrogenase activity and ambient temperature (Tables 6.3.7 – 6.3.11).

In FYM plot, root phosphorus content was positively correlated with microbial biomass carbon, urease and phosphatase activities, soil potassium and rainfall (Tables 6.3.8 – 6.3.12).

In NPK+FYM plot root phosphorus content was positively correlated with phosphatase activity, pH, rainfall and soil temperature (Tables 6.3.9 - 6.3.13).

(ii) Shoot phosphorus

In the first year, maximum shoot phosphorus content of 633.34 µg g-1 dry plant and in the second year 496.0 µg g-1 dry plant was observed in FYM plot at 90 DAS, whereas, the minimum root phosphorus of 45.0 µg g-1 dry plant in the first year in FYM plot at 30 DAS and in the second year of 246.67 µg g-1 dry plant in CTRL plot at 120 DAS was observed (Fig. 6.3.4).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of shoot phosphorus content between the treatments (Table 6.3.1).

In CTRL plot, shoot phosphorus content was positively correlated with fungal population, soil respiration, moisture content, soil available phosphorus and ambient temperature (Tables 6.3.6 – 6.3.10).

In NPK plot, shoot phosphorus content was positively correlated with fungal population, soil respiration and ambient temperature (Tables 6.3.7 – 6.3.11).

In NPK+FYM plot, shoot phosphorus content was positively correlated with phosphatase activity, pH, rainfall and soil temperature (Tables 6.3.9 - 6.4.13).

(iii) Leaf phosphorus

The leaf phosphorus content in the first year was generally lower than the second year. In the first year, the maximum leaf phosphorus content of 986.67 µg g-1 dry plant and in the second year of 1003.34 µg g-1 dry plant was observed in FYM plot at 90 DAS, whereas, the minimum leaf phosphorus in the first year 85.0 µg g-1 dry plant in NPK+FYM plot at 30 DAS and in the second year 436.67 µg g-1 dry plant in FYM plot at 60 DAS was observed (Fig. 6.3.4).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of leaf phosphorus content between the treatments (Table 6.3.1).

In CTRL plot, leaf phosphorus content was positively correlated with fungal population, soil respiration, moisture content, soil available phosphorus and ambient temperature (Tables 6.3.6 – 6.3.10).

In NPK plot, it was positively correlated with fungal population, soil respiration and ambient temperature (Tables 6.3.7 – 6.3.11).

At NPK+FYM plot, it was positively correlated with acid phosphatase activity, pH, rainfall and soil temperature (Tables 6.3.9. – 6.3.13).

(c) Potassium

(i) Root potassium

The maximum root potassium content in the first year (0.400%) and in the second year (0.835%) was observed in NPK+FYM plot at 120 DAS, whereas, the minimum root potassium content in the first year (0.295%) in NPK+FYM plot at 60 DAS and in the second year (0.245%) in FYM plot at 90 DAS was observed (Fig. 6.3.5).

Analysis of variance showed significant ($P \leq 0.05$) variation of root potassium content between CTRL x NPK x FYM x NPK+FYM, CTRL x NPK+FYM, NPK x NPK+FYM and FYM x NPK+FYM plots (Table 6.3.1).

In CTRL plot, the root potassium content was positively correlated with shoot potassium and fungal population (Tables 6.3.2 – 6.3.6).

In NPK plot, it was positively correlated with leaf potassium, shoot potassium, soil respiration and ambient temperature (Tables 6.3.3, 6.3.7 and 6.3.11).

In FYM, plot it was positively correlated with leaf potassium, soil respiration and ambient temperature (Tables 6.3.4, 6.3.8 and 6.3.12).

In NPK+FYM, plot it was positively correlated with leaf potassium, shoot potassium, fungal population, soil respiration, ambient temperature, moisture content, organic carbon and phosphorus (Tables 6.3.5, 6.3.9 and 6.3.13).

(ii) Shoot potassium

The shoot potassium showed dissimilar distribution pattern in both the years. The result showed maximum shoot potassium content in the first year

(0.570%) in NPK at 30 DAS and in the second year (0.980%) in NPK+FYM plot at 120 DAS, whereas, the minimum root potassium content in the first year (0.355%) in FYM plot at 90 DAS and in the second year (0.420%) in CTRL plot at 60 DAS was observed (Fig. 6.3.5).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of shoot potassium content between the treatments (Table 6.3.1).

In CTRL plot, the shoot potassium content was positively correlated with leaf potassium, root potassium, fungal population, soil respiration and ambient temperature (Tables 6.3.2, 6.3.6 and 6.3.10).

In NPK plot, it was positively correlated with leaf potassium, root potassium, fungal population, soil respiration and ambient temperature (Tables 6.3.3, 6.3.7 and 6.3.11).

In NPK+FYM plot, it was positively correlated with leaf potassium, root potassium, fungal population, soil respiration, ambient temperature, moisture content, organic carbon and phosphorus (Tables 6.3.5, 6.3.9 and 6.3.13).

(iii) Leaf potassium

The inconsistent distribution of leaf potassium content was observed in both the years, where the leaf potassium content in the first year showed a close distribution within the treatments. The maximum leaf potassium content in the first year (0.508%) at 30 DAS and in the second year (0.972%) at 120 DAS in NPK+FYM plot was observed. The minimum leaf potassium content in the first year (0.412%) in NPK plot at 90 DAS and in the second year (0.440%) in CTRL plot at 60 DAS was observed (Fig. 6.3.5).

Analysis of variance showed insignificant ($P \leq 0.05$) variation of leaf potassium content between the treatments (Table 6.3.1).

In CTRL plot, leaf potassium was positively correlated with shoot potassium, fungal population, soil respiration and ambient temperature (Tables 6.3.2, 6.3.6 and 6.3.10).

In NPK plot, it was positively correlated with shoot potassium, root potassium, fungal population, soil respiration and ambient temperature (Tables 6.3.3, 6.3.7 and 6.3.11).

In FYM plot, it was positively correlated with root potassium, soil respiration and ambient temperature (Tables 6.3.4, 6.3.8 and 6.3.12).

In NPK+FYM, plot it was positively correlated with shoot potassium, root potassium, fungal population, soil respiration, ambient temperature, moisture content, organic carbon and available phosphorus (Tables 6.3.5, 6.3.9 and 6.3.13).

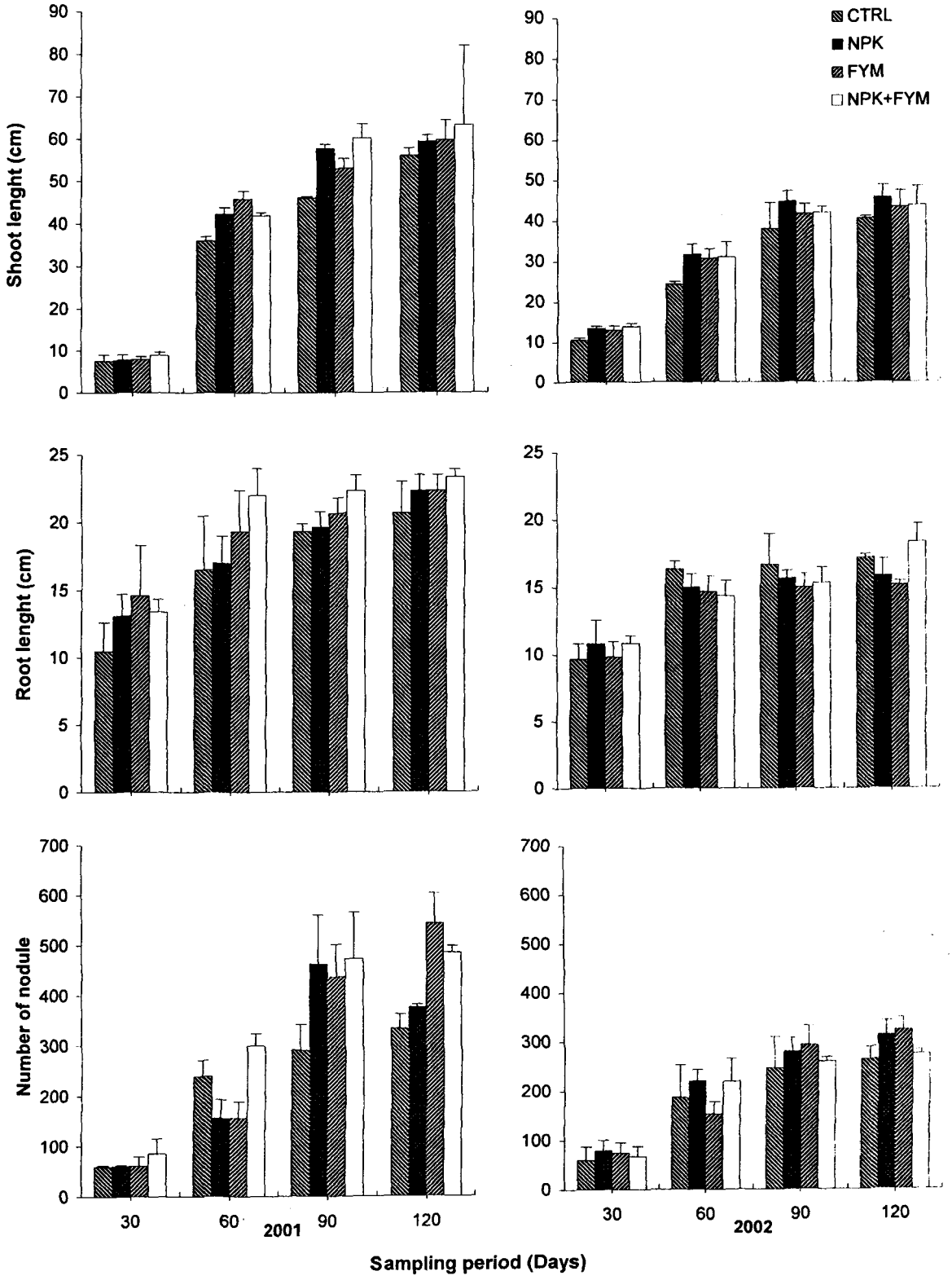


Fig. 6.3.1. Shoot length, root length and number of nodule of groundnut plant.

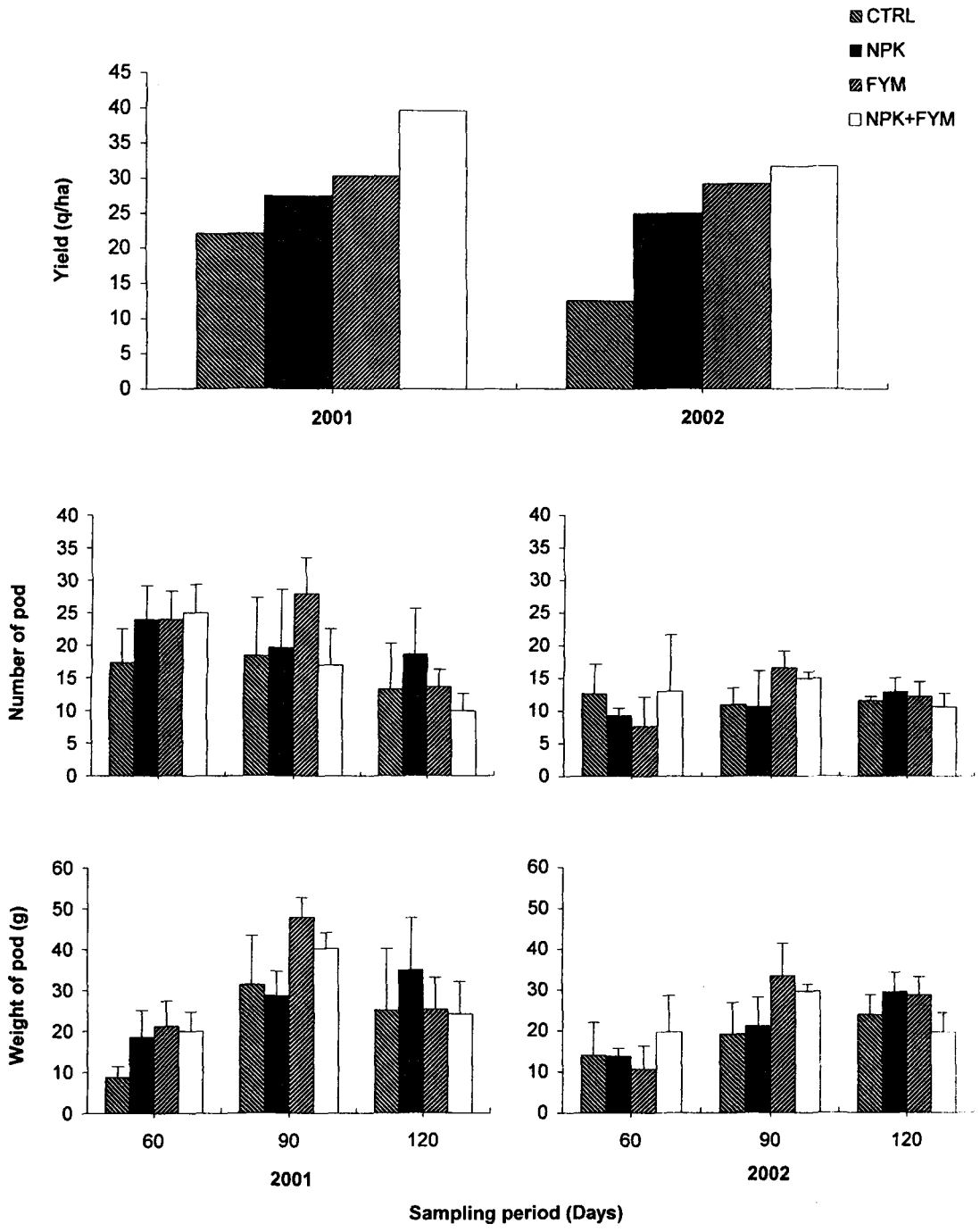


Fig. 6.3.2. Yield, number of pod and weight of pod of groundnut.

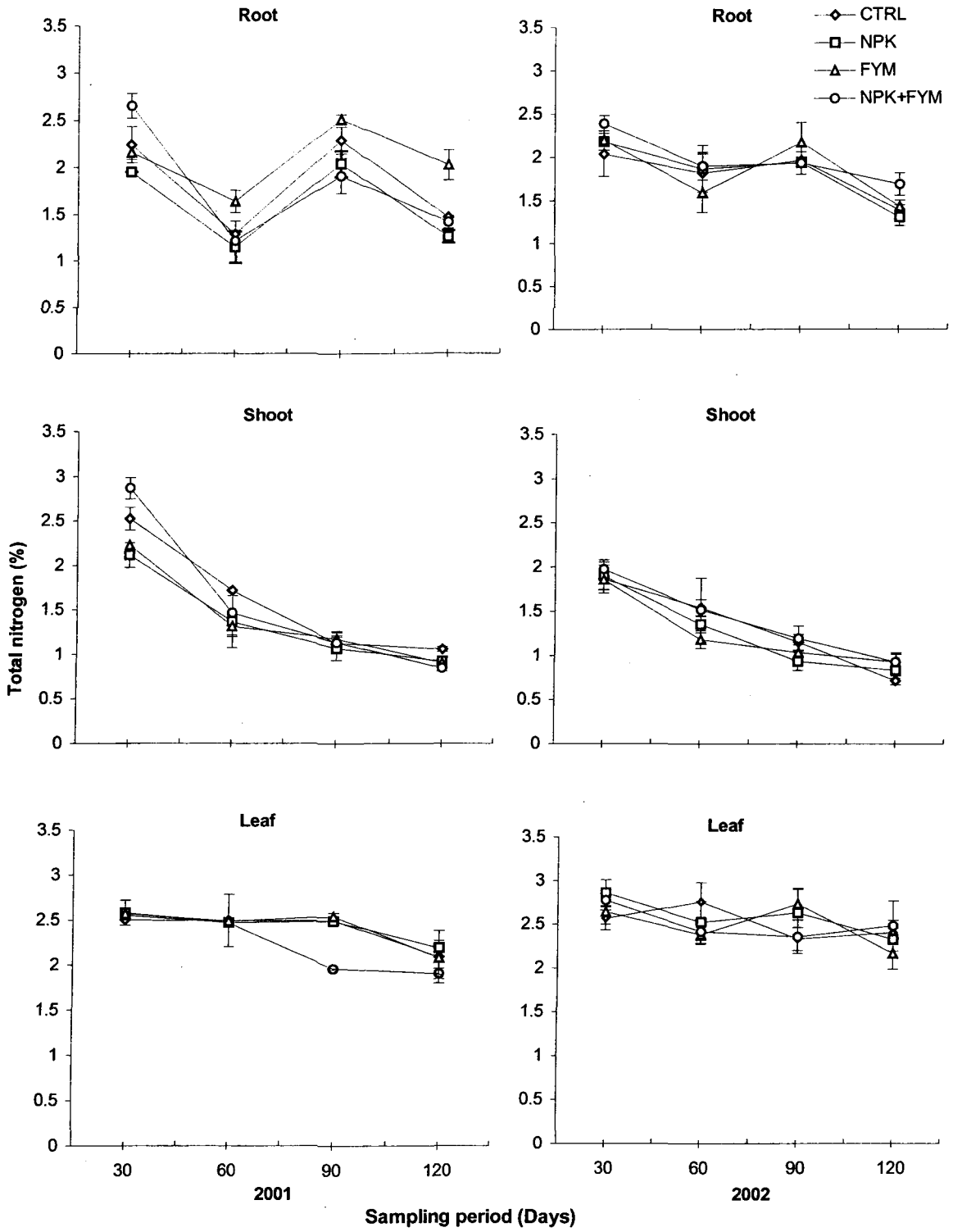


Fig. 6.3.3. Concentration of total nitrogen in root, shoot and leaf of groundnut plant.

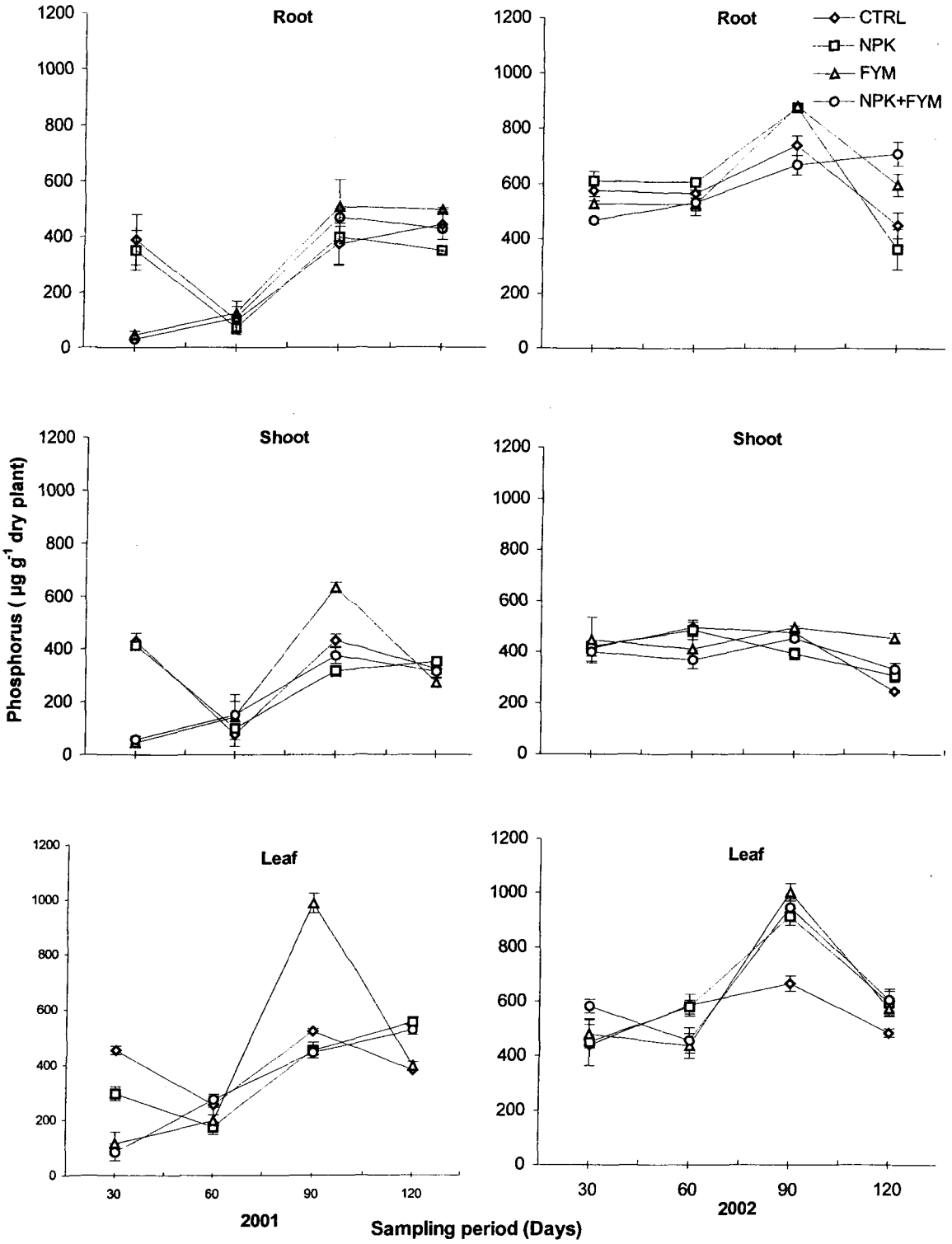


Fig. 6.3.4. Concentration of phosphorus in root, shoot and leaf of groundnut plant.

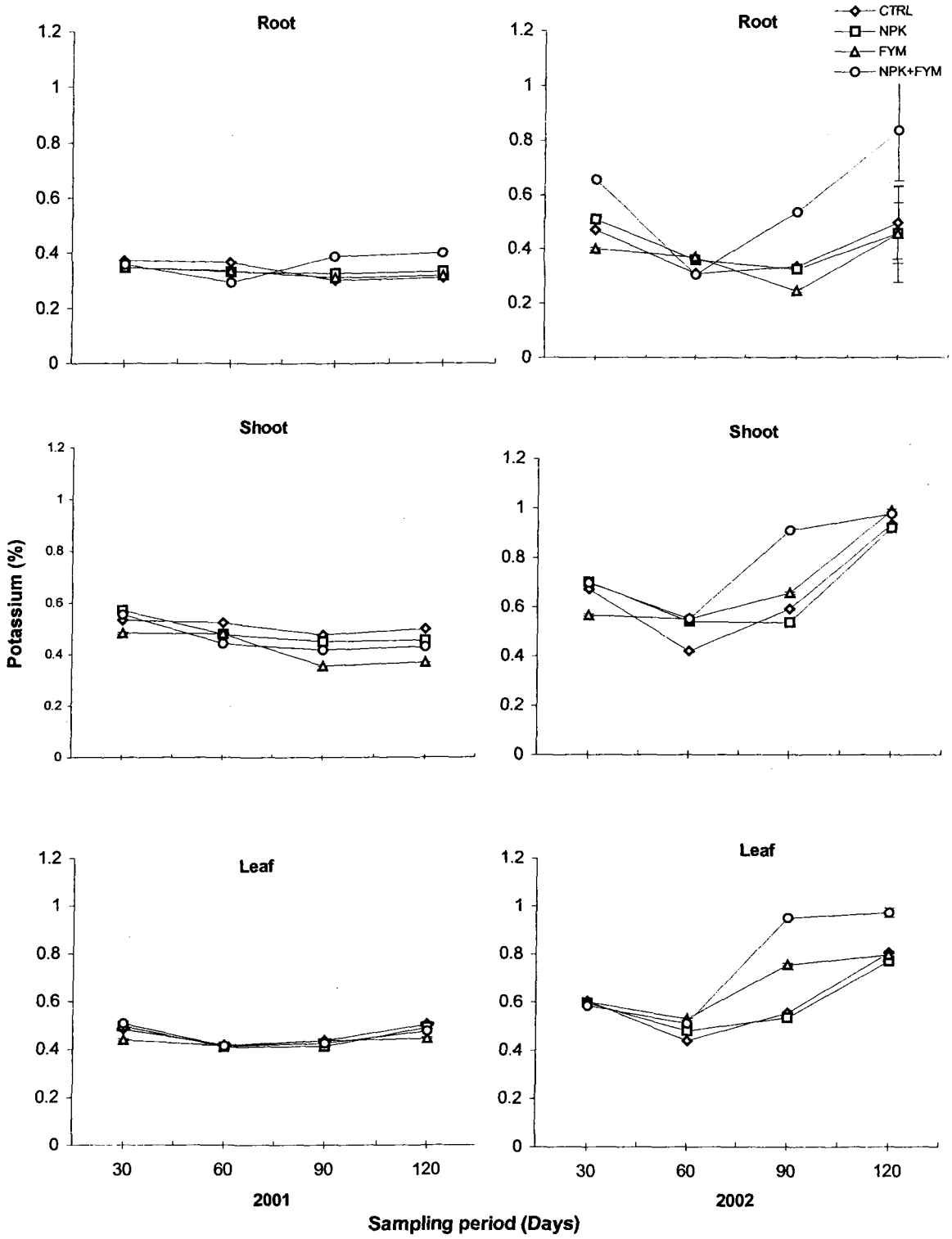


Fig. 6.3.5. Concentration of potassium in root, shoot and leaf of groundnut plant.

6.4. Discussion

6.4.1. Effects of organic and inorganic fertilizers on plant performance

Generally shoot and root lengths were more in treated plots as compared to the CTRL plot. This result could be due to the higher availability of soil nutrients, which was applied in to the field in the form of inorganic (NPK) or organic (FYM) fertilizers. The maximum shoot and root lengths observed in NPK+FYM plot might be due to the more availability of soil nutrients for plant growth as compared to the other treatments. Agbenin *et al.* (1997) reported that farmyard manure in combination with N+P+K fertilization probably stimulates immobilization on N and P at the expense of reaction with soil inorganic constituents and possible leaching from the soil profile.

The result that showed lower shoot height, root length and number of root nodules in the second year could be due to the lower activity of phosphatase enzyme activity, rainfall and soil temperature. The correlation coefficient of shoot height, root length and number of root nodules showed a positive correlation with phosphatase activity, rainfall and soil temperature.

It was observed that the number of root nodules increased along with age of the plant and fertilizers treatment. Nambiar (1994) reported that from long-term manuring experiment, application of farmyard manure and NPK fertilizers improved the soil microbial populations and nodulation of soybean (legume). Though FYM plot displayed the maximum number of nodules, NPK, NPK+FYM, CTRL plots also exhibited higher number of nodules in some sampling periods. This inconsistent distribution numbers of root nodules could be due to the effect of retention of fertilizers.

The yield of groundnut showed a consistent trend during the entire investigation. The analysis of variance showed a significance ($P \leq 0.05$) variation of yield between the treatments. The highest yield which was noted in NPK+FYM plot could be due to the improvement of soil physical properties and nutrients, which translated to higher yield. Anikwe *et al.* (2003) also observed that combination of manure with NPK had higher groundnut yield than CTRL or application of NPK alone. There is also increasing evidence that fertilizer alone cannot sustain yields for long period. For example, in continuous rice cropping with two to three crops grown annually, the use of fertilizer N increased with time but the yields often remained stagnant (Cassman and Pingali, 1995).

The distribution of number and weight of pods displayed inconsistent trend within the treatments and sampling period. But the maximum number and weight of pods were observed in FYM plot at 90 DAS. This result might be due to the higher availability of soil nutrients for the plant. This result was in agreement with the report of Lovell and Jarvis (1996) that after 12 weeks the labile C substrates from the dung were likely to have become depleted, leaving large amounts of dead microbial materials as a possible energy source for other microorganisms.

It can be concluded that inorganic (NPK) or organic (FYM) fertilizers have a beneficial effect on the root and shoot lengths. Combination of inorganic and organic fertilizers (NPK and NPK+FYM) has great effects on the yield of groundnut.

6.4.2. Effects of organic and inorganic fertilizers on plant nitrogen content

The maximum plant nitrogen content observed at 30 DAS could be due to the higher availability of nitrogen in the soil system. Though maximum plant nitrogen content (root, shoot and leaf) was displayed in fertilized plots (NPK+FYM and NPK), an inconsistent trend of nitrogen distribution within each treatment was observed. It was also observed that, during some sampling periods, higher doses of NPK plot showed lower plant N content and this inconsistent distribution could be due to the inhibition of biological N fixation by the addition of inorganic fertilizer N or retention of N fertilizers. This is in agreement with the findings of Caroll and Mathews (1990), that the application of N fertilizer to legume crops reduced biological N_2 fixation.

The positivel correlation of plant N content with soil respiration could be due to the higher activity of N fixing microorganisms in the soils system, where the amount of soil respiration was an indicator of the activity of organisms. The correlation coefficient indicated that soil moisture content was positively correlated with N content. Novoa and Loomis (1981) also reported that soil moisture availability is the main factor influencing nitrogen uptake by the root and transport to the leaf.

6.4.3. Effects of organic and inorganic fertilizers on plant phosphorus content

Though the maximum plant phosphorus (P) content was observed at 90 DAS in FYM plot, it was observed that higher plant P content was displayed in CTRL, NPK, and NPK+FYM plots during some sampling months. Maximum plant

P content was expected to display in P fertilized plot (NPK and NKP+FYM), where Parham *et al.* (2002) indicated that animal manure-P was relatively more mobile but less available for plants than inorganic fertilizer-P. Taiwo *et al.* (1999) also reported that the application of fertilizer P in soybean increased P content in plant tissue when compared with the control. The result that showed the inconsistent distribution of plant P content within treatments could be due to the retention of P fertilizer or nutrient support from previous crop roots (Singh and Shekhar, 1989).

Moreover, Agbenin *et al.* (1997) also reported that farmyard manure in combination with N+P and N+P+K fertilization probably stimulates immobilization on P at the expense of reaction with soil inorganic constituents. The analysis of variance also showed insignificance ($P \leq 0.05$) variation of plant P content in root, shoot and leaf between the treatments.

Since phosphatase enzyme mediates the release of inorganically phosphorus from organically bound phosphorus returned to soil in leaf litter, dead root systems and other organic debris, it was supposed to show more correlation with plant P content. Wherein the correlation coefficient showed that, phosphatase enzyme activity and soil temperature were positively correlated with plant P content in NPK+FYM treated plot.

6.4.4. Effects of organic and inorganic fertilizers on plant potassium content

It is well documented that, potassium was taken up by plant from soil solution, and the concentration in solution will be replenished by the exchangeable fraction. The result showed that the highest potassium (K) content in plant was displayed only at K fertilizer treated plot during the entire investigation, thus

indicating that the availability of K for plant uptake could be compensated through the addition of fertilizer K. But it was observed that, CTRL and FYM plots displayed higher K content than treated plot during some periods of sampling, which reflects that the K distribution within treatments was inconsistent. This contradictory result could be due to the retention of fertilizers or due to the availability of soil K than the addition of K through fertilizer (NPK). This result was in conformity with the reports of Havlin *et al.* (1999) and Brady and Weil (1999) that some non-exchangeable K could also released into the soil solution and may thus be taken up by plants. The capacity of soil to supply plants with K does not depend only on the amounts of K reserves in soil, but also on the rate of availability to plant. Soon and Arshad (1996) concluded that the effects of cropping systems on K was influenced by crop type, and cropping and tillage frequencies.

The result which showed higher K content in plant in NPK+FYM plot could be due to the effect of soil moisture content, where the statistical analysis showed that plant K content was positively correlated with soil moisture content. Novoa and Loomis (1981) also reported that soil moisture availability was the main factor influencing nitrogen uptake by the root and transport to the leaf.

Table 6.3.1. One way analysis of variance (ANOVA) of the various characteristics of groundnut in control (CTRL), $N_{20}P_{60}K_{40}$ kg/h (NPK), farm yard manure 10 t/h (FYM) and $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) plots ($P \leq 0.05$).

Plant properties	Source of variation	F-ratio	P-level
Shoot length	CTRL X NPK X FYM X PK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Root length	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Number of nodule	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Number of pod	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Weight of pods	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Yield	CTRL X NPK X FYM X NPK+FYM	17.5267	9.1×10^{-3}
	CTRL X NPK	73.9230	0.0132
	CTRL X FYM	-	-
	CTRL X NPK+FYM	81.0	0.0121
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Root nitrogen	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	5.1965	0.0273
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Shoot nitrogen	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Leaf nitrogen	CTRL X NPK X FYM X NPK+FYM	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-

Root phosphorus	**CTRL X NPK X FYM X NPK+FYM**	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Shoot phosphorus	**CTRL X NPK X FYM X NPK+FYM**	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Leaf phosphorus	**CTRL X NPK X FYM X NPK+FYM**	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Root potassium	**CTRL X NPK X FYM X NPK+FYM**	5.06501	2.7×10^{-3}
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	5.4341	0.0241
	NPK X FYM	-	-
	NPK X NPK+FYM	5.1561	0.0278
	FYM X NPK+FYM	8.1366	6.4×10^{-3}
Shoot potassium	**CTRL X NPK X FYM X NPK+FYM**	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-
Leaf potassium	**CTRL X NPK X FYM X NPK+FYM**	-	-
	CTRL X NPK	-	-
	CTRL X FYM	-	-
	CTRL X NPK+FYM	-	-
	NPK X FYM	-	-
	NPK X NPK+FYM	-	-
	FYM X NPK+FYM	-	-

Note: Insignificant values are marked with ' – ' sign

Table 6.3.2. Correlation coefficient (r) values among various characteristics of plant in control (CTRL) ($P \leq 0.05$).

Parameters	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
SL	-	0.9802^{c}	-	-	-0.9521^{b}	-0.9921^{c}	-	-0.8947^{a}	-0.9721^{c}	-0.9669^{b}	-	-0.9256^{b}	-0.9976^{c}	0.9973^{c}
RL		-	0.9050^{a}	0.8393^{a}	-0.8779^{a}	-	-	-	-0.8164^{a}	-	-	-0.8241^{a}	-	-
NND				-	-0.9442^{b}	-0.9576^{b}	-	-0.8312^{a}	-0.9418^{b}	-0.9171^{b}	-0.8357^{a}	-0.9199^{b}	-0.9690^{c}	0.9716^{c}
NPD				-	-	-	-	-	-	-	-	-	-	-
WPD					-0.8452^{a}	-	-0.9814^{c}	-	-	-0.8403^{a}	-	-	0.8185^{a}	0.8480^{a}
RN						0.9502^{b}	-	0.9026^{a}	0.9724^{c}	0.9320^{b}	0.8207^{a}	0.9794^{c}	0.9391^{b}	-0.9608^{b}
SN							-	0.9379^{b}	0.9883^{c}	0.9720^{c}	-	0.9116^{a}	0.9963^{c}	-0.9979^{c}
LN								-	-	-	-	-	-	-
RP									0.9521^{b}	0.9425^{b}	-	0.8198^{a}	0.9109^{a}	-0.9233^{b}
SP										0.9498^{b}	-	0.9358^{b}	0.9737^{c}	-0.9855^{c}
LP											-	0.9780^{a}	0.9716^{c}	-0.9729^{c}
RK												0.8674^{b}	-	-
SK													0.9044^{a}	-0.9272^{b}
LK														-0.9974^{c}

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield)
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.3. Correlation coefficient (r) values among various characteristics of plant in $N_{20}P_{60}K_{40}$ kg/h (NPK) ($P \leq 0.05$).

Parameters	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
SL	-	0.9282[b]	-	-	-0.9822[c]	-0.9055[a]	-	-0.9618[b]	-0.9936[c]	-0.9528[b]	-0.9707[c]	-0.9911[c]	-0.9955[c]	0.9978[c]
RL		-	-	-	-	-	-0.9699[c]	-	-	-	-	-	-	-
NND			-	-	-	-	-	-	-	-	-	-	-	
NPD				-	-	-	-	-	-	-	-	-	-	-
WPD					-	-	-	-	0.9429[b]	-	-	-	-	-
RN						0.9112[a]	-	0.9282[b]	0.9744[c]	0.9008a	0.9770[c]	0.9622[b]	0.9722[c]	-0.9729[c]
SN							-	0.8937[a]	0.9132[a]	0.8341a	0.9387[b]	0.8755[a]	0.8872[a]	-0.8955[a]
LN								-	-	-	-	-	-	-
RP									0.9617[b]	0.9788[c]	0.9376[b]	0.9408[b]	0.9519[b]	-0.9575[b]
SP										0.9646[b]	0.9495[b]	0.9936[c]	0.9969[c]	-0.9965[c]
LP											0.8801[a]	0.9582[b]	0.9614[b]	-0.9611[b]
RK												0.9327[b]	0.9451[b]	-0.9540[b]
SK													0.9988[c]	-0.9975[c]
LK														-0.9993[c]

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield)
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.4. Correlation coefficient (r) values among various characteristics of plant in farm yard manure 10 t/h (FYM) ($P \leq 0.05$).

Parameters	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
SL	-	0.8852[a]	-	-	-0.9512[b]	-0.9918[c]	-0.9402[b]	0.8540[a]	-	-	-0.9249[b]	-	-0.9794[c]	0.9981[c]
RL		-	-	-	-	-	-	-	-	-	-	-	-	-
NND			-	-	-0.8529[a]	-0.8979[a]	-0.8449[a]	-	-	-	-	-	-	0.9075[a]
NPD				-	-	-	-	-	-	-	-	-	-	-
WPD					-0.8222[a]	-0.8266[a]	-0.9469[b]	-	-0.9347[b]	-0.95.03[b]	0.8171[a]	0.9475[b]	-	0.9475[b]
RN						0.9157[b]	0.9985[c]	-	-	-	-	-	0.9146[a]	-0.9580[b]
SN							0.9057[a]	-0.8515[a]	-	-	0.9241[b]	-	0.9743[c]	-0.9884[c]
LN								-	-	-	-	-	0.9036[a]	-0.9469b
RP									0.9547[b]	0.8400[a]	-0.9015[a]	-	-0.8467[a]	0.8266[a]
SP										0.9235[b]	-0.8840[a]	-	-	-
LP											-0.9382[b]	-	-0-.8696[a]	
RK												-	0.9689[c]	-0.9045[a]
SK													-	-
LK														-0.9701[c]

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield)
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.5. Correlation coefficient (r) values among various characteristics of plant in $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Parameters	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
SL	0.9678[b]	0.9855[c]	-	-	-0.9917[c]	-0.9966[c]	-0.9985[c]	0.9820[c]	0.8418[a]	0.9762[c]	-0.9938[c]	-0.9986[c]	-0.9981[c]	0.9993[c]
RL		0.9863[c]	-	-	-0.9434[b]	-0.9480[b]	-0.9574[b]	0.9779[c]	-	0.9292[b]	-0.9432[b]	-0.9626[b]	-0.9536[b]	0.9583[b]
NND			-	-	-0.9621[b]	-0.9708[c]	-0.9756[c]	0.9710[c]	-	0.9367[b]	-0.9754[c]	-0.9866[c]	-0.9813[c]	0.9793[c]
NPD				-	-	-	-	-	-	-	-	-	-	-
WPD					-	-0.8444[a]	-	-	-0.8948[a]	0.9153[b]	0.9250[b]	-	0.9393[b]	0.9442[b]
RN						0.9916[c]	0.9937[c]	-0.9738[c]	-0.8283[a]	-0.9938[c]	0.9905[c]	0.9915[c]	0.9909[c]	-0.9944[c]
SN							0.9982[c]	-0.9774[c]	-0.8558[a]	-0.9762[c]	0.9947[c]	0.9944[c]	0.9969[c]	-0.9986[c]
LN								-0.9780[c]	-0.8634[a]	-0.9819[c]	0.9918[c]	0.9961[c]	0.9971[c]	-0.9991[c]
RP									-	0.9641[b]	-0.9695[c]	-0.9750[c]	-0.9712[c]	0.9798[c]
SP										0.8331[a]	-0.8131[a]	-0.8283[a]	-0.8431[a]	0.8436[a]
LP											-0.9690[c]	-0.9732[c]	-0.9719[c]	0.9794[c]
RK												0.9966[c]	0.9975[c]	-0.9961[c]
SK													0.9991[c]	-0.9983[c]
LK														-0.9988[c]

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield)
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.6. Correlation coefficient (r) values among various characteristics of plant with microbial population, soil biological and biochemical properties of soil in control(CTRL)($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
FP	-0.9431^{b}	-	-0.9683^{c}	-	-	0.9494^{b}	0.9056^{a}	-	-	0.8940^{a}	0.9076^{a}	0.8640^{a}	0.9363^{b}	0.9205^{b}	-0.9310^{b}
BP	-	-	-	-	0.9099^{a}	-	-	-	-	-	-	-	-	-	-
SR	-0.9249^{b}	-	-0.9408^{b}	-	0.8206^{a}	0.9171^{b}	0.8827^{a}	-	-	0.8568^{a}	0.9137^{a}	-	0.8990^{a}	0.9036^{a}	-9096^{a}
C_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DHA	-	-	-	-	-0.8468^{a}	-	-	-	-	-	-	-	-	-	-
URA	0.9163^{b}	-	0.8417^{a}	-	0.8602^{a}	-0.8647^{a}	-0.9313^{b}	-	-0.9362^{b}	-0.8992^{a}	-0.9855^{c}	-	-	-0.9296^{b}	0.9259^{b}
PA	0.9967^{c}	-	0.9750^{c}	-	-0.8768^{a}	-0.9672^{b}	-0.9932^{c}	-	-0.9042^{a}	-0.9844^{c}	-0.9600^{b}	-	-0.9469^{b}	-0.9931^{c}	0.9975^{c}

Table 6.3.7. Correlation coefficient (r) values among various characteristics of plant with microbial population, soil biological and biochemical properties of soil in $N_{20}P_{60}K_{40}$ kg/h (NPK) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
FP	-0.8386^{a}	-0.8844^{a}	-	-	-	0.8255^{a}	-	0.8603^{a}	0.8233^{a}	0.8773^{a}	0.8962^{a}	-	0.8757^{a}	0.8758^{a}	-0.8588^{a}
BP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	-0.9411^{b}	-	-	-	-	0.8913^{a}	0.9083^{a}	-	0.9262^{b}	0.9658^{b}	0.9494^{b}	0.8743^{a}	0.9594^{b}	0.9559^{b}	0.9555^{b}
C_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DHA	-	-	-	-	-	-	-	-	0.8344^{a}	-	-	-	-	-	-
URA	0.8498^{a}	-	-	-	-	-0.8301^{a}	-	-	-0.8805^{a}	-0.8898^{a}	-0.9315^{b}	-	-0.8722^{a}	-0.8779^{a}	0.8654^{a}
PA	0.9978^{c}	-	0.9054^{a}	-	-	-0.9730^{c}	-0.9047^{a}	-	-0.9591^{b}	-0.9973^{c}	-0.9606^{b}	-0.9564^{b}	-0.9966^{c}	-0.9986^{c}	0.9998^{c}

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield, FP=fungal population, BP=bacterial population, SR=soil respiration, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity).
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.8. Correlation coefficient (r) values among various characteristics of plant with microbial population, soil biological and biochemical properties of soil in farm yard manure 10 t/h (FYM) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
FP	-	-	-0.8636[a]	-	-	-	-	-	-	-	-	-	-	-	-
BP	-	-	-	-	0.8526[a]	-	-	-	-	-	-	-	-	-	-
SR	-0.9865[c]	-	-0.8635[a]	-	0.9706[c]	0.9803[c]	0.9617[b]	0.9711[c]	-	-	-	0.8985[a]	-	0.9710[c]	-0.9884[c]
C_{mic}	0.9925[c]	-	0.8617[a]	-	-	-0.9284[b]	-0.9883[c]	-0.9172[b]	0.9039[a]	-	-	-0.9260[b]	-	-0.9650[b]	0.9864[c]
DHA	-	-	-	-	-0.9568[b]	-	-	-	-	-	-	-	-	-	-
URA	0.9051[a]	-	-	-	0.9495[b]	-0.8611[a]	-0.8755[a]	-0.8429[a]	0.9180[b]	-	-	-0.8237[a]	-	-0.8380[a]	0.9000[a]
PA	0.9922[c]	-	0.9192[b]	-	-0.9220[b]	-0.9266[b]	-0.9889[c]	-0.9114[a]	0.8317[a]	-	-	-0.9065[a]	-	-0.9602[b]	0.9947[c]

Table 6.3.9. Correlation coefficient (r) values among various characteristics of plant with microbial population, soil biological and biochemical properties of soil in $N_{10}P_{30}K_{20}$ kg/h + farm yard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
FP	-0.9511[b]	-0.9140[b]	-0.9366[b]	-	-	0.9311[b]	0.9612[b]	0.9462[b]	-0.9599[b]	-	-0.8978[a]	0.9587[b]	0.9469[b]	0.9511[b]	-0.9534[b]
BP	-	-	-	-	0.9330[b]	-	-	-	-	-	-	-	-	-	-
SR	-0.9159[b]	-0.8901[a]	-0.9083[a]	-	-	0.9383[b]	0.8956[a]	0.9125[a]	-0.8798[a]	-	-0.9412[b]	0.9138[a]	0.9264[b]	0.9158[b]	-0.9148[a]
C_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DHA	-	-	-	-	-0.8834[a]	-	-	-	-	-	-	-	-	-	-
URA	-	-	-	-	0.9362[b]	-	-	-	-	-	-	-	-	-	-
PA	0.9989[c]	0.9603[b]	0.9771[c]	-	0.9501[b]	-0.9932[c]	-0.9987[c]	-0.9997[c]	0.9822[c]	0.8549[a]	0.9805[c]	-0.9926[c]	-0.9961[c]	-0.9969[c]	0.9994[c]

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield, FP=fungal population, BP=bacterial population, SR=soil respiration, C_{mic}=microbial biomass carbon, DHA=dehydrogenase activity, URA=urease activity, PA=phosphatase activity).

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.10. Correlation coefficient (r) values among various characteristics of plant with soil physico-chemical properties of soil in control (CTRL)($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
MC	-0.9098[a]	-0.8648[a]	-0.8874[a]	-	-	0.9723[c]	0.9052[a]	-	0.8922[a]	0.9205[b]	0.9422[b]	-	0.9399[b]	0.8961[a]	-0.9192[b]
pH	-	-	-	-	-	-	-0.8169[a]	-	-	-	-0.8663[a]	-	-	-0.8341[a]	-
OC	-	-	-	-	-0.8297[a]	-	-	-	-	-	-	-	-	-	-
TN	-	-	-	-	-	-	-	-0.8344[a]	-	-	-	-	-	-	-
AP	-0.9777[c]	-	-0.9486[b]	-	-	0.9758[c]	0.9892[c]	-	0.9386[b]	0.9988[c]	0.9492[b]	-	0.9482[b]	0.9771[c]	-0.9883[c]
K	0.9983[c]	-	0.9869[c]	-	0.8417[a]	-0.9439[b]	-0.9868[c]	-	-0.8742[a]	-0.9650[c]	-0.9518[b]	-	-0.9208[b]	-0.9948[c]	0.9931[c]
RF	0.9973[c]	-	0.9716[c]	-	0.8480[a]	-0.9608[b]	-0.9979[c]	-	-0.9233[b]	-0.9855[c]	-0.9729[c]	-	-0.9272[b]	-0.9974[c]	-
AT	-0.9973[c]	-	-0.9716[c]	-	-0.8480[a]	0.9608[b]	0.9979[c]	-	0.9233[b]	0.9855[c]	0.9729[c]	-	0.9272[b]	0.9974[c]	-
ST	0.9864[c]	-	0.9667[b]	-	-0.8277[a]	-0.9644[b]	-0.9903[c]	-	-0.9433[b]	-0.9826[c]	-0.9785[c]	-	-0.9111[a]	-0.9871[c]	0.9929[c]

Table 6.3.11. Correlation coefficient (r) values among various characteristics of plant with soil physico-chemical properties of soil in $N_{20}P_{60}K_{40}$ kg/h NPK) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
MC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	-	-	-	-	-	-	-	-	-	-	-0.8479[a]	-	-0.8331[a]	-0.8173[a]	0.8261[a]
OC	-	-	-	-	-0.8874[a]	-	-	-	-	-	-	-0.8182[a]	-	-	-
TN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AP	-	-	-	-	-	-	-	-	-	-	-	0.8395[a]	-	-	-
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RF	0.9978[c]	-	0.9090[a]	-	-	-0.9729[c]	0.8955[a]	-	-0.9575[b]	-0.9965[c]	-0.9611[b]	-0.9540[b]	-0.9975[c]	-0.9993[c]	-
AT	-0.9978[c]	-	-0.9090[a]	-	-	0.9729[c]	0.8955[a]	-	0.9575[b]	0.9965[c]	0.9611[b]	0.9540[b]	0.9975[c]	0.9993[c]	-
ST	0.9850[c]	-	0.8884[a]	-	-	-0.9624[b]	-0.8788[a]	-	-0.9254[b]	-0.9923[c]	-0.9465[b]	-0.9237[b]	-0.9978[c]	-0.9959[c]	0.9929[c]

Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rain fall, AT=ambient temperature, ST=soil temperature).
Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Table 6.3.12. Correlation coefficient (r) values among various characteristics of plant with soil physico-chemical properties of soil in farmyard manure 10 t/h (FYM) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
MC	-0.9198^{b}	-	-0.9079^{a}	-	-0.9417^{b}	0.9780^{c}	0.8907^{a}	0.9783^{c}	-	-	-	-	-	0.8455^{a}	-0.9351^{b}
pH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OC	0.9409^{b}	-	0.9650^{b}	-	-0.9490^{b}	-0.9005^{a}	-0.9374^{b}	-0.8871^{a}	-	-	-	-	-	-0.8586^{a}	0.9544^{b}
TN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AP	0.9151^{a}	-	0.9377^{b}	-	0.9835^{c}	-0.8195^{a}	-0.9222^{b}		-	-	-	-	-	-0.8418^{a}	0.9258^{b}
K	0.9981^{c}	-	0.9075^{a}	-	0.9053a	-0.9580^{b}	-0.9884^{c}	-0.9469^{b}	0.8266^{a}	-	-	-0.9045^{a}	-	-0.9701^{c}	-
RF	0.9981^{c}	-	0.9075^{a}	-	0.9475^{b}	-0.9580^{b}	-0.9884^{c}	-0.9469^{b}	0.8266^{a}	-	-	-0.9045^{a}	-	-0.9701^{c}	-
AT	-0.9981^{c}	-	-0.9075^{a}	-	-0.9475^{b}	0.9580^{b}	0.9884^{c}	0.9469^{b}	-0.8266^{a}	-	-	0.9045^{a}	-	0.9701^{c}	-
ST	0.9922^{c}	-	0.8771^{a}	-	-0.9434^{b}	-0.9599^{b}	-0.9778^{c}	-0.9491^{b}	-	-	-	-0.9208^{b}	-	-0.9843^{c}	0.9929^{c}

Table 6.3.13. Correlation coefficient (r) values among various characteristics of plant with soil physico-chemical properties of soil in control $N_{10}P_{30}K_{20}$ kg/h + farmyard manure 5 t/h (NPK+FYM) ($P \leq 0.05$).

Parameters	SL	RL	NND	NPD	WPD	RN	SN	LN	RP	SP	LP	RK	SK	LK	YL
MC	-0.8421^{a}	-	-	-	-0.9483^{b}	0.8796^{a}	0.8743^{a}	0.8530^{a}	-	-	-0.8634^{a}	0.8872^{a}	0.8503^{a}	0.8626^{a}	-0.8617^{a}
pH	0.9800^{c}	0.9763^{c}	0.9799^{c}	-	-	-0.9502^{b}	-0.9754^{c}	-0.9755^{c}	0.9791^{c}	0.8368^{a}	0.9278^{b}	-0.9627^{b}	-0.9723^{c}	-0.9722^{c}	0.9750^{c}
OC	-0.8713^{a}	-0.8962^{a}	-0.8824^{a}	-	-0.9519^{b}	0.8706^{a}	0.8622^{a}	0.8545^{a}	-0.9302^{b}	-	-0.8516^{a}	0.8773^{a}	0.8703^{a}	0.8587^{a}	-0.8697^{a}
TN	-	-	-	-	-0.9663^{b}	-	-	-	-	-	-	-	-	-	-
AP	-09379^{b}	-0.9484^{b}	-0.9551^{b}	-0.8964^{a}	-	0.8982^{a}	0.9339^{b}	0.9251^{b}	-0.9559^{b}	-	-0.8595^{a}	0.9316^{b}	0.9324^{b}	0.9310^{b}	-0.9324^{b}
K	-	-	-	-	0.9296^{b}	-	-	-	-	-	-	-	-	-	-
RF	0.9993^{c}	0.9583^{b}	0.9793^{c}	-	0.9442^{b}	-0.9944^{c}	-0.9986^{c}	-0.9991^{c}	0.9798^{c}	0.8436^{a}	0.9794^{c}	-0.9961^{c}	-0.9983^{c}	-0.9988^{c}	-
AT	-0.9993^{c}	-0.9583^{b}	-0.9793^{c}	-	-0.9442^{b}	0.9944^{c}	0.9986^{c}	0.9991^{c}	-0.9798^{c}	-0.8436^{a}	-0.9794^{c}	0.9961^{c}	0.9983^{c}	0.9988^{c}	-
ST	0.9958^{c}	0.9734^{c}	0.9927^{c}	-	-0.9478^{b}	-0.9847^{c}	-0.9860^{c}	-0.9914^{c}	0.9711^{c}	0.8245^{a}	0.9669^{b}	-0.9885^{c}	-0.9973^{c}	-0.9943^{c}	0.9929^{c}

(Note: SL=shoot length, RL=root length, NND=number of nodule, NPD=number of pod, WPD=weight of pod, RN=root nitrogen, SN=shoot nitrogen, LN=leaf nitrogen, RP=root phosphorus, SP=shoot phosphorus, LP=leaf phosphorus, RK=root potassium, SK=shoot potassium, LK=leaf potassium, YL=yield, MC=moisture content, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, K=exchangeable potassium, RF=rain fall, AT=ambient temperature, ST=soil temperature).

Values marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; insignificant values are marked with ' – '

Chapter-7

General discussion

The present investigation showed an increased trend in microbial population from pre-treatment to post-treatment and this can be attributed to the increase in soil fertility levels (N, P and K), cropping (groundnut) and soil management (ploughing). The agricultural practice particularly input of manure and cover crops could have large impact on the size and activity of soil microbial communities and application of fertilizers increased the soil fertility level and the number of microorganisms (Kirchner *et al.,* 1993). Sarathchandra *et al.* (1993) also stated that increased in bacterial population was observed two weeks after the application of fertilizer, whereas no change in population of these bacteria was observed in unfertilized plot. The peak fungal population in NPK treated plot is in accordance with the report of Upadhayay and Rai (1979), that higher fertility and aeration of soil favoured wider spectrum of fungal genera and species. The peak bacterial population observed at FYM and NPK+FYM treatment is due to the increase in nutrient supply, pH, organic carbon and cation exchange capacity by farmyard manures (Bache and Heathcote, 1969; Heathcote, 1970).

The inconsistent distribution of microbial population within treatment could be due to the retention of fertilizers i.e. long history of fertilization and accumulation of nutrients reserves in the soil before the experiment began (Sarathchandra *et al.*, 1988 and Bardgett and Leemans, 1994) and due to the

enrichment of soil nitrogen through biological fixation of nitrogen by the host legume, which altered the microbial diversity (Bardgett and Shine, 1999) whereas lower microbial population was observed in pre-sowing and post harvest of groundnut. Thies *et al.* (1995) also stated that legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect and bacterial functional diversity in agro-ecosystems would be affected by plant growing stages (Lahav Lavian and Steinberger, 2001). The higher microbial population at the surface soil than the subsurface soil layer is due to the high organic matter, nutrient status and better aeration in the surface layer (Balasubramanium *et al.,* 1972) and moisture regime (Selvraj and Rangaswamy, 1978; Clarholm and Rosswall, 1980). The decreased in population at 10-20 cm depth was linked to the decrease in CO_2 evolution (Tiwari *et al.,* 1986). The peak diversity of fungi noted at FYM plot in the surface and subsurface soil layers could be due to the higher functional diversity of population and the availability of favorable condition (Staddon *et al.*, 1997). Whereas bacterial peak population was noted at NPK+FYM plot at surface and subsurface soil layers and in general higher population was observed during the cropping season. This finding could be attributed to the influence of the host legumes plant rather the types and doses of fertilizers treatment. This observation is in conformity with the result of Bowen and Rovira (1991) and Bolton *et al.* (1992) that the variety of organic compounds released by plants has been postulated to be a key factor influencing the diversity of microorganisms in the rhizospheres of different plant species. Species of *Pseudomonas, Flavobacterium, Acaligenes* and *Agrobacterium* had been

stimulated particularly in the rhizosphere due to the release of exudates and lysates (Curl and Truelove, 1986). The maximum similarity index of fungal species was observed at a paired treatment of organic and inorganic fertilizers (FYM x NPK) and at a combination of organic and inorganic fertilizers (FYM x NPK+FYM or NPK x NPK+FYM). This implies that, some fungal species were favoured only when soil was treated with fertilizers or it could be due to the higher degree of tolerance into a new soil environment. Minimum similarity index was observed at paired treatment of control with combination of inorganic and organic (CTRL x NPK+FYM) and with inorganic fertilizers (CTRL x NPK). The maximum similarity index of bacterial species was observed at paired treatment between at least the combination of inorganic and organic fertilizer with other treatments (NPK+FYM x NPK; NPK+FYM x FYM & NPK+FYM x CTRL). Thus, it was hypothesized that NPK+FYM treatment had higher bacterial species diversity than the other treatments or the NPK+FYM treatment might be the optimum dosage for some bacteria.

The soil microbial biomass carbon (C_{mic}) increased shortly after the application of fertilizers and this could be attributed to the increase in the populations of fungi and bacteria and plant roots (Jordan *et al.*, 1995). This observation is in conformity with the finding of Polyanskaya *et al.* (1997), that microbial biomass carbon measures the total biomass C (fungi + bacteria) whereas fungi are dominant component of the total soil microbial biomass accounting for up to 90% of total. Perfect *et al.* (1990) reported that higher C_{mic} are commonly found in crops with intensive root growth and density. Maximum C_{mic},

which was observed in fertilized plots could be due to the higher accumulation of organic carbon. Goyal *et al.* (1992) reported that the effects of inorganic fertilizer and organic amendments on organic matter-microbial biomass relationships in field experiments under tropical conditions have shown that soil microbial biomass C increased with balanced fertilization and the addition of the organic amendments increased microbial biomass even when the organic C content of the soil did not increase. Meanwhile there are lots of reports on the reduction of soil microbial biomass carbon under the application of inorganic fertilizer (Biederbeck *et al.,* 1984; McAndrew and Malhi, 1992; Ladd *et al.*, 1994). The control and FYM plots showed higher amount of microbial biomass carbon than in those of inorganic (NPK) treated plot (Sakamoto and Oba, 1994; Lovell *et al.*, 1995 and, Hopkins and Shiel, 1996). It was observed that C_{mic} showed inconsistent distribution within each sampling period and treatment. The possibility of the inconsistent distribution of C_{mic} might be due to the retention of fertilizers and this hypothesis was in agreement with the observation of Bardgett and McAlister (1999) that neither the cessation of fertilizer application nor changes in cutting and grazing management significantly affected soil microbial biomass or the fungal: bacterial biomass ratio and they suggested that the lack of effects on the soil microbial community may be related to high residual fertility caused by retention of fertilizer N in the soil. Some workers have reported that the application of inorganic fertilizer has increased the size of microbial biomass (Fraser *et al.*, 1994; Omay *et al.,* 1997), whereas others have shown the opposite results (Biederbeck *et al.,* 1984; McAndrew and Malhi, 1992; Ladd *et al.,* 1994), which led to the contradictory reports among the

researchers. During the investigation, it was observed that the C_{mic} in the agricultural soil was lower than the unfertilized forest soil. These reductions in C_{mic} in fertilized soil have been discussed by Lovell *et al.* (1995) and have been attributed to the changes in substrate quality and root growth (Ennik *et al.,* 1980; Hassink, 1992; Lovell *et al.,* 1995) and the acidifying effect of nitrogenous fertilizers (microbial production of nitric oxide) in soil (Christie and Beattie, 1989). Thus, it is suggested that fertilizers application could have lowered the amount of soil microbial biomass carbon. The long-term soil management practices (primarily tillage and fertilizers application) have led to the decrease in total microbial biomass (Ananyeva *et al.*, 1999). Higher accumulation of microbial biomass carbon at the surface soil layer could be due to the higher microbial population and to more accumulation of organic carbon than the subsurface soil layer. Maithani *et al.* (1996) also reported that microbial biomass C at the surface soil layer of disturbed sub-tropical humid forests was significantly ($P \leq 0.01$) greater than that of the subsurface soil layer. This was attributed to the greater accumulation of litter and fine root biomass.

The maximum soil respiration observed at FYM plot in the month of July indicates that FYM could enrich the soil nutrient status, which in turn promoted the soil micro biota. It can be hypothesized that the maximum soil respiration in the month of July than at the initial stage of fertilization might be due to the lower availability of organic carbon, where FYM was supposed to provide higher amount of organic carbon. This hypothesis is in conformity with the result of Lovell and Jarvis (1996) that, after 12 weeks the labile carbon substrates from the dung were

likely to have become depleted, leaving large amounts of dead microbial materials as a possible energy source for other microorganisms. Franzluebbers *et al.* (1995) reported that the soil CO_2 evolution was greater during the growing season than during fallow in all crops and legumes could enrich their immediate soil environment with rhizobia through rhizosphere effect (Thies *et al.,* 1995). Kursar (1989) stated that soil respiration includes root exudation, microbial decomposition of litter and dead roots as well as respiration by root symbionts. It can also be hypothesized that high rainfall, optimum temperature and high soil moisture contents in July, influence FYM fertilizer to enable more plant growth, high root respiration and as well as high CO_2 evolution of microbes through root environment. Other soil factors potentially influencing rate of soil respiration *in situ* includes the availability of C substrates for microorganisms (Seto and Yanagiya, 1983), plant root densities and activities (Ben-Asher *et al.,* 1994), soil organism levels (Rai and Srivastava, 1981), soil physical and chemical properties (Boudot *et al.,* 1986). The positive correlation of soil respiration with temperature and moisture contents, are in agreement with the findings of Kursar (1989), Raich and Nadelhoffer (1989), Cavelier and Penuela (1990), Maggs and Hewett (1990) and Jurik *et al.* (1991). The maximum rainfall and optimum temperature in July coincided with the highest rate of CO_2 evolution (Rout and Gupta, 1989). The inconsistent trend of soil respiration within a treatment could be due to the influence of environment i.e. temperature, rainfall, soil moisture content. Carlyle and Than (1988) also stated that, rates of soil respiration were largely depending upon soil temperature and moisture condition.

The activity of soil enzymes (dehydrogenase, urease and phosphates) showed an increase trend from pre-fertilizers treatment to post fertilizers treatment. This could be due to the increase in soil microbial population or due to the effects of soil management practices i.e. fertilization and ploughing. The activity of soil microorganisms and soil management (fertilization and ploughing) were strongly linked to the activity of soil enzyme (Miller and Dick, 1995; Deng and Tabatabai, 1997; Klose *et al.*, 1999). Ross (1970) stated that dehydrogenase activity appeared to be more dependent on the biological activity of microbial population than on any free enzyme present in the soil. Zantua and Bremner (1997) also reported that soil urease are microbial products that could accumulate in cell free form in the soil because of they are highly resistant to environmental degradation, they occur in agricultural soils with a variety of cultural histories. Speir and Ross (1990) also mentioned that phosphatase activity is originated from microorganisms.

FYM and NPK+FYM plots showed maximum dehydrogenase activity and it coincided with the observation of Simek *et al.* (1999) that dehydrogenase activity was low in soil that received the largest amount of fertilizers and it is suggested that the dehydrogenase activity was highly sensitive to the inhibitory effects associated with large amount of fertilizer additions. Parham *et al.* (2002) observed that within each sampling period, the highest dehydrogenase activity was in soil treated with animal manure, while lowest was in the CTRL or NP-treated plots. From this observation, it can be hypothesized that FYM treatment was expected to influence more on the activity of dehydrogenase than that of NPK+FYM treatment.

This hypothesis is in conformity with the result of James *et al.* (1996) that the addition of manure saturated soil's capacity to retain manure-P and soil P status might also influence microbial growth directly, through its effect on plant root growth and consequently influence the amount of C released by roots (Perrott and Sarathchandra *et al.*, 1989). So that any management practice that increases total C accumulation should also increase the size and activities of soil microbial biomass (Buchanan, 1990) and this observation strongly confirmed our finding that dehydrogenase activity significantly correlated ($P \leq 0.05$) with soil microbial biomass carbon (C_{mic}) and organic carbon (Leiros *et al.*, 2000). The significant variation of dehydrogenase activity between surface and sub-surface layers was in agreement with Das (1980), Baruah and Mishra (1984) and Tiwari *et al.* (1987b) that higher dehydrogenase activity in the surface soil layer was due to presence of higher bacterial population, organic carbon content, favorable moisture content and temperature.

In general, greater urease activity was observed at fertilizers treated plots than the control plot. Garcia-Gil *et al.* (2000) reported that mineral fertilization plot had the greatest urease activity than unfertilized plot. This observation is also in conformity with the finding of Tiwari (1996 a) that urease activity was considerably greater in NPK+OM (organic matter), OM and NPK than control plots. So, the higher activity of enzyme in treated plot could be due to higher organic matter, N contents and higher soil microbial population in treated plots. Beri *et al.* (1978) and Tiwari *et al.* (1989) also reported that urease activity was principally associated with the organic mater contents of the soil. Studies from long-term field

experiments have shown that a high portion of legumes in the rotation led to greater contents of organic C and N in soils (Bolton *et al.*, 1985) and thus contributed to higher microbial activities. The result, which showed the inconsistent activity within sampling months, could be due the rhizosphere effect (Burns, 1978) and the retention of fertilizers. The variation in urease activity was mainly due to the changes in organic matter content of soils (Bremner and Mulvaney, 1978) and legumes rotation that led to greater contents of organic C and N in soils (Bolton *et al.*, 1985).

The peak phosphatase activity was recorded in NPK+FYM and generally higher activity was observed at NPK+FYM and FYM plots within sampling periods. The finding that consistent distribution is in agreement with Spiers and McGill (1979) that greater phosphatase activity in NPK+OM (organic manure); NPK and OM plots were due to mainly higher organic matter contents and microbial populations (Nilson and Eiland, 1980). It also indicated that soil organic matter level and soil microbial activities are vital for the nutrients turnover and the long-term productivity of the soil was enhanced by use of organic amendments along with inorganic fertilizers (Goyal *et al.*, 1999). This enhancement of biological activities in the manure treated soil was evidenced by relatively high phosphatase activity (Parham *et al.*, 2002) and they also suggested that the possible reason of higher enzyme activity in a manure treatment was that manure promoted biological and microbial activities, which accelerated the breakdown of organic substances in the added manure. The soil treated with NPK+FYM and FYM fertilizers which were highly bound unavailable form of organic P was likely exhibited more enzyme

activity. Parham *et al.* (2002) also reported that phosphatase activity was significantly higher in the soil treated with cattle manure than P, NP, NPK and NPK plus lime. So, it can be hypothesized that the phosphatase activity was activated when there was low P availability in soil. The peak phosphatase activity in the month of September could be due to the rhizosphere effect (Burns, 1978) wherein the groundnut plant attained its maximum growth (120 DAS) and root exudation of plant enhanced the microbial populations and the activity of soil microorganisms was strongly linked to the activity of enzymes (Deng and Tabatabai, 1997; Klose *et al.*, 1999). A positive correlation between phosphatase and temperature was in agreement with the finding of Sinsabaugh *et al.* (1991) that temperature is a controlling factor of the enzyme activity and it effects the enzyme activity indirectly through influencing microbial proliferation, and also directly, by modifying enzyme kinetics (Chrost, 1991).

The positive correlation of soil temperature with soil enzymes is in agreement with the findings of Sinsabaugh *et al.* (1991) that temperature has been controlling factor of the enzyme activities in upland soils. High soil temperature at surface soil than subsurface soil layers could be due to the heating up of surface soil by solar radiation and also due to the higher moisture content in the deeper soil layer. The moisture content significantly ($P \leq 0.05$) varied among the treatments in the 0-10 cm. The greater moisture content was noted at FYM plot, it could be due to the greater water retention capacity of farmyard manure. Mogaddeghi *et al.* (2000) also reported that application of farmyard manure at the rate of 50 mg ha^{-1} increased soil wetness traffic ability range, thus reducing soil

compatibility. The decreased soil pH in the surface layer after the application of fertilizers and sowing of groundnut was in conformity with the report of Simek *et al.* (1999) and stated that soil pH decreased by the addition of organic manure plus inorganic fertilizers in the absence of liming. Yan *et al.* (1996) also reported that during cultivation of legumes, soil is acidified due to proton release from roots and they further mentioned that soil pH significantly decreased by field legumes (beans) from 6.00 to 5.64 in a cultivation period of 45 days. The inconsistent trend in soil pH within treatments in surface and subsurface soil layers could be due to the retention of fertilizers, which were applied in the field in the earlier experiment. Colting (1997) stated that the plots that were continuously applied with pure organic fertilizer showed slight increase in soil pH and soil organic matter content. Conversely, the continuous application of pure inorganic fertilizer resulted in a decreasing trend in soil pH.

The higher soil organic carbon in FYM and NPK+FYM plots might be due to the higher organic matter content of farmyard manure. Saviozzi *et al.* (1999) reported that FYM treated plot showed higher amount of total organic matter (TOC). It was known that soil organic matter levels and soil microbial activities, vital for the nutrient turnover and long-term productivity of the soil were enhanced by use of organic amendments along with inorganic fertilizers (Goyal *et al.*, 1999). The peak organic carbon observed in NPK+FYM plot in surface and subsurface soil layers could be due to the availability C, resulting in a more diverse and dynamic microbial system than inorganically fertilized soil (Peacock *et al.*, 2001). It was also reported by Agbenin and Goladi (1997) that the combination of farmyard

manure with N+P and N+P+K fertilization could enable soil carbon to be maintained equal to, or greater than the native site soil. Large amount of organic carbon in subsurface soil layer in NPK+FYM plot could also be due the significant increase in soluble organic carbon (Liang *et al.*, 1998) and the downward movement of soluble carbon in the soil profile (Bhogal and Shepard, 1997).

Though the maximum soil nitrogen content was displayed in NPK plot, but within monthly sampling the peak N showed inconsistent distribution i.e. CTRL and FYM plots showed higher ranges of soil N in some months where Omay *et al.* (1997) and Simek *et al.* (1999) observed that the soil N contents were greater in fertilized treatments as compared to the control. This could be due to the biological fixation of atmospheric nitrogen through the nodules present in the root system. This suggests that nitrogen fertilizer (urea) was not the only controlling factor on the distribution of soil N but was highly controlled by availability of N through biological nitrogen fixation. There are also reports on the higher soil N content in FYM treated soil (Saviozzi *et al.*1999). However, combination of farmyard manure with N+P+K fertilization enable N to be maintained equal to, or greater than, the native site soil (Agbenin and Goladi, 1997).

The increase in soil P from pre-fertilization to post treatment could be due to the availability of inorganic P through the addition of P fertilizer (single super phosphate). Similar result was observed by Ishaq *et al.* (2002) and Agbenin and Goladi (1998) that the P fertilizer application significant increased soil P concentration. Thus it can be assumed that though the result showed maximum phosphorus in FYM plot, which could be due to the highly bound unavailable form

of organic P in manures but the soil P distribution within each monthly sampling showed inconsistent distribution. This inconsistent distribution might be due to the effect of retention of fertilizers.

NPK and NPK+FYM treated plots displayed increased soil exchangeable potassium after the addition of fertilizers. Simek *et al.* (1999) also reported that the soil concentration of all the inorganic nutrients (NPK) measured were greater following fertilizer applications as compared to the unfertilized plots, and this effect was most marked for K in soil from plot that had received the largest amounts of these nutrients as fertilizers. But the present result indicated that the CTRL and FYM plots in 2001 at surface and subsurface soil layers displayed greater amount of K than combination of NPK+FYM in the month of May. The possibility of this result might be due to the effect of K retention, which was applied earlier for other experimental purposes.

Root and Shoot lengths were more in treated plot as compared to CTRL plot and this could be due to the higher availability of soil nutrients, which was applied into the field in the form of inorganic (NPK) or organic (FYM) fertilizers. The maximum root and shoot lengths in NPK+FYM plot was due to more availability of soil nutrients and the combination of farmyard manure with NPK fertilizer probably stimulates immobilization on N and P at the expense of reaction with soil inorganic constituents and possible leaching from the soil profile (Agbenin *et al.*, 1997). It was observed that the number of root nodules increased along with age of the plant and fertilizers treatment. Nambiar (1994) reported that from long-term manuring experiment, application of farmyard manure and NPK fertilizers

improved population of soil microorganisms and nodulation of soybean (legume). The maximum yield was noted in NPK+FYM plot and this could be due to the improvement of soil physico-chemical characteristics. Anikwe *et al.* (2003) also observed that combination of manure with NPK had higher groundnut yield than CTLR or application of NPK alone. Yield of groundnut showed a significant variation ($P \leq 0.05$) between the treatments and a positive correlation coefficient of groundnut yield with soil temperature in all treatments was observed. The maximum number and weight of pods were observed in FYM plot at 90 DAS and the possibility of this result might be due to the higher availability of soil nutrients for the plant. This is in conformity with the findings of Lovell and Jarvis (1996) that after 12 weeks, the labile C substrates from the dung were likely to have become depleted, leaving large amounts of dead microbial materials as a possible energy source for other microorganisms.

The plant nitrogen content was highest at 30 days after sowing (30 DAS) and this could be due to the higher availability of nitrogen in the soil system. Though fertilized plots (NPK+FYM and NPK) showed peak plant nitrogen content, inconsistent trend of nitrogen distribution within treatments was observed and the inconsistent distribution could be attributed by the inhibition of biological N fixation by the addition of inorganic fertilizer N and retention of fertilizers. This is in agreement with the findings of Caroll and Mathews (1990) that the application of N fertilizer to legume crops reduced biological N_2 fixation. The analysis of variance also showed insignificant ($P \leq 0.05$) variation of N content of the plant within treatments except between shoot N in NPK and FYM plots. Plant N content

positively correlated with soil respiration and soil moisture content and this result could be due to the higher activity of N fixing microorganisms in the soil system, where the amount of soil respiration was an indicator of the activity of organisms. Novoa and Loomis (1981) reported that soil moisture availability is the main factor influencing nitrogen uptake by the root and transport to the leaf. Maximum plant phosphorus (P) content was displayed at 90 DAS in FYM plot, whereas CTRL, NPK, and NPK+FYM plots showed higher P content in some of the sampling months. Maximum plant P content was expected to display in P fertilized plots only (NPK and NKP+FYM) and Taiwo *et al.* (1999) also reported that the application of fertilizer P in soybean increased P content in plant tissue when compared with the control. The contradictory result could be due to the retention of P fertilizer in FYM or nutrient support from previous crop roots (Singh and Shekhar, 1989). Since phosphatase enzyme activity mediates the release of inorganic phosphorus from organically bound phosphorus to soil, we also observed that phosphatase enzyme activity and soil temperature were positively correlated with plant P content in NPK+FYM treated plot. The highest potassium content in plant was displayed only at K fertilizer treated plot during the entire investigation and this indicated that the availability of K for plant uptake could be compensated through the addition of fertilizer K. However, in some periods of sampling, CTRL and FYM plots displayed higher K content than treated plot, which reflects that the K distribution within treatments was inconsistent. This contradictory result could be due to the retention of fertilizers or due to the availability of soil K rather than the addition of K through fertilizer (NPK) and this result is in conformity with the reports of Havlin *et al.*

(1999) and Brady and Weil (1999) that some non-exchangeable K could also be released into the soil solution and may thus be taken up by plants.

Chapter-8

Summary

The present research investigation deals with the enumeration and isolation of soil microorganisms and the effect of different levels of inorganic fertilizers (NPK) and farmyard manure on microbial community, biomass C, microbial enzymes activities (dehydrogenase, urease, phosphatase), carbon dioxide evolution, physico-chemical properties of soils (moisture content, pH, organic carbon, N, P and K) and groundnut plant performance within the proposed agro-ecosystem at monthly intervals under two crop cycles.

The investigation was carried out at an Upland Experimental Block of Agronomy Division, Indian Council of Agricultural Research (ICAR) for North Eastern Hill (NEH) region complex at Barapani, Shillong, Meghalaya, on Groundnut (*Arachis hypogaea* L.) cultivation in northeast India. The geographical position of the study site is at 25^0 38' N latitude and 91^0 52' E longitudes and is situated at an altitude of 850 msl. High yielding variety of groundnut ICGS-76 (International culture of groundnut selection-76) from International Crop Research Institute for Semi-Arid Tropics (ICRISAT) Hyderabad was sown for the study. The optimum fertilizers dosage for groundnut was applied into the field as recommended by ICAR.

At the initial stage of fertilization and soil management, microbial population increased, however, at the time of pre-sowing and post harvest of groundnut, low

microbial population was recorded. In general, the bacterial population was higher than the fungal population at the surface and subsurface soil layer. The surface soil layer harbored higher microbial population than the subsurface soil layers. The peak fungal population was recorded in NPK plot whereas bacterial peak population was recorded in FYM and NPK+FYM plots, inconsistent distribution of microbial population within a treatment was marked throughout the investigation. The peak species diversity of fungi was noted at FYM plot at surface and subsurface soil layers, whereas bacterial peak population was noted at NPK+FYM plot at surface and subsurface soil layers and in general higher population was observed during the cropping season. The maximum similarity index of fungal species was observed at a paired treatment of organic and inorganic fertilizers (FYM x NPK) and at a combination of organic and inorganic fertilizers (FYM x NPK+FYM or NPK x NPK+FYM). Minimum similarity index was observed at paired treatment of control with combination of inorganic and organic fertilizer (CTRL x NPK+FYM) and with inorganic fertilizer (CTRL x NPK). The maximum similarity index of bacterial species was observed at paired treatment between the combination of inorganic and organic fertilizer with other treatments (NPK+FYM x NPK; NPK+FYM x FYM & NPK+FYM x CTRL). The significant variation of microbial population and positive correlation between surface and sub-surface soil layers were observed. All together 56 fungal species and 2 sterile mycelia were isolated and out of this *Aspergillus sp., Penicillium sp.* and *Trichoderma sp.* were the dominant fungal species. *Aspergillus versicolor, Eupenicillium lapidosum, Idriella lunata* were isolated only at surface soil layer at NPK+FYM, NPK and FYM,

NPK and NPK+FYM plots respectively whereas *Ramichloridium schulzeri, Ulocladium consortiale* were isolated only at subsurface soil layer at NPK and FYM plots. All together 8 bacterial species were isolated and *Arthrobacter sp. Bacillus sp. and Rhizobium sp.* were the dominant bacterial species whereas *Arthrobacter* sp. was isolated only from NPK and FYM treated soils at subsurface soil layer.

The soil microbial biomass carbon (C_{mic}) increased shortly after the application of fertilizers but it showed inconsistent distribution within each sampling period and treatment. Fertilizers application has lowered the amount of soil microbial biomass carbon and the surface soil layer showed higher accumulation microbial biomass carbon than the subsurface soil layer. It varied significantly ($P \leq 0.001$) between surface and subsurface soil layers except NPK+FYM plot. Maximum soil respiration was recorded in FYM plot in the month of July and high rainfall; optimum temperature and high soil moisture contents influenced CO_2 evolution. However, positive correlations of soil respiration with temperature and moisture contents were recorded in the two layers. The inconsistent distribution of soil respiration within a treatment was also noted. Soil respiration varied significantly ($P \leq 0.05$) between NPK and FYM plot at surface soil layer, whereas, at subsurface soil layer, it varied significantly among the treatments except in between CTRL and NPK plots. Soil respiration varied significantly ($P \leq 0.001$) between surface and subsurface soil layers and surface layer was positively correlated with subsurface soil layer.

The activities of soil enzymes (dehydrogenase, urease and phosphates) increased from pre-fertilizers treatment to post fertilizers treatment and it was noted that the distribution of these enzymes showed inconsistent distribution within treatments. The surface soil enzymes activities were positively correlated with subsurface soil layer. Peak dehydrogenase activity was displayed at FYM and NPK+FYM plots. The significant variation of dehydrogenase activity between surface and sub-surface layers was observed except NPK+FYM. Greater urease activity was observed at a fertilizers treated plots other than control plot and the peak activity was noted at NPK plot. The insignificant variation ($P \leq 0.05$) of urease activity between surface and sub-surface layers was observed. The peak phosphatase activity was recorded in NPK+FYM and generally higher activity was observed at NPK+FYM and FYM plots within sampling periods. Phosphatase activity was positively correlated with temperature and soil moisture content.

The surface soil layer showed higher temperature than the subsurface soil layers and a positive correlation of soil temperature with soil enzymes was observed. Greater soil moisture content was noted at FYM plot and significant ($P \leq 0.05$) variation within treatment at surface layer was noted. The soil pH decreased after the addition of fertilizers and groundnut and the inconsistent distribution of soil pH within treatments was marked at surface and subsurface soil layers. Higher soil organic carbon was displayed at FYM and NPK+FYM plots and inconsistent distribution within treatment was observed. The organic carbon varied significantly ($P \leq 0.001$) between surface and subsurface soil layers in all plots. The fertilization increased total soil nitrogen at the initial stage of treatment at surface and

subsurface soil layers except in FYM plot and it reduced at post harvest. NPK plot showed peak nitrogen content, whereas inconsistent distribution of N within each monthly sampling was observed. A significant variation ($P \leq 0.05$) and a positive correlation ($P \leq 0.001$) of total nitrogen between surface and subsurface soil layers were observed. The soil phosphorus increased from pre-fertilization to post treatment and a maximum P was noticed in FYM plot, whereas inconsistent distribution within each monthly sampling was observed. It showed significant and positive correlation between surface and subsurface soil layers ($P \leq 0.05$). At the initial stage of fertilization NPK and NPK+FYM plots displayed increase in soil exchangeable potassium and inconsistent distribution within each monthly sampling was observed. A significant variation ($P \leq 0.05$) and a positive correlation ($P \leq 0.001$) between surface and subsurface soil layers were observed.

Root and shoot lengths were more in treated plot as compared to the CTRL plot and shoot length was positively correlated ($P \leq 0.05$) with number of nodules, yield, phosphatase, rainfall and soil temperature in all treatments. The number of root nodules increased along with age of the plant and fertilizers treatment and a positive correlation ($P \leq 0.05$) with phosphatase, rainfall and soil temperature in all treatments was observed. The maximum number and weight of pods were observed in FYM plot at 90 DAS and the weight of pod were positively correlated with bacterial population and urease enzyme activity except in NPK plot. NPK+FYM plot showed maximum yield and a significant ($P \leq 0.05$) variation between treatments and positive correlation of yield with soil temperature was observed in all treatment.

The plant nitrogen content was highest in fertilized plot at 30 DAS and inconsistent distribution within treatment was observed. Plant N content was positively correlated with soil respiration and soil moisture content. Maximum plant phosphorus content was observed in FYM plot at 90 DAS and inconsistent distribution within treatment was observed. The highest plant potassium content was displayed at K fertilizer treated plot and inconsistent distribution within treatment was observed.

References

Abawi, G.S. and Widmer, T.L. 2000. Impact of soil health management practices on soil-borne pathogens, nematodes and root diseases of vegetable crops. *Appl. Soil Ecol.* 15: 37-47.

Agbenin, J.O. and Goladi, J.T. 1997. Carbon, nitrogen and phosphorus dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. *Agric. Ecosyst. Environ.* 63: 17-24.

Agbenin, J.O. and Goladi, J.T. 1998. Dynamics of phosphorus fractions in a savanna Alfisol under continous cultivation. *Soil Use Manage.* 14: 59-64.

Allen, S.E., Grinshaw, H.M., Parkinson, J.A. and Quarmby, C. 1974. *Chemical Analysis of Ecological materials.* Blackwell Scientific Publications, Oxford.

Alexander, M. 1977. Microbiology of the rhizosphere. In *Introduction to Soil Microbiology.* pp. 423-437. Wiley, Chichester.

Alexander, M. 1980. Effect of acidity on microorganisms and microbial processes in soil. In: *Effects of Acid Precipitation on Terrestrial Ecosystems* (T.C. Hutchinson and M. Havas. Eds.) pp. 363-374 Plenum Press, New York.

Allison, F.E. 1973. *Soil Organic matter and its Role in Crop Production.* Elsevior, Amsterdam. pp. 637.

Alvarez, R., Alvarez, C. R. and Lorenzo, G. 2001. Carbon dioxide fluxes following tillage from a mollisol in the Argentine Rolling Pampa. *European Journal of Soil Biology.* 37(3): 161-166.

Ananyeva, N.D., Demkina, T.S., Jones, W.J., Caberra, M.L. and Steen, W.C. 1999. Microbial biomass in soils of Russia under long-term management practices. *Biol. Fertil. Soils.* 29: 291-299.

Anderson, J.P.E. and Domsch, K.H. 1975. Measurement of bacterial and fungal contribution to respiration of selected agricultural and forest soils. *Canadian Journal of Microbiology.* 21: 314-322.

Anderson, J.P.E. and Domsch, K.H. 1978. A physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biol. & Biochem.* 10: 215-221.

Anderson, T.H. and Domsch, K.H. 1986. Carbon link between microbial biomass and soil organic matter. In: *Perspective in Microbial Ecology* (E. Megusar and M. Gantan Eds.). Malinska Knijiga, Ljubljana, pp. 467-216.

Anderson, J.P.E. and Domsch, K.H. 1980. Quantities of plant nutrients in the microbial biomass of selected soils. *Soil Science.* 130: 211-216.

Anderson, J.P.E. and Domsch, K.H. 1989. Ratios of microbial biomass carbon to total organic-C in arable soils. *Soil Biol. & Biochem.* 21: 471-479.

Anderson, T.H. and Domsch, K.H. 1990. Application of eco-physiological quotients (qCO_2 and qD) on microbial biomass from soils of different cropping histories. *Soil Biol.& Biochem.* 22: 251-255.

Anderson, J.M. and Ingram, J.S.I. 1993 (Eds.). *Tropical Soil Biology and Fertility*: A handbook of methods. C. A. B. International, Oxford.

Anikwe, M.A.N., Obi, M.E. and Agbim, M.M. 2003. Effect of crop and soil management practices on soil compatibility in maize and groundnut plots in a Paleustult in Southeastern Nigeria. *Plant and Soil.* 25: 457-465.

Aon, M.A. and Colaneri, A.C. 2001.II. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. *Applied Soil Ecology.* 18 (3): 255-270.

Asiegbu, J.E. 1984. Organic manure substrates and their effects on early weed incidence, earthworm activities, and microbial population. *Beitrage Tropical landwirtsch Veterinarmed.* 22: 371-376.

Atlas, R.M. 1984. Use of microbial diversity measurements to assess environmental stress, pp. 540-545. In: M.J. Klug & C.A. Reddy (Eds.). Current perspectives in microbial ecology. *American society for microbiology*, Washington D.C.

Ayanaba, A. and Omayuli, A.P.O. 1975. Microbial ecology of acid tropical soils. A preliminary report. *Plant and Soil.* 43: 519-522.

Ayanaba, A. Tuckwell, S.B. and Jenkinsosn, D.S. 1976. The effects of clearing and cropping on the organic reserves and biomass of tropical forest soils. *Soil Biol. & Biochem.* 8: 519-525.

Baath, E. and Soderstrom, B. 1979. Fugal biomass and fungal immobilization of plat nutrients in Swedish coniferous forest soils. *Rev. Ecol. Biol. Soil.* 16: 477-489.

Baath, E. and Soderstrom, B. 1982. Seasonal and spatial variation in fungal biomass in a forest soils. *Soil Biol. & Biochem.* 14: 353-358.

Bache, B.W. and Heathcote, R.G. 1969. Long-term effects of fertilizers and manures on soil and leaves of cotton in Nigeria. *Exp. Agric.* 241-247.

Bagyaraj, J. and Rangaswami, G. 1976. Effect of fertilizers on the microflora of soil and the rhizosphere of ragi (*Eleucine coracana*). *Mysore J. Agric. Sci.* 7: 176-186.

Balasubramaniam, A., Shantaram, M.V., Sardesh Pande, J.S. and Rangaswami, G. 1972. Studies on certain microbiological properties of the old permanent manorial plots at Coimbatore, Tamilnadu. *Madras Agric. J.* 59: 443-448.

Baldensperger, J.F. 1981. Short-term variations of microbiological and physico-chemical parameters in submersion water over a rice field. *Ann. Microbiol.* 128: 101-122.

Banerjee, M.R., Burton, D.L., McCaughery, W.P.P. and Grant, C.A. 1997. Influence of pasture management on soil biological quality. *J Range Manage.* 53: 127-133.

Bardgett, R.D., Frankland, J.C. and Whittaker, J.B. 1993. The effects of agricultural practices on the soil biota of some upland grassland. *Agric. Ecosyst. Environ.* 45: 25-45.

Bardgett, R.D. and Leeman, D.K. 1994. The short-term effects of cessation of fertilizer applications, liming and grazing on microbial biomass and activity in a reseeded upland grassland soil. *Biol. Fertil. Soils.* 19: 148-154.

Bardgett, R.D., Speir, T.W., Ross, D.J., Yeates, G.W. and Kettles, H.A. 1994. Impact of pasture contamination by copper, chromium and arsenic timber preservative on soil microbial properties and nematodes. *Biol. Fertil. Soils.* 18: 71-79.

Bardgett, R.D. and McAlister, E. 1999. The measurement of soil fungal:bacterial biomass ratios as an indicator of ecosystem self-regualtion in temperate meadow grasslands.

Bardgett, R.D. and Shine, A. 1999. Linkages between litter diversity, soil microbial biomass and ecosystem function in temperate grasslands. *Soil Biol. & Biochem.* 31: 317-321.

Barnett, K.L. and Hunter, B.B. 1972. *Illustrated Genera of Imperfect Fungi.* Burgess Publishing Company, Minneapolis.

Baruah, M. and Mishra, R.R. 1984. Carbon-dioxide evolution and microbial population in flooded and upland rice (Oryza sativa L.) field soils of North-East India. *J. Soil Biol. Ecol.* 3: 69-76.

Baruah, M. and Mishra, R.R. 1984. Dehydrogenase and urease activities in rice-field soils. *Soil Biol. & Biochem.* 16: 423-424.

Batra, L., Kumar, A., Manna, M.C. and Chhabra, R. 1997. Dehydrogenase activity and microbial biomass carbon in salt affected soils of semiarid and arid region. *Experi. Agric.*, 4: 389 – 397.

Bauhus, J. and Khanna, P.K. 1994 Carbon and nitrogen turnover in two acid forest soils of southeast Australia as affected by phosphorus addition and drying and rewetting. *Biol. Fertil. Soils.* 17: 212-218.

Bauhus, J., Pare, D. and Cote, L. 1998. Effect of tree species, stand age and soil type on soil microbial biomass and its activity in a southern boreal forest. *Soil Biol. & Biochem.* 30 (8): 1089 – 1998.

Beare, M.H., Parmelee, R.W., Hendrix, P.F. and Cheng, W. 1992. Microbial and faunal interactions and affects on litter nitrogen and decomposition in agroecosystems. *Ecological Monographs.* 62: 569-591.

Beare, M.H., Coleman, D.C., Crossley, D.A. Jr., Hendrix, P.F. & Odum, E.P. 1995. A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. *Plant and Soil.* 170: 5-22.

Beare, M.H., Vikram Reddy, M., Tian, G., and Srivastava, S.C. 1997): Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota. *Applied Soil Ecology*. 6 (1): 87-108.

Beck, T., Capriel, P., Borchert, H. and Brandhuber, R. 1995. Die mikrobielle Biomass in landwirtschaftlich genutzten Boden, 2. Mitteilung: Beziehungen der Biomasse zu chemischen und physikalischen Bodeneigenschaften. *Agribiological Research.* 48: 74-82.

Behera, N., Joshi, S.K. and Pati, D. 1990. Root contribution to total soil metabolism in a tropical soil from Orissa, India. *For. Ecol. Manage*. 36: 125-134.

Belay, A, Claassens and Wehner, F. C. 2002. Effect of direct nitrogen and potassium and residual phosphorus fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation. *Biol. Fertil. Soils.* 35: 420-427.

Ben-Asher, J., Cardon, G.E., Peters, D., Rolston, D.E., Biggar, J.W., Phene, C.J. and Ephrath, J.E. 1994. Determining root activity distribution by measuring surface carbon dioxide fluxes. *Soil Sci. Soc. Am. J.* 58: 926-930.

Berendse, F., Beltman, B., Bobbink, R., Kwant, R. and Schmitz, M. 1987b. Primary production and nutrient availability in wet heatland ecosystems. *Acta Oecologia*. 8: 265-279.

Bergstrom, D.W., Monreal, C.M. and King, D.J. 1998. Sensitivity of soil enzyme activity to conservation practices. *Sci. Soc. Am. J.* 62: 1286-1295.

Beri, V., Goswami, K.P. and Brar, S.S. 1978. Urease activity and its Michaelis constant for soil enzymes. *Plant and Soil.* 49:105-115.

Beyer, L., Wachendorf, C., balzer, F.M. and Balzer-Graf, U.R. 1992. The effect of soil texture and soil management on microbial biomass and soil enzyme activities in arable soils of Nortwest Germany. *Agrobiol. Res.* 45: 276-283.

Bhatti, A.U. and Mulia, D.J. 1995. Spatial variability of soil and wheat yield on complex hills and their fertility management. *Journal of Indian Society of Soil Science*. 43: 53-56.

Bhogal, A. and Shepard, M. 1997. Effect of poultry manure on the leaching of carbon from a sandy soil as a potential substrate for denitrification in the subsoil. *Journal of the Science of Food and Agriculture.* 74: 313-322.

Biederbeck, V.O., Campbell, C.A. and Zentner, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. *Can. J. soil Sci.* 64: 355-367.

Blah, E.M. 1999. *Studies on soil microbiology of coal mine spoils of Jaintia hills, Meghalaya*. Ph.D. Thesis, North Eastern Hill University, Shillong, India, pp. 31-41.

Boero, G. and Thien, S. 1979. Phosphatase activity and phosphorus availability in the rhizosphere of corn roots. In: Handlyanow, J.L. and Russel, R.S. (eds.). *The soil root interface*, pp. 231-242, Academic Press, London.

Bohn, H., McNeal, B. and O'Conner, G. 1979. *Soil Chemistry*. Wiley, New York.

Bolton, J., Elliot, L.F., Papendick, R.P. and Bezdicek, D.F. 1985. Soil microbial biomass and selected soil enzyme activities: effect of fertilization and cropping practices. *Soil Biol. & Biochem.* 17: 297-302.

Bolton, H., Frederickson, J.K. and Elliot, L.F. 1992. Microbial ecology of the rhizosphere. In *Soil Microbial Ecology* (F.B. metting, Ed.), pp. 27-36. Mercel Dekker, New York.

Bottner, P. 1985. Response of microbial biomass to alternate moist and dry conditions in a soil incubated with ^{14}C and ^{15}N labeled plant material. *Soil Biol. & Biochem.* 17: 329-337.

Boudot, J.P., Bel Hadj, B.A. and Chone, T. 1986. Carbon mineralization in andosols and aluminium rich highland soils. *Soil Biol. & Biochem.* 18: 457-461.

Bowen, G.D. and Rovira, A.D. 1991. The rhizosphere, the hidden half of the hidden half. In *Plant Roots-The Hidden half* (Y. Waisel and U. Kafkafi, Eds.), pp. 641-649. marcel Dekker, New York.

Brady, N.C. 1995. *The Nature and Properties of Soils*. Tenth Edition, Prentice-Hall of India Pvt. Ltd., New Delhi, pp 621.

Brady, N.C. and Weil, R.R. 1999. *The nature and Properties of Soils*, 12th ed. Prentice Hall, New Jersey.

Bremner, J.M. and Douglas, L.A. 1971. Inhibition of urease activity in soils. *Soil Biol. & Biochem.* 3: 297.

Bremner, J.M. Mulvaney, C.S. 1978. Urease activity in soils. In: burns, R.G. (ed) *Soil enzymes*. Academic Press, London, pp. 149-197.

Broadbent, F.E., Hill, G.N. and Tyler, K.B. 1958. Transformations and movement of urea in soils. *Soil Sci. Soc. Am. Proc.* 2: 303-307.

Broadbent, F.E. and Nakashima, T. 1971. Nitrogen immobilization in flooded soils. *Soil Sci. Soc. Am. Proc.* 34: 218-221.

Brock, T.D. and Madigan, M.T. 1988. Biology of Microorganisms, fifth edition, Prentice Hall International Inc, London.

Brookes, P.C., Powlson, D.S. and Jenkinson, D.S. 1982. Measurement of microbial biomass phosphorus in soil. *Soil Biol. & Blochem.* 14: 319-329.

Brookes, P.C., Landman, A., Pruden, G. and Jenkinson, D.S. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biol. & Biochem.* 17: 837-842.

Brookes, P.C. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. *Biol. Fertil. Soils.* 19:269-279.

Buchanan, M.A. 1990. *Carbon and phosphorus cycling in no-till and reduced chemical input maize agroecosystems: Experimental and simulation analysis.* Ph.D. Diss. North Carolina State Univ., Raleigh.

Burangulova, M.N. and Khaziev, F.H. 1965. Nuclease activity of soil. *Soviet Soil Science.* 13: 1523-1526.

Burket, J.Z. and Dick, R.P. 1998. Microbial and soil parameters in relation to N mineralization on soils of diverse genesis under different management systems. *Biol. Fertil. Soils.* 7: 430-438.

Burns, R.G. 1978. *Soil enzymes.* Academic Press, London.

Burns, R.G. 1982. Enzyme activity in soil. Location and possible role in microbial activity. *Soil Biol. & Biochem.* 14: 423-427.

Cabarello-Mellado, J. and Martinez-Romero, E. 1999. Soil fertilization limits the genetic diversity of Rhizobium in bean nodules. *Symbiosis.* 26: 111-121.

Campbell, C.A. 1978. Soil organic carbon, nitrogen and fertility. In: Schnitzer M. Khan SU (eds). *Soil organic matter.* Elsevier, New York, pp. 173-321.

Cambell, C.A. and Biederbeck, V.O. 1976. Soil bacterila changes as affected by growing season weather conditions: A field and laboratory study. *Can. J. Soil Science.* 56: 293-310.

Carlyle, J.C. and Than, U.B. 1988. Abiotic controls of soil respiration beneath an eighteen-year-old *Pinus radiata* stand in south-eastern Australia. *J. Ecol.* 76: 654-662.

Caroll, B.J. and Mathews, A. 1990. Nitrate inhibition of nodulation in legumes. In *Molecular Biology of Symbiotic Nitrogen Fixation.* Ed P.M. Gresshoff. pp. 159-180. CRC Press, Boca Raton, FL.

Casida, L.E. Jr., Klein, D.A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98: 371-376.

Casida, L.E. 1977. Microbial metabolic activity in soil as measured by dehydrogenase determination. *Appl. Environ. Microb.* 34: 630-636.

Cassman, K.G and Pingali, P.L. 1995. Extrapolating trends from long-term experiments to farmer fields: The case of irrigated rice systems in Asia. Pp. 63-84. In: Agricultural Sustainability in Economic, Environmental and Statistical Terms, Marnett, V., R. Payne, and R. Steiner, (eds.). Wiley, London, pp. 63-84.

Cavellier, J. and Penuela, M.C. 1990. Soil respiration in the cloud forest and dry deciduous forest of Cerrania de Macuira, Colombia. *Biotropica.* 22: 345-352.

Cheng-Sheng Tsai, Killham, K. and Cresser, M.S. 1997. Dynamic response of microbial biomass, respiaration rate and ATP to glucose additions. *Soil Biol. & Biochem.* 29: 1249-1256.

Chin, W.T. and kroontje, W. 1963. Urease hydrolysis and subdequent loss to ammonia. *Soil Sci. Soc. Am. Proc.* 27: 316-318.

Christensen, M. 1989. A view of fungal ecology, *Mycologia.* 81: 1-19.

Christie, P. and Beattie, J.A.M. 1989. Grassland soil microbial biomass and accumuation of potentially toxic metals from long-term slurry application. *J Appl Ecol.* 26: 597-612.

Chrost, R.J. 1991. Environmental control of the synthesis and activity of aquatic microbial ectoenzymes. In: Chrost, R.J. (Ed.), *Microbial Enzymes in Aquatic Environments.* Springer-Verlag, New York, pp. 29-53.

Cisse, L.M. 1986. *Etude des effect d' apports de matiere organique sur les bilans hydriques et et. la production du mil et de l'arachide sur un sol sableaux degrade du center-nord du Senegal.* These Doct. Sc. Agro., INPL, Nancy, France.

Clarholm, M. and Rosswall, T. 1980. Biomass and turnover of bacteria in forest soil and peat. *Soil Biol. & Biochem.* 12: 49-57.

Clark, F.E. and Paul, E.A. 1970. The microflora of grassland. *Adv. Agron.* 22: 375-435.

Colting, R.D. 1997. Revitalizing degraded soils for organic farming of vegetables. *Philippine-Journal-of-Crop-Science* (Philippines). 22(supplement no. 1) p. 31.

Conyers, M. K., Uren, N. C. and Helyar, K. R. 1995. Causes of changes in pH in acidic mineral soils. *Soil Biol. & Biochem.* 27 (11): 1383-1392.

Consuelo Quilchano and Teodoro Marañón. 2002. Dehydrogenase activity in Mediterranean forest soils. *Biol. Fertil. Soils.* 35: 102-107.

Cook, G.W. 1969. Fertilizers in 2000 AD phosphorus in Agriculture, Bull. Doc. No. 53. *International superphosphate and compound manufacturer's Association,* Paris. 1-13.

Cropper, W.P. Jr., Katherine, C.E. and James, W.R. 1985. The measurement of soil carbon-dioxide evolution *in situ. Pedlobiologia,* 28: 35-40.

Curl, E.A. and Truelove, B. 1986. *The Rhizosphere,* pp. 9-54. Springer-Verlag. New York.

Dalal, R.C. 1975. Urease activity in some Trinidal soils. *Soil Biol. & Biochem.* 7: 5-8.

Dash, M.C., Mishra, P.C., Mohanty, R.K. and Bhatt, N. 1981. Effects of specific conductance and temperature on urease activity in some Indian soils. *Soil Biol. & Biochem.* 13: 73-74.

Das, P.K. 1980. *Microbial decomposition of pine (Pinus kesia D.) litter: an ecological study. Ph.D. Thesis, North Eastern Hill University, Shillong, India, pp-233.*

Das, P.K. and Mishra, R.R. 1986. Dehydrogenase activity and CO_2 evolution from pine (*Pinus kesiya* Ex-Gordon) forest soil. *Geobios.* 13: 12-15.

Dedalauri, T.G. 1975. Effect of ecological factors on the vertical distribution of micromycetes in the soils of eastern Georgian USSR. *Mikol. Fitol. Patol.* 9: 327-331.

Deng, S.P. and Tabatabai, M.A. 1996 a. Effect of tillage and residue management on enzyme activities in soils. I Amidohydrolases. *Biol. Fertil. Soils.* 22:202-207.

Deng, S.P. and Tabatabai, M.A. 1996. Effect of tillage and residue management on enzyme activities in soils. II Glycosidases. *Biol. Fertil. Soils.* 22:208-213.

Deng, S.P. and Tabatabai, M.A. 1997. Effect of tillage and residue management on enzyme activities in soils. III Phosphatases and arylsulphatase. *Biol Fertil Soils.* 22:208-213.

De Vos, J.A., Raats, P.A.C. and Vos, E.C. 1994. Microscopic soil physical processes considered within an agronomical and a soil biological context. *Agric. Ecosyst. & Environ.* 51: 43-73.

Dick, R.P., Rasmusen, P.E. and Kerle, E.A. 1988. Influence of long-term residue management on soil enzyme activities in relation to soil chemical properties of a wheat-fallow system. *Biol. Fertil. Soils.* 6: 159-164.

Dick, R.P. 1992. A review: Long term effect of agricultural system on soil biochemical and microbial parameters. *Agric. Ecosyst. & Environ.* 40: 25-36.

Dick, W.A. and Tabatabai, M.A. 1992. Potential uses of soil enzymes. In: Metting, B. (Ed). *Soil Microbial Ecology,* Mercel Dekker, New York, pp. 95-127.

Dick, R.P. 1994. Soil enzymes activities as indicator of soil quality. *In*: Doran, J.W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A. (Eds.). *Defining soil quality for a sustainable environment.* Soil Science Society of America. Madison, Wis. Pp.107 – 124.

Dick, R.P., Breakwill, D. and Turco, R. 1996. Soil enzyme activities and biodiversity measurements as integrating biological indicators. *In: Doran, J.W., Jones, A.J.* (Eds.). *Handbook of Methods for Assessment of Soil Quality.* Soil Science Society America. Madison, pp. 247-272.

Dick, R.P. 1997. Soil enzymes activities as integrative indicator of soil health. *In*: Pankhurst, C.E., Doube, B.M, Gupta, V.V.S.R. (Eds.).*Biological indicators of soil health.* CAB International, New York, pp121-156.

Dick, R.P., Rasmusen, P.E. and Kesle, E.A. 1998. Influence of long-term residue management on soil enzyme activities in relation to soil chemical properties of a wheat fallow system. *Biol. Fertil. Soils.* 6: 1259-1264.

Difco Manual. 1953. Difco laboratories, Defroit, Mich.

Dkhar, M.S. and Mishra, R.R. 1987. Microbial population, fungal biomass and CO_2 evolution in maize (Zea mays L.) field soils. *Plant and soil.* 99: 227-233.

Domsch, K.H., Gams, W. and Anderson, T.H. 1980. *Compendium of soil fungi.* Academic Press, London.

Domsch, K.H. 1986. Influence of management on microbial communities in soil. In: V. Jensen, A., Kjoller, A. and Sorensen, L.H., *Microbial communities in soil.* London, Elsevier Appl. Sci. Publ.,105 – 112.

Dooley, M. and Dickinson, C.H. 1970. *Plant Soil.* 32: 454-467.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distribution in no-tillage and plowed soils. *Biol. Fertil. Soils.* 5: 68-75.

Doran, J.W. and Parkin, T.B. 1994. Defining and Assessing Soil Quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.). *Defining soil quality for a sustainable environment.* Soil Science Society of America. Madison, pp.3-21.

Dutta, B,G. and Ghosh, G.R. 1964. Soil fungi from Orissa (India) IV. Soil fungi of paddy fields. Mycopath. *Mycol. Appl.* 25: 316-321.

Duxbury, J.M., Smith, M.S. and Doran, J.W. 1989. Soil organic matter as a source and sink of plant nutrients. In: *Dynamic of Soil Organic Matter in Tropical Ecosystem.* Eds D.C. Coleman, J.M. Oades and G. Uehara, pp. 33-67. University of Hawai Press. Honolulu.

Elliot, L.F. and Lynch, J.M. 1994. Biodiversity and soil resillience. In: *Soil resilience and sustainable land use*, ed. D.J. Greenland & I. Szaboles. pp.353-364. CAB International, London.

Ennik, G.C., Gillet, M. and Sibma, L. 1980. Effect of high nitrogen supply on sward deterioration and root mass. In: Rinns, W.H., Arnold, G.H. (eds) *The role of N in intensive grassland production Pudoc.* Wageningen, pp 67-76.

Eriksen, J. and Jensen, L. S. 2001. Soil respiration, nitrogen mineralization and uptake in barley following cultivation of grazed grasslands. *Biol. Fertil. Soils.* 33(2): 139-145..

Fauci, M.F. and Dick, R.P. 1994. Soil microbial dynamics: short- and long-term effects of inorganic and organic nitrogen. *Soil Sci. Soc. Am. J.* 58: 801-806.

Feher, D. 1933. Untersuchungen uber die Mikrobiologie des waldbodens. Springer, Berlin.

Fierer, N., Schimel, J.P. and Holden, P.A. 2003. Variation in microbial community composition through two soil depth profiles. *Soil Biol. & Biochem.* 35: 167-176.

Fog, K. 1988. The effect of added nitrogen on the rate of decomposition of organic matter. *Biol. Rev.* 63: 433-462.

Frankenberger, W.T. Jr. and Dick, W.A. 1983. Relationships between enzyme acrivities and microbial growth and activity indices in soil. *Soil Science Soc. Am. J.* 47: 945-951.

Franzluebbers, A.J., Hons, F.M. and Zuberer, D.A. 1995. Tillage and crop effects on seasonal dynamics of soil CO_2 evolution, water content, temperature, and bulk density. *Applied Soil Ecology.* 2(2): 95-109.

Fraser, D.G., Doran, J.W., Sahs, W.W. and Lesoing, G.W. 1988. Soil microbial populations and activities under conventional and organic management. *J. of Env. Quality.* 17: 585-590.

Frey, S.D., Elliott, E.T. and Paustian, K. 1999. Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. *Soil Biol. & Biochem.* 3: 573-585.

Fujisaka, S. 1990. Rainfed lowland rice: building research on farmer practice and technical knowledge. *Agric. Ecosyst. Environ.* 33: 57-74.

Gaarder, T. 1957. *Studies in Soil Respiration in Western Norway,* The Bergeen District (Naturvitenskapelig rekks Nr. 3). Universitetet I Bergeen Arbok.

Garbaye, J. and Le Tacon, F. 1982. Influence of mineral fertilization and thinning intensity on the fruit body production of geous fungi in an artificial spruce stand (Picea excelsa Link) in north eastern France. *Acta Ecol. Planta.* 3: 153-160.

Garcia, C., Hernandez, T., Costa, F., Ceccanti, B. and Masciandaro, G. 1993. Kinetics of phosphatase activity in organic wastes. *Soil Biol. & Biochem.* 25(5): 561-565.

Garcia-Gil, J.C., Plaza, C., Soler-Rovira, P. and Polo, A. 2000. Long-term effects of municioal solid waste compost appliocation on soil enzyme activities and microbial biomass. *Soil Biol. & Biochem.* 32: 1907-1913.

Garlang, J.I. 1997. Analysis and interpretation of community level physiological profiles in microbial ecology. *FEMS Microbiology Ecology.* 24: 289-300.

Gasser, J.K.R. 1964. Urea as a fertilizer. *Soils Fertilizer.* 27: 175-180.

Ghathak, P.N. and Roy, T.C. 1939. Studies in the soil fungi of the paddy fields of Bengal. 1. Fungi of an unmanured paddy field of the Chinsurah agricultural farm. *J. Ind. Bot. Soc. 18: 113-127.*

Ghoshal, N. and Singh, K.P. 1994. The influence of soil amendments on the proportion of organic carbon and nitrogen in the microbial biomass in a dry land agroecosystem. *Tropical Ecology.* 35: 309-319.

Giller, K.E., Beare, M.H., Lavelle, R., Izac, A.M.N. and Swift, M.S. 1997. Agricultural intensification, Soil biodiversity and agro ecosystem function. *Applied soil Ecol.* 6: 3-16.

Goyal, S., Mishra, M.M., Hooda, I.S. and Sing, R. 1992. Organic matter-microbial biomass relationship in field experiment under tropical conditions. Effect of inorganic

fertilization and organic manure amendments. *Soil Biol. & Biochem.* 24: 1081-1084.

Goyal, S., Chander, K., Mundra, M. C. & Kapoor, K. K 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. *Biol. Fertil. Soils.* 29 (2): 196-200.

Gray, T.R.F. and Williams, S.T. 1971. Microbial productivity in soil. *Symposium of the society of general Microbiology.* 21: 255-286.

Gray, T.R.G. 1976. Survival of vegetative microbes in soil. *Symposia of the Society for General Microbiology.* 26: 327-367.

Grayston, S.J., Wang, S.Q., Campbell, C.D. and Edwards, C.D. 1998. Selective influence of plant species on microbial diversity in the rhizosphere. *Soil Biol. & Biochem.* 30: 369-378.

Gregorich, E.G., Rochette, P., McGuire, S., Liang, B.C. and Lessard, R. 1998. Soluble organic and carbon dioxide fluxes in maize fields receiving spring-applied manure. *J. Environ. Quality.* 27: 209-214.

Gupta, S.R. and Singh, J.S. 1977. Effect of alkali concentration, volume and absorption area on the measurement of soil respiration in a tropical sward. *Pedobiologia.* Bd. 17S: 233-239.

Gupta, S.R. 1992. Nitrogen mineralization and immobilization transformation in soil, pp. 28. In: *Commission of the European Communities Consolidated Report of Activities 1988-1990 EC-India.* E CSC-EEC-EAEC, Brussels, Luxembourg.

Gupta, S.R. and Singh, J.S. 1981. Soil respiration in tropical grassland. *Soil Biol. & Biochem.* 13: 261-268.

Gupta, S.R. & Malik, V. 1996. Soil ecology and sustainability. *Tropical Ecology.* 37(1): 43-55.

Harrison, A.F. 1979. Variation of four phosphorus properties in woodland soils. *Soil Biol. & Biochem.* II: 393-403.

Harrison, A.F. and Pearce, T. 1979. Seasonal variation in phosphatase activity in woodland soils. *Soil Biol. & Biochem.* 11: 405-410.

Harris, R.F. 1981. Effect of water potential on microbial growth and activity. In *Water potential relations in soil microbiology.* (J.F. Parr, W.R. Gardner and C.F. Elliot, Eds.) pp. 23-95. Soil Science Society of America Special Publication Number of Madison.

Hassink, J. 1992. Effects of soil texture and structure on carbon and nitrogenmineralisation in grassland soils. Biol. Fertil. Soils. 14: 126-134.

Hassink, J. 1994. Effect of soil texture on the size of the microbial biomass and on the amount of C and N mineralized per unit of microbial biomass in Dutch grassland soils. *Soil Biol. & Biochem.* 26: 1573-1581.

Hassink, J. 1997. The capacity of soils to preserve C and N by their association with clay and silt particles. *Plant and Soil.* 191: 77-87.

Hatch, D. J. Lovell, R. D. Antil, R. S. Jarvis, S. C. Owen, P. M. 2000. Nitrogen mineralization and microbial activity in permanent pastures amended with nitrogen fertilizer or dung. *Biol. Fertil. Soils.* 30 (4): 288-293.

Hattori, T. 1973. *Microbial Life in Soil.* An Introduction. Marcel Dekker Inc. New York. Pp. 97.

Hayashi, S. and Furusaka, C. 1979. Studies on Propioni bacterium isolated from paddy soils. *J. Microbiol.* 45: 565-574.

Hazarika, U.K., Singh, R. and Singh, N.P. 2001. *Ecological Distribution of Weed Flora in Meghalaya: Their Intensity of Occurrence in Field Crops and Management.* Division of Agronomy ICAR Research Complex for NEH Region, India. Pp. 16.

Heathcote, R.G. 1970. Soil fertility under continuous cultivation in northern Nigeria. I. The role of organic manure. *Exp. Agric.* 6: 229-237.

Hendrix, P.F., Crossley, D.A. Jr., Blair, J.M. & Coleman, D.C. 1990. Soil biota as a component of sustainable agroecosystems. Pp. 637-654. In: C.A. Edwards *et al.* (eds.) *Sustainable Agriculture Systems.* Soil and Water Conservation Society. Ankeny, Iowa.

Hengeveld, R. 1996. Measuring Ecological biodiversity. *Biodiv. Etteers.* 3: 58-65.

Henrot, J. and Robertson, G.P. 1994. Vegetation removal in two soils of humid tropics: Effects on microbial biomass. *Soil Biol. & Biochem.* 26(1): 111-116.

Hino, S. 1989. Characterization of orthophosphate release from dissolved organic phosphorous by gel filtration and several hydrolytic enzymes. *Hydrobiologia.* 174: 49-55.

Hoffman, G. and Elias-Azar, K. 1965. Various soil fertility factors of north Persian soils and their connection with the activity of hydrolytic enzymes. *Zeitschrift fur Pflanzenernahrung Dungung und Bodenkunde.* 108: 199-217.

Hopkins, D.W. and Shiel, R.S. 1996. Size and activity and soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. *Biol. Fertil. Soils.* 22: 66-70.

Hu, S., Coleman, D.C., Carroll, C.R., Hendrix, P.F. and Beare, M.H. 1997. Labile soil carbon pools in subtropical forest and agricultural ecosystems as influenced by management practices and vegetation types. *Agric. Ecosyst. Enviro.* 65: 69-78.

Hu, S.J., van Bruggen, A.H.C and Grünwald, N.J. 1999. Dynamics of bacterial populations in relation to carbon availability in a residue-amended soil. *Applied Soil Ecology.* 13(1): 21-30.

Insam, H. and Domsch, K.H. 1988. Relationship between soil organic carbon and microbial biomass carbon on chronosequences of reclamation sites. *Microb. Ecol.* 15: 177-188.

Insam, H. and Haselwandter, K.H. 1989. Metabolic quotient of the soil microflora in relation to plant succession. *Oecologia.* 79: 174-178.

Insam, H., Mitchell, C.C. and Dormaar, J.F. 1991. Relationship of soil microbial biomass and activity with fertilization practice and crop yield of three Ultisols. *Soil Biol. & Biochem.* 23: 459-464.

Ishaq, M. Ibrahim, M. and Lal, R. 2002. Tillage effects on soil properties at different levels of fertilizer application in Punjab, Pakistan. *Soil Tillage Res.* 68(2): 93-99.

Islam, A., Mandal, R. and Osman, K.T. 1979. Direct absorption of organic phosphate by rice and jute plants. *Plant Soil.* 53: 49-54.

Izaguirre-Mayoral, M. L., Flores, S. and Carballo, O. 2002. Determination of acid phosphatase and dehydrogenase activities in the rhizosphere of nodulated legume species native to two contrasting savanna sites in Venezuela. *Biol. Fertil. Soils.* 35: 470-472.

Jackson, M.L. 1973. *Soil chemical analysis.* New Delhi, Prentice Hall India (P) Limited.

Jalaluddin, M. 1975. Study of microorganisms from root region of rice. *Plant and Soil.* 43: 337-345.

James, D.W., Kotuby-Amacher, J., Anderson, G.L. and Huber, D.A. 1996. Phosphorus mobility in calcareous soil under heavy manuring. *J. Environ. Qual.* 25: 770-775.

Jenkinson, D.S. 1988. Determination of microbial carbon and nitrogen in soil, pp. 368-386. In: J.B. Wilson (ed.) *Advance in Nitrogen Cycling.* CAB International, Wallingford, England.

Jenkinson, D.S. and Powlson, D.S. 1976. The effect of biological treatment on metabolism in soil. V. Method of measuring soil biomass. *Soil Biol. & Biochem. 8: 209-213.*

Jenkinson, D.S. and Ladd, J.N. 1981. Microbial biomass in soils: measurement and turnover. In: *Soil Biochemistry, Vol. 5* (E.A. Paul and J.N. Ladd, Eds.). Pp. 415-471. Marcel Dekker, New York.

Jenkinson, D.S. and Parry, L.C. 1989. Nitrogen cycle in the broadbalk wheat experiment: A model for the turnover of nitrogen through the soil microbial biomass. *Soil Biol. & Biochem.* 21: 535-541.

Jensson, S.L and Persson, J. 1982. Mineralization and immobilization of soil nitrogen. In: *Nitrogen in agricultural soil.* (F.J. Stevenson, Ed.) Agronomy No 22, pp. 229-252. American Society of Agronomy, Madison.

Jones, P.C.T. and Mollison, J.E. 1948. A technique for quantitative estimation of soil micro-organisms. *J. Gen. Microbiol.* 27: 273.

Jones, S., Rees, B. and Skiba, U. 2003. Grassland management and soil emissions of CO_2, N_2O and CH_4. 5th International Workshop on Field Technique for Environmental Physiology, Tenerife.

Jordan, D., Kremer, R.J., Bergfield, W.A., Kim, K.Y. and Cacnio, V.N. 1995. Evaluation of microbial methods as a potential indicators of soil quality in historical agricultural fields. *Biol. Fertil. Soils.* 19: 297-302.

Julia, G. and Pedziwilk, Z. 1985. Carbon-dioxide release as an index of biological activity of cultivated soils. *Acta. Microbiol. Pol.* 33: 249-256.

Jurik, T.W., Briggs, G.M. and Gates, D.M. 1991. Soil respiration of five aspen stands in northern Lower Michigan. *American Midland Naturalist.* 126: 68-75

Kahindi, J.H.P., Woomer, P., George, T., de Souza Moreira, F.M., Karanja, N.K. and Giller, K.E. 1997. Agricultural intensification, soil biodiversity and ecosystem function in the tropics: the role of nitrogen-fixing bacteria. *Applied Soil Ecology.* 6(1): 55-76.

Kaiser, E.A., Muller, T., Joergensen, R.G., Insam, H. and Heinemeyer, O. 1992. Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. *Soil Biol. & Biochem.* 24: 675 – 683.

Kampichler, C., Kandeler, E., Bardgett, R., Jones, T.H. and Thompsons, J. 1998. Impact of elevated atmospheric CO_2 concentration on soil microbial biomass and activity in a complex, weedy field model system. *Global Change Biol.* 4: 335-346.

Kandeler, P.M.E. and Marschner, B. 2003. Structure and function of the soil microbial community in a long-term fertilizer experiment. *Soil Biol. & Biochem.* 35(3): 453-461.

Kang, B.T. 1993. Changes in soil chemical properties and crop performance with continuous cropping on an Entisol in the humid tropics. In: mulongoy, K., Merckx, R. (Eds.), *Soil organic matter dynamic and sustainability of tropical agriculture.* John Wiley and sons, New York. pp. 297-305.

Kang, H. and Freeman, C. 1999. Phosphatase and arylsulphatase activities in wetland soils: annual variation and controlling factors. *Soil Biol. & Biochem.* 31: 449-454.

Katayama, A., Hu, H-Y., Nozawa, M., Yamakawa, H. and Fujie, K. 1998. Long-term changes in microbial community structure in soils subjected to different fertilizing practices revealed by quinine profile analysis. *Soil Science and Plant Nutrition.* 44: 559-570.

Kaufman, D.D. and William, L.E. 1964. Effect of mineral fertilization and soil reaction on soil fungi. *Phytopathology.* 54: 134-139.

Keeney, D.R., Sahrawat, L.L. and Susans, A. 1985. CO_2 concentration in soil. Effects on nitrification denitrification and associated nitous oxide production. *Soil Biol. & Biochem.* 17: 571-574.

Keith, H., Jakobson, K.L. and Ravson, R.J. 1997. Effect of soil phosphorus availability, temperature and moisture on soil respiration in and *Eucalyptus pauciflora* forest. *Plant and Soil.* 190: 127-141.

Kennedy, A.C. and Smith, K.L. 1995. Soil microbial diversity and the sustainability of agricultural soils. *Plant and Soil.* 170: 75-86.

Kennedy, A.C. 1998. The rhizosphere and spermosphere. In: Sylvia, D.M., Fuhrmann, J.J., Hartel, P.G., Zuberer, D.A. (Eds.). *Principal and Applications of Soil Microbiology.* Prentice Hall, Upper saddle River, New Jersey, pp. 389-407.

Khan, S.U. 1970. Enzymatic activity in grey wooded soil as influenced by cropping systems and fertilizers. *Soil Biol. & Biochem.* 2: 137-139.

Kirchner, M.J., Wollum. I.I. A.F. and King, L.D. 1993. Soil microbial populations and activities in reduced chemical input agro- ecosystem. *Soil Sci. Soc. Am. J.* 57:1289 -1295.

Kiss, S.M., Dragan-Bularda, M. and Radulescu, D. 1975. Biological significance of enzymes accumulated in soil. *Advance in Agronomy.* 27: 25-87.

Klein, D.A., Metzger, W.C., Frederick, B.A. & Redente, E.F. 1986. Environmental stress functional diversity relationships in semiarid terrestrial microbial communities. In: *Microbial communities in soil*, ed. V. Jensen, A. Kjoller and L.H. Sorensen. Pp. 105-112. Elsevier Applied Science Publisher, London.

Klose, S., Moore, J.M. and Tabatabai, M.A. 1999. Arylsulphatase activity of microbial biomass in soils as affected by cropping systems. *Biol. Fertil. Soils.* 29: 46-54.

Klose, S. and Tabatabai, M. A. 2000. Urease activity of microbial biomass in soils as affected by cropping systems. *Biol. Fertil. Soils.* 31(¾): 191-199.

Kostava, M.S. and Tsilosani, G.A. 1985. Determining the numbers of microorganisms in soils in order to evaluate their biological potential. *Dokl. Vse. Ordena. Lenina. Ordena. Trud. Krasnoyo. Znameni. Akad. S.Kh. Nauk. Im. Vl Zenina*, 4: 19-20.

Krebs, C.J. 1989. *Ecological Methodology.* Harper and Row, New York.

Kshattriya, S., Sharma, G.D. Mishra, R.R. 1992. Enzymes activity related to litter in forests of different age and altitude in North-East India. *Soil Biol. & Biochem.* 24: 265-270.

Kuprevich, V.F. 1951. The biological activity of soils and methods for its determination. Dokl. Akad. Nauk. *SSSR.* 79: 863-866.

Kursar, T.A. 1989. Evaluation of soil respiration and soil CO_2 concentration in a lowland moist forest in Panama. *Plant and Soil.* 113: 21-29.

Kuske, C.R., Barns, S.M. and Busch, J.D. 1997. Diverse uncultivated bacterial group from soils of the arid Southwestern United States that are present in many geographic regions. *Appl. Environ. Microbiol.* 63: 3614-3621.

Kuster, E. and Gardiner, J.J. 1968. *Influence of fertilizers on microbial activities in peat land.* Ref: Ph.D Thesis S.K. Grover 1977. Gorakhpur University, Gorakhpur.

Ladd, J.N. 1978. Origin and range of enzymes in soil. In: Burns, R.G. (Ed.), *Soil Enzymes.* Academic Press. London, pp. 51-96.

Ladd, J.N., Amato, M., Li-Kai, Z. and Schultz, J.E. 1994. Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian alfisol. *Soil Biol. & Biochem.* 26: 821-831.

Ladd, J.N., Amato, M., Grace, P.R. and Van Veen, J.A. 1995. Simulation of ^{14}C turnover through the microbial biomass in soils incubated with ^{14}C-labeled plant residues. *Soil Biol & Biochem.* 27: 777-783.

Lahav (Lavian), I. and Steinberger, Y. 2001. Soil bacterial functional diversity in a potato field. *European Journal of Soil Biology.* 37(1): 59-67.

Larson, W.E. and Pierce, F.J. 1994. The dynamic of soil quality as a measure of sustainable management, pp. 37-51. In: J.W. Doran, D.C. Coleman, D.F. Bezdicek and B.A. Steward (eds.) *Defining Soil Quality for a Sustainable Environment* SSSA special publication. Number 36, USA.

Latter, P.M., Cragg, J. and Band Heal, O.W. (1967): Comparative studies on the microbiology of mooland soils in the Northern Pennines. *J. Ecol.* 55: 495-464.

Lavahun, M.F.E., Joergensen, R.G. and Meyer, B. 1996. Activity and biomass of soil microorganisms at different depths. *Biol. Fertil. Soils.* 23: 38 – 42.

Lavelle, P.M., Dangerfield, C., Fragoso, V., Eschenbrenner, D., Lopez-Hernandez, B., Pashanasi & Brussaard, L. 1994. The relationship between soil microfauna and tropical soil fertility, pp. 137-169. In: P.L. Woomer & M.J. Swift (eds.).*The Biological Management of Tropical Soil Fertility.* John Wiley & Sons, U.K.

Lee, K.E. and Pnakhurst, C.E. 1992. Soil organisms and sustainable productivity. *Aus. J. Soil Res.* 30: 855-892.

Leiros, M.C., Trasar-Cepeda, C., Seoane, S. and Gil-Sotres, F. 2000. biochemical properties of acid soils under climax vegetation (Atlantic Oakwood) in an area of the European temperate-humid zone (Galicia, NW Spain): general parameters. *Soil Biol. & Biochem.* 32: 733-745.

Lenhard, V.G. 1956. Die dehydrogenase aktivitat de Bondens als Mass fur die Mikroorganisms entatigkeit in Boden. *Zeitschrift fur pflanzenernabrung Dungung Bodenkunde.* 73: 1-11.

Lewis. D.C., Potter, T.D. & Weckert, S.E. 1991. The effect of nitrogen, phosphorous and potassium fertilizer application on the seed yield of sunflower (*Helianthus annuus* L.) grown on sandy soil and the prediction of phosphorous and potassium responses by soil tests. *Fertilizer Research.* 28: 185-190.

Liaghat, M. and Prasher, S.O. 1996. A lysimeter study of grass cover and water table depth effects on pesticide residue in drainage water. *Am. Soc. Agric. Engrs.* 39: 1731-1738.

Liang, B.C., Mackenzie, A.F., Schnitzer, M., Monreal, C.M. Voroney, P.R. and Beyaert, R.P. 1998. Management-induced change in labile soil organic matter under continous corn in eastern Canadian soils. *Biol. Fertil. Soils.* 26: 88-94.

Lie, T. 1981. Environmental physiology of the legume-*Rhizobium* sysbiosis. In: Broughton, W.J. (Ed.). *Nitrogen Fixation* Vol. I: Ecology. Clarendon Press, Oford, pp. 104-134.

Liljeroth, E., Baath, E., Mathiasson, I. And Lundborg, T. 1990. Root exudation and rhizoplane bacterial abundance of barley (*Hordeum vulgare* L.) in relation to nitrogen fertiliser and root growth. *Plant and Soi.* 127: 81-89.

Lima, J.A., Nahas, E. and Gomes, A.C. 1996. Microbial populations and activities in sewage sludge and phosphate fertilizer-amended soil. *Applied Soil Ecology.* 4(1): 75-82.

Linn, D.M. and Doran, J.W. 1984. Effect of water filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Soc. Am. J.* 48: 1267-1272.

Lloyd, A.B. and Sheaffe, M.J. 1973. Urease activity in soils. *Plant and Soil.* 39: 71-80.

Lovejoy, T.E. 1994. The quantification of biodiversity an esoteric quest or a vital component of sustainable development? *Phil. Trans. R. Soc. lond.* 345: 81-87.

Lovell, R.D., Jarvis, S.C. and Bardgett, R.D. 1995. Soil microbial biomass and activity in a long-term grassland: effects of management changes. *Soil Biol. & Biochem.* 27: 969-975.

Lovell, R.D. and Jarvis, S.C. 1996. Effect of cattle dung on soil microbial biomass C and N in a permanrnt pasture soil. *Soil Biol. & Biochem.* 28: 291-299.

Lundegardh, H. 1927. Carbon dioxide evolution of soil in crop growth. *Soil Science.* 23: 417-453.

Luizao, R.C.C., Bonde, T.A. and Rosswall, T. 1992. Seasonal variation of soil microbial biomass- The effects of clear felling a tropical rain forest and establishment of pasture in the Central Amazon. *Soil Biol. & Biochem.* 24: 805-813.

Lynch, J.M. and Bragg, E. 1985. Microorganisms and aggregate stability. *Adv. Soil Sci.* 2: 133-171.

Lynch, J.M. and Whipps, J.M. 1990. Substrate flow in the rhizosphere. *Plant and Soil.* 129: 1-10.

Maccio, D., Fabra, A. and Castro, S. 2002. Acidity and calcium interaction affect the growth of Bradyrhizobium sp. and the attachment to peanut roots. *Soil Biol. & Biochem.* 34: 201-208.

Macfadyen, A. 1970. Soil metabolism in relation to ecosystem energy flow and to primary and secondary production. In: *Method of study in soil Ecology.* Proceeding of the Paris symposium. UNESCO, J. (Ed). I.B.P. 167- 172.

Macura, J. 1958. *Cesk. Mikrobiol.* 3: 17-26.

Maggs, J. and Hewett, B. 1990. Soil and litter respiration in rain forest of contrasting nutrient status and physiognomic structure near lake Eacham, north-east Queensland. *Aus. J. Ecol.* 15: 329-336.

Mahmood, T., Azak, F. Hussian, F. and Malik, K.A. 1997. Carbon availability and microbial biomass in soil under irrigated wheat-maize cropping system receiving different fertilizer treatments. *Biol. Fertil. Soils.* 25: 63-68.

Maithani, K. 1996. *Microbial nutrient dynamics and mineralization in degraded subtropical forest ecosystems undergoing recovery.* Ph. D thesis, North Eastern Hill University, Shillong.

Manna, M.C. and Ganguli, T.K. 1997. Soil biological activity and yield of crops as influenced by compost and inorganic fertilizers under cereal-legume on a typic Haplustert. *J. Soil Biol. Ecol.* 17: 88-94.

Mao, D.M., Min, Y.W., Yu, L.L., Martens, R. and Insam, H. 1992. Effect of afforestation on microbial biomass and activity in soils of tropical China. *Soil Biol. & Biochem.* 24: 865-872.

Martikainen, P. and Palojarvi, A. 1990. Evaluation of the fumigation extraction method for the determination of microbial biomass C and N in a range of forest soils. *Soil Biol. & Biochem.* 22 : 797 – 802.

Martin, J.P. 1950. Use of acid, rose Bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science.* 69: 215-232.

Martyniuk, S. and Wagner, G.H. 1978. Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Sci.* 125: 343-350.

Marumoto, T., Anderson, J.P.E. and Domsch, K.H. 1982. Mineralization of nutrients from soil microbial biomass. *Soil Biol. & Biochem.* 14: 469-475.

Mathan, K.K., Sankaran, K., Kanakabushani, N. and Krishnamoorthy, K.K. 1978. Effect of continuous rotational cropping on the organic carbon and total nitrogen content in a black soil. *J. Ind. Soc. Soil.* 26(2): 283-285.

Mawdsley, J.L. and Bardgett, R.D. 1997. Continuous defoliation of perennial ryegrass (*Lolium perenne*) and white clover (Trifolium repens) and associated changes in the microbial population of an upland grassland soil. *Soil Biol. & Biochem.* 27: 969-975.

Mazzola, M. 1999. Transformation of soil microbial community structure and Rhizoctonia-suppressive potential in response to apple roots. *Phytopathol.* 89: 920-927.

McAndrew, D.W. and Malhi, S.S. 1992. Long-term N fertilization of a solonetzic soil: effects on chemical and biological properties. *Soil Biol. & Biochem.* 27: 1245-1250.

McCarty, G.W., Shogren, D.R. and Bremner, J.M. 1992. Regulation of urease production in soil by microbial assimilation of nitrogen. *Biol. Fertil. Soils.* 12: 261-264.

McGarity, J.W. and Myer, M.C. 1967. A survey of Urease activities in soil of northern new south Wales. *Plant and Soil.* 27: 217-238.

McGill, W.B., Cannon, K.R., Robertson, J.A. and Cook, F.D. 1986. Dynamics of soil microbial biomass and water-soluble organic carbon in Breton L after 50 years of cropping to two rotations. *Can. J. Soil Science.* 66: 1-19.

McLaren, R.G. 1975. Marginal sulphur supplies for grassland herbage on south East Scotland. *J. Agric. Science*, Cambridge, 85 : 571 – 573.

McLaughlin, A. and Mineau, P. 1995. The impact of agricultural practice on biodiversity. *Agri Ecvosyst Environ.* 55: 201-202.

Merrien, A., dechamps, B., Durouchoux, M.J., Maisonneuve, C. and Roux, B. 1989. World Soybean Research Conf. IV Proceedings. (A.J. Pascale, ed.), Orientaction Graficia Editora, Buenos Aires, Argentina, p. 485.

Miller, R.H. 1990. Soil microbiological inputs for sustainable agriculture systems. Pp. 614-623. in: C.A. Edwards *et al.* (eds.) *Sustainable Agriculture Systems.* Soil and Water Conservation Society. Ankeny, Iowa.

Miller, M. and Dick, R.P. 1995. Thermal stability and activities of soil enzymes as influenced by crop rotations. *Soil Biol. & Biochem.* 27: 1161-1166.

Mirchink, T.G. 1988. Soil mycology. Moscow State University, Moscow.

Mishra, R.R. 1966. Influence of soil environments and surface vegetation on soil mycoflora. *Proc. Natl. Acad. Sci. (India).* 26(B): 117-123.

Mishra, R.R. 1971. Effect of certain chemical fertilizers on the rhizosphere mycoflora of *Oryza sativa*. I. Nitrogen fertilizers: Ammonium nitrate and urea. *Mycopath. Et. Mycol. Applic.* 44: 167-176.

Mishra, R.P. and Das, S.N. 1975. Attendant changes in the bacterial flora of rice rhizosphere as influenced by fertilizer treatments. *Plant and Soil.* 42: 359-365.

Moe, P.G. 1967. Nitrogen losses from urea as affected by altering soil urease activity. *Soil Sci. Soc. Am. Proc.* 31: 380-382.

Mogaddeghi, M.R., Hajabbasi, M.A., Henmart, A and Afyumi, M. 2000. Soil compactibility as affected by moisture content and farmyard manure in Central Iran. *Soil Tillage Res.* 55: 87-97.

Moldenhauer, W.C., Wischmeier, W.H. & Parker, D.T. 1997. The influence of crop management on runoff, erosion and soil properties of a Marshall silty clay loam. *Soil Sci. Soc. Am. J.* 31. 541-546.

Moller, H. 1981. Investigation of urease and saccharase activity in relation to soil humus type undertaken in three Melico-Fagetum communities in the Deister Mountain. A contribution toward the determination of enzyme indicator values of soil biological activity. *Flora.* 171: 367-386.

Moore, R., Anderson, A.R., Ray, D., Walker, C., Pyatt, D.G., Evans, H.F., Carter, C.I., Staw, N.A., Warnhouse, D. & Winter, T.G. 1995. *Soil biodiversity: a literature review.* Scotish Natural Heritage. No. 17.

Morrall, R.A.A. 1974. Soil microfungi associated with aspen in Saskatchewan, Synecology and quantitative analysis. *Can. J. Bot.* 52: 1803-1817.

Munda, G.C., Hazarika, U.K., Singh, R.., Sharma, B.K. and Singh, J. 1997. *Groundnut cultivation in North Eastern Hills.* Published by the Director, ICAR Research Complex for NEH Region, Meghalaya, India. Pp. 1.

Murwira, H. & Kirchmann, H. 1993. Carbon and nitrogen mineralization of cattle manures, subject to different treatments, in Zimbabwean and Swedish soils. In: Mulongoy, K., Merckx, R. (Eds.), *Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture.* John Wiley and Sons, New York, pp. 189-198.

Myers, R.J.K., Palm, C.A., Cuevas, E., Gunatilleke, I.U.N. and Brossard, M. 1994. The synchronization of nutrient mineralisation and plant nutrient demand. In: *The Biological Mangement of Tropical Soil Fertility.* (Eds.) P.L. Woomer and M.J. Swift. A Wiley-Sayce Publication.

Nakada, T., Yokozawa, M., Ikeda, H. and Koizumi, H. 2002. Diurnal changes of carbon dioxide flux from bare soil in agricultural field in Japan. *Applied Soil Ecology.* 19(2): 161-171.

Nambiar, K.K.M. 1994. *Soil Fertility and Crop Productivity under Long-Term Fertilizer use in India.* Indian Council of Agricultural Research. New Delhi India.

Nannipieri, P., Johnson, R.L. and Paul, E.A. 1978. Criteria for measurement of microbial growth and activity in soil. *Soil Biol. & Bichem.* 10: 223-229.

Nannipieri, P., Pechozzimi, F., Areada, P.G. and Pioranelli, C. 1979. Changes in amino acids, enzyme activities and biomass during soil microbial growth. *Soil Science.* 127: 26-34.

Nannipieri, P. 1984. Microbial biomass and activity measurements in soil: Ecological significance. In: *Current Perspectives in Microbial Ecology* (M. J. Klug and C. A. Reddy, Eds.) pp 515 –521, American Society for Microbiology, Washington.

Nannipieri, P., Grego, S. and Ceccanti, B. 1990. Ecological significance of biological activity in soil. In: *Soil Biochemistry*, Eds. J.M. Bollag and G. Stotzky. Vol. 6, pp. 293-335. Marcel Dekker, New York.

Nayak, D.C. and Srivastava, R. 1995. Soils of shifting cultivated area in Arunachal Pradesh and their suitability for land use planning. *J. Ind. Soc. Soil Scienc*e. 43: 246-251.

Nilson, J.D. and Eiland, F 1980. Investigation on the relationship between phosphorus fertility, phosphatase activity, and ATP content in soils. *Plant and Soils* 57: 95-103.

Novoa, R. and Loomis, R.S. 1981. Nitrogen and plant production. *Plant and Soil.* 102: 177-204.

Novogrudsky, D.M. 1950. Problems of the intra- and inter-species interrelationships of soil microorganisms. *Agrobiologiya.* 5: 48.

Nusslein, K. and Tiedje, J.M. 1999. Soil bacterial community shift correlated with change from forest to pasture vegetation in a tropical soil. *Appl. Environ. Microbiol.* 65: 3622-3626.

Oades, J.M. and Jenkinson, J.M. 1979. Adenosine triphosphate content of the soil microbial biomass. *Soil Biol. & Biochem.* 11: 201-204.

Odum, E.P. 1971. *Fundamentals of Ecology.* 3rd Edn., WB Saundrs & Co., Tokyo.

Okano, S., Nishio, M. & Sawada, Y. 1987. Turnover rate of soil biomass nitrogen in the root mat layer of pasture. *Soil Science & Plant Nutrition.* 37: 47-53.

Omay, A.B., Rice, C.W., Maddux, L.D. and Gordon, W.B. 1997. Changes in soil microbial and chemical properties under long-term crop rotation and fertilization. *Soil Sci. Soc. Am. J.* 61: 1672-1678.

Orchard, V.A. and Cook, F.J. 1983. Relationship between soil respiration and soil moisture. *Soil Biol. & Biochem.* 15: 447-453.

Osa-Afiana, L.O. and Alexander, M. 1982. Differences among cowpea rhizobia in tolerance to high temperature and desiccation in soil. *Appl. Environ. Microb.* 43: 435-439.

Palma, R.M., Arrigo, N.M., Saubidet, M.E. and Conti, M.E. 2000. Chemical and biochemical properties as potential indicators of disturbances. *Biol. Fertil. Soils.* 32: 381-384.

Pancholy, S.K. and Rice, E.R. 1972. Effect of storage conditions on activities of urease, invertase, amylase and dehydrogenase in soil. *Soil Sci. Soc. Am. Proc.* 30: 536-537.

Pankhurst, C.E., Hawke, B.G., McDonald, H.J., Buckerfield, J.C., Michellsen, P., O'Brien, K.A., Gupta, V.V.S.R. and Doube, B.M. 1995. Evaluation of soil biological properties as potential bioindicators of soil health. *Aus. J. Exp. Agric.* 35: 1015-1028.

Pankhurst, C.E., Ophel-Keller, K., Doube, B.M., and Gupta, V.V.S.R. 1996. Biodiversity of soil microbial communities in agricultural systems. *Biodiversity and Conservation.* 5: 197- 209.

Pant, H.K., Edwards, A.C. and Vaughan, D. 1994. Extraction, molecular fraction and enzyme degradation of organically associated phosphorous in soil solutions. *Biol. Fertil. Soils.* 17: 196-200.

Parham, J.A., Deng, S.P., Raun, W.R. and Johnson, G.V. 2002. Long-term cattle manure application in soil I. Effect of soil phosphorus levels, microbial biomass C, and dehydrogenase and phosphatase activities. *Biol. Fertil. Soils.* 35: 328-337.

Parinkina, O.M. and Klyueva, N.V. 1995. Microbiological aspects of soil deterioration at agricultural practices. *Soil Science.* 5: 573 – 581.

Parker, L.W., Santos, P.F., Philips, J. and Whitford, W.G. 1983. *Carbon and nitrogen dynamics during the decomposition of litter and roots of a Chihuahuren desert annual.* Ecological monographs.

Parkinson, P., Gray, T.R.G. and William, S.T. 1971. Methods for studying the ecology of soil microorganisms. Blackwell Scientific Publication Oxford, p. 116.

Pascula, J.A., Garcia, C., Hernandez, T., Moreno, J.L. and Ross, M. 2000. Soil microbial activity as a biomarker of degradation and remediation processes. *Soil Biol. & Biochem.* 32: 1877-1883.

Paterson, N.V. 1967. Dehydrogenase activity in the soil as a mirror of activity of its microflora. *Mikrobiology.* 36: 518-525.

Patil, R.G. and Sarkar, M.C. 1993. Mineralization and immobilization of nitrogen in soils mixed with wheat straw. *Ind. J. Soil Science.* 41: 33-37.

Paul, E.A. and Clark, F.E. 1989. Soil Microbiology and Biochemistry. Academic Press, New York.

Paulson, K.N. and Kurtz, L.T. 1969. Locus of urease activity in soil. *Proc. Soil Sei. Soc. Am.* 33: 897-901.

Peacock, A.D., Mullen, M.D., Ringelberg, D.B., Tyler, D.D., Hedrick, D.B., Gale, P.M. and White, D.C. 2001. Soil microbial community responses to dairy manure or ammonium nitrate applications. *Soil Biol. & Biochem.* 33: 1011-1019.

Perfect, E., Kay, B.D., Van Loon, W.K.P., Sheard, R.W. and Pojasok, T. 1990. Factors influencing soil structural stability within a growing season. *Soil Sci. Soc. Am. J.* 54: 173-179.

Perrott, K.W., Sarathchandra, S.V. 1989. Phosphorus in the biomass of New Zealand soils under established pasture. *NZ. J. Agric. Res.* 32: 409-413.

Perrott, K.W., Sarathchandra, S.V. and Dow, B.W. 1992. Seasonal and fertilizer effect on the organic cycle and microbial biomass in a hill country soil under pasture. *Aust. J. Soil Res.* 30: 383-394.

Perucci, P. 1992. Enzyme activity and microbial biomass in a field soil amended with municipal refuse. *Biol. Fertil. Soils.* 14: 54-60.

Peterjohn, W.T., Melillo, J.M., Stuedler, P.A., Newkirk, K.M., Bowles, F.P. and Aber, J.D. 1994. Responses of trace gas fluxes and N availability to experimentally elevated soil temperatures. *Ecol. Appl.* 4: 617-625.

Polyanskaya, L.M., Lukin, S.M. and Zvyaginzev, D.G. 1997. Changes of soil microbial biomass composition at soil cultivation. *Soil. Science,* 2: 206 – 212.

Powlson, D.S., Brookes, P.C. and Christenson, B.T. 1987. Measurement of soil microbial biomass provides and early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol. & Biochem.* 19: 159-164.

Prakash, D. and Khan, A.M. 1971. Fungal population in sugarcane soils. *J. Ind. Bot. Soc.* 50: 153-157.

Pugh, G.J.F. 1963. Ecology of soil fungi in developing coastal soils. In: *Soil Organisms,* North Holland Publishing Company, Amsterdam 439-445.

Rai, B. and Srivastava, A.K. 1981. Studies on microbial population of tropical dry deciduous forest soil in relation to soil respiration. *Pedobiol.* 22: 185-190.

Raich, J.W. and Nadelhoffer, K. 1989. Belowground carbon allocation in forest ecosystem: global trends. *Ecology.* 70: 1346-1354.

Raich, J.W. and Potter, C.S. 1995. Global patterns of carbon dioxide emission from soils. *Global Biogeochem. Cycles.* 9: 23-36.

Rama Rao, N. 1986. Potassium requirement for growth and related processes determined for plant analysis in wheat. *Plant and Soil.* 96: 125-131.

Ramirez-Martinez and McLaren 1966b. Some factors influencing the determination of phosphatase activity in native soils and in soils sterilizes by irradiation. *Enzymologia.* 31: 23-38.

Rao, D.N.L. and Ghai, S.K. 1985. Urease and dehydrogenase activity of alkali and reclaimed soils. *Aus. J. Soil Res.* 23: 661-665.

Rastin, N., Rosenplanter, K. and Huttermann, A. 1988. Seasonal variation of enzyme activity and their dependence on certain soil factors in a beech forest soil. *Soil Biol. & Biochem.* 20 : 637 – 642.

Reddy, G.B. and Faza, A. 1989. Dehydrogenase activity in sludge amended soil. *Soil Biol. & Biochem.* 21: 327-328.

Resenzweig, C. & Parry, M.L. 1994. Potential impact of climate change on world food supply. *Nature.* 367: 133-556.

Ritz, K., Wheatley, R.E. and Griffiths, B.S. 1997. Effects of animal manure application and crop plants upon size and activity of soil microbial biomass under organically grown spring barley. *Biol. Fertil. Soils.* 24: 372-377.

Roder, W., Mason, S.C., Cleff, M.D., Doran, J.W. and Knieo, K.R. 1988. Plant and microbial responses to Sorghum-soybean cropping systems and fertility management. *Soil Sci. Soc. Am. J.* 52: 1337-1342.

Ropper, M.M. and Gupta, V.V.S.R. 1995. Management practices and soil biota. *Soil Biol. & Biochem.* 33: 321-339.

Roscoe, R. Vasconcellos, C. A., Furtini-Neto, A. E., G. Guedes, A. A. and Fernandes, L. A. 2000. Urease activity and its relation to soil organic matter, microbial biomass nitrogen and urea-nitrogen assimilation by maize in a Brazilian Oxisol under no-tillage and tillage systems. *Biol. Fertil. Soils.* 32(1): 52-59.

Ross, D.J. 1970. Effects of storage on dehydrogenase activities of soils. *Soil Biol. & Biochem.* 2: 55-61.

Ross, D.J. 1971. Some factors influencing the estimation of dehydrogenase activities of some soils under pasture. *Soil Biol. & Biochem.* 3: 97-110.

Ross, D.J. and Cairns, A. 1978. Influence of temperature on biochemical processes in some soils from tussock grasslands. Respiratory activity. *NZ. J. Sci.* 21: 581-589.

Ross, D.J. and Cairns, A. 1982. Biochemical changes in a yellow-brown loam and a central gley soil converted from pasture to maize in the Waikato area New Zealand. *J. Agric. Res.* 25: 35-42.

Rotini, O.T. 1935. Enzymatic transformation of urea in soil. *Ann. Labor. Ferment. L. Spallanzani, Milan.* 3: 173-184.

Rouatt, J.W. and Katznelson, M. 1961. A study of bacteria on the root-surface and in the rhizosphere soil of crop plants. *J. Appl. Bact.* 24: 164.

Rout, S.K. and Gupta, S.R. 1989. Soil respiration in relation to abiotic factors, forest floor litter, root biomass and litter quality in forest ecosystems of Siwaliks in northern India. *Acta Oecologia (Oecologia Plantarum)* 10: 229-244.

Rovira, A.D. 1953. Plant root exudates and their influence upon soil microorganisms. In *Ecology of Soil Borne Pathogens – Prelude to Biological Control* (K.F. Baker and W.C. Snyder, Eds.), pp. 170-186. University of California Press. Berkely. CA.

Ruppel, S. and Makswitat, E. 1998. Effect of nitrogen fertilization and irrigation soil microbial activities and population dynamics-a field study. *Journal of Plant Nutrition Soil Science.* 162: 75-81.

Rygiewicz, P.T. and Anderson, C.P. 1994. Mycorrhizae alter quality and quantity of carbon allocated belowground. *Nature.* 369: 58-60.

Sahrawat, K.L. 1982. Assay of nitrogen supplying capacity of tropical rice sois. *Plant and Soil.* 65: 111-121.

Sakamoto, K. and Oba, Y. 1994. Effect of fungal to bacterial biomass ratio on the relationship between CO_2 evolution and total soil microbial biomass. *Biol. Fertile. Soils.* 17: 39-44.

Saksena, S.B. 1955. Ecological factors governing distribution of soil microfungi in some forest soils of Saugor. *J. Ind. Bot. Soc.* 34: 262-299.

Sarathchandra, S.U., Perrot, K.W. and Upsdell, M.P. 1984: Microbiological and biochemical characteristics of a range of New Zealand soils under established pasture. *Soil Biol. & Biochem.* 16: 177-183.

Sarathchandra, S.U., Perrot, K.W., Boase, M.R. and Waller, J.E. 1988. Seasonal changes and the effects of fertilizer on some chemical, biochemical and microbiological characteristics of high producing pastoral soil. *Biol. Fertil. Soils.* 6: 328-335.

Sarathchandra, S.U., Lee, A., Perrot, K.W., Rajan, S.S.S., Oliver, E.H.A. and Gravett, I.M. 1993. Effects of phosphate fertilizer applications on microorganisms in pastoral soil. *Aus. J. Soil Res.* 31: 299-309.

Sarathchandra, S.U., Ghani, A, Yeates, G.W., Burch, G. and Cox, N.R. 2001. Effect of nitrogen and phosphate fertilizers on microbial and nematode diversity in pasture soils. *Soil Biol. & Biochem.* 33: 953-964.

Sato, K. 1981. Relations between soil microflora and CO_2 evolution upon decomposition of cellulose. *Plant and Soil.* 61: 251-258.

Saviozzi, A, Biasci, A. Riffaldi, R. Levi-Minzi. R. 1999. Long-term effects of farmyard manure and sewage sludge on some soil biochemical characteristics. *Biol. Fertil. Soil.* 30 (1/2): 100-106.

Schiner, F.A., Neederbacher, R. and Neuwinger, T. 1980. Influence of compound fertilizer and cupric sulfate on soil enzymes and CO_2 evolution. *Plant and Soil.* 57: 85-93.

Schlenther, R.E. and Cleve, V. 1985. Relationship between CO_2 evolution and substrate temperature and moisture in four mature forest types in interior Alaska. *Can. J. For. Res.* 15: 97-107.

Schneider, A., Castillon, P. and Pellerin, S. 2003. Relationship between soil potassium supply characteristics based on soil solution concentration and buffer power and field responses of winter wheat and maize. *Plant and Soil.* 254: 269-278.

Schnurer, J., Claholm, M. and Rosswell, T. 1985. Microbial biomass and activity in an agricultural soil with different organic matter contents. *Soil Biol. & Biochem.* 17: 611-618.

Schnurer, J., Claholm, M., Bastrom, S. and Rosswell, T. 1986. Effects of microorganisms and nematodes. A field experiment. *Microbial Ecology.* 12: 217-230.

Scholefield, D. and Stone, A.C. 1995. Nutrient losses in runoff water following application of different fertilizers to grassland cut for silage. *Agric. Ecosyst. Environ.* 55: 181-191.

Selvaraj, K.V. and Rangaswamy, P.P. 1978. Effect of moisture regimes and soil depth on microbial populations. *Food Farming Agric.* 10: 178-179.

Senwo, Z.N. and Tabatabai, M.A. 1998. Amino acid composition of soil organic matter. *Biol. Fertil. Soils.* 26: 235-242.

Seto, M. and Yanagiya, K. 1983. Rate of CO_2 evolution from soil in relation to temperature and amount of dissolved organic carbon. *Jap. Ecol.* 33: 199-205.

Shanon, C.E. and Weaver, W. 1948. *The Mathematical Theory of Communication.* University of Illinois Press, Urbana.

Shen, D. 1997. Microbial diversity and application of microbial products for agricultural purposes in China. *Agric. Ecosyst. Environ.* 62 (2-3): 237-245.

Shibahara, F. and Inubushi, K. 1997. Effects of organic-matter applications on microbial biomass and available nutrients in various types of paddy soils. *Soil Sci. Plant Nutr.* 43: 191-203.

Sierra, J. 1997. Temperature and soil moisture dependence of N mineralization in intact soil cores. *Soil Biol. & Biochem.* 29: 153-158.

Silvola, J., Alm, .J., Ahlholm, U., Nykänen, H. and Martikainen, P. J. 1996. The contribution of plant roots to CO_2 fluxes from organic soils. *Biol. Fertil. Soils.* 23(2): 126-131.

Silvola, J., Alm, J., Ahlholm, U., Nyanen, H. and Martikainen, P.J. 1996. CO_2 fluxes from peat in boreal mires under varying temperature and moisture conditions. *Journal of Ecology.* 84: 219-228.

Simek, M., Hopkins, D. W., Kalcík, J., Picek, T., Santrucková ,H., Stana, J., Trávník, K. 1999. Biological and chemical properties of arable soils affected by long-term organic and inorganic fertilizer applications. *Biol. Fertil. Soils.* 29(3): 300-308.

Simpson, E.H. 1949. Measurement of diversity. *Nature.* 163: 688.

Singh, J. 1984. Effects of temperature, rainfall and soil moisture on soil respiration and litter decomposition in a subtropical humid forest ecosystem. *Acta. Bot. Indica.* 12: 167-173.

Singh, J.S. and Gupta, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Review.* 43: 449-528.

Singh, M. and Yadav, D.S. 1981. *Plant and Soil.* 63: 511.

Singh, K.P. and Shekhar, C. 1989. Concentration and release patterns of nutrients (N, P and K) during decomposition of maize and wheat roots in a seasonally dry tropical region. *Soil Biol. & Biochem.* 21: 81-85.

Singh, S.P. and Singh, J.S. 1989. Ecology of Central Himalayan forests with special reference to Sal forest ecosystem, pp. 193-232. In: J.S. Singh and B. Gopal (Eds.) *Perspective in Ecology.* Jagmander Book Agency, New Delhi, India.

Singh, J.S., Raghubanshi, A.S, Singh, R.S. and Srivastava, S.C. 1989. Microbial biomass acts as a source of plant nutrient in dry tropical forests and savanna. *Nature.* 338: 499-500.

Singh, R.S., Srivastava, S.C., Raghuvanshi, A.S., Singh, J.S. and Singh, S.P. 1991. Microbial C, N and P in dry tropical savanna. Efects of burning and grazing. *Journal of Applied Ecology.* 28: 869-878.

Singh, H. and Singh, K.P. 1993. Effect of residue placement and chemical fertilizer on soil microbial biomass under tropical dryland cultivation. *Biol. Fertil. Soils.* 16: 275-281.

Singh, A. Malik, V. and Gupta, S.R. 1995. Effect of nitrogen fertilization on decomposing rice straw, p. 79. In: Usha Goel, P.S. Pathak and B. Gopal (Eds.) National Symposium on Agriculture and Environment: Issue in Sustainable Agriculture and Rural Development (Abstract). National Institute of Ecology, New Delhi, India.

Sinsabsugh, R.L., Antibus, R.K. and Linkins, A.E. 1991. An enzyme approach to the analysis of microbial activity during plant litter decomposition. *Agric. Ecosyst. Environ.* 34: 43-54.

Skujins, J.J. and McLaren, A.D. 1968. Persistence of enzymatic activities in stored and geologically preserved soils. *Enzymologia.* 34: 213-225.

Skujins, J.J. 1976. Extracelular enzyme in soil. CRC. *Critical Reviews of Microbiology.* 4: 383-421.

Skujins, J.J. 1973. Dehydrogenase: An indicator of Biological activities in arid soils. *Bull. Ecol. Res. Comm. (Stockholm).* 17: 235-241.

Skujins, J.J. 1978. History of abiotic soil enzyme research. In: *Soil Enzymes* (R.G. Burns, Ed.), pp. 1-49. Academic Press, New York.

Smith, J.L. and Paul, E.A. 1990. The significance of soil microbial biomass estimatation. In : *Soil Biochemistry* (Eds. T. M. Bollag and G. Stotzky). Marcel Dekker, New York.

Smith, S.N. and Pugh, G.J.F. 1979. Evaluation of dehydrogenase as a suitable indicator of soil microflora activity. *Enzyme Microb. Technol.* 1: 279-281.

Sommerfeldt, T.G. and Chang, C. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci Soc Am J 49: 983-987.

Soon, Y.K. and Arshad, M.A. (1996): Effects of cropping systems on nitrogen, phosphorus and potassium forms and soil organic carbon in a Gray Luvisol. *Biol. Fertil. Soils.* 22 (1): 184-190

Sparling, G.P. 1985. The soil biomass. In *Soil organic matter and Biological activity* (D. Vaughan and R. E. Malcolm, Eds.). pp.223-262. W. Junk, Dordrecht.

Sparling, G.P. 1997. Soil microbial biomass, activity and nutrient cycling as indicators of soil health. In: Pankhurst, C.E., Doube, B.M., Gupta, V.V.S.R. (eds) *Biological Indicators of Soil Health*, CAB International, pp 97-119.

Speir, T.W. and Ross, D.J. 1978. Soil phosphatase and sulphatase. In: Burns, R.G. (Ed.), Soil Enzymes. Academic Press, New York, pp. 197-250.

Speir, T.W., Ross, D.J. and Orchard, V.A. 1984. Spatial variability of biochemical properties in a taxonomically uniform soil under grazed pasture. *Soil Biol. & Biochem.* 16

Speir, T.W. and Ross, D.J. 1900. Temporal stability of enzymes in a peatland soil profile. *Soil Biol. & Biochem.* 22: 1003-1005.

Spiers, G.A. and McGill, W.B. 1979. Effects of phosphorus addition and energy supply on acid phosphatase production and activity in soils. *Soil Biol. & Biochem.* 11: 3-5.

Srivastava, S.C. 1992. Microbial C, N and P in dry tropical soils: Seasonal changes and influence of soil moisture. *Soil Biol. & Biochem.* 24: 711-714.

Staddon, W.J., Duchesne, L.C. and Trevors, J.T. 1997. Microbial Diversity and Community Structure of Postdisturbance Forest Soils as Determined by Sole-Carbon-Source Utilization Patterns. *Microb. Ecol.* 34:125-130.

Staley, J.T. and Konopka, A. 1985. Measurement of in situ activities of non-phptosynthetic of microorganism in aquatic and terrestrial habitata. *Ann. Rev. Microbiol.* 39: 321-346.

Stewart, W. D. P. 1991. The importance to sustainable Agriculture and biodiversity among Invertebrates and microorganism. *In*: *The biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture.*, Red Wood Press, Melksham, P.3.

Stojanovic, B.J. 1959. Hydrolysis of urea in soil as affected by season and by added urease. *Soil Sci.* 88: 251-255.

Stolp, H. 1988. *Microbial Ecology Organism, Habitats, Activities.* Cambridge University Press, Cambridge.

Stotozky, U. 1960. A simple method for the determination of the respiratory quotient of soils. *Can. J. Microbiol.* 6: 439-452.

Stott, D.E., Dick, W.A. and Tabatabai, M.A. 1985. Inhibition of pyrophosphatase activity in soils by trace elements. *Soil Science.* 134: 112-117.

Subramanian, C.V. 1971. Hyphomycetes: an account of Indian species, except *Cercospora*. ICAR, New Delhi.

Sumner, J.B. 1926. The isolation and crystallization of the enzyme urease. *J. Biol. Chem.* 69: 435-441.

Sumner, J.B. and Somers, G.F. 1953. Chemistry and Methods of Enzymes. 3rd ed. Acadamic Press, New York.

Swenson, B. and Bakken, L.R. 1998. Nitrification potential and urease activity in a mineral subsoil. *Soil Biol. & Biochem.* 30: 1333-1341.

Swift, M.J. (eds.) 1987. Soil Biological Processes and Tropical Soil Fertility. A proposal for a Collaborative programme of Research. Special Issue 5. Biology International. Paris, France, IUBS.

Swift, M.J., Heal, O.W. & Anderson, J.M. 1979. Decomposition in terrestrial ecosystems. Blackwell Scientific Publications. Oxford England.

Tabatabai, M.A. and Bremner, J.M. 1969. Use of p-nitrophenyl phosphate for assay of soil Phosphatase activity. *Soil Biol. & Biochem.* 1: 301-307.

Tabatabai, M.A. 1982. Soil enzymes: In methods of soil analysis, part 2, chemical and microbiological properties (A.C. Pace, R.H. Miller and D.R. Keeney, Eds.) pp. 903-947. American Society of Agronomy, Madison.

Tabatabai, M.A. 1994. Enzymes. In: Weaver, R.W., Augle, S., Bottomly, P.J., Bezdicek, D., Smith, S., Tabatabai, A., Wollum, A. (Eds.). Methods of soil analysis. Part 2. Microbiological and biochemical properties. No. 5. Soil Science Society of America. Madison, pp. 775-833.

Tabatabai, M.A., Fu, M.H. and Basta, N.T. 1992. Effects of cropping systems on nitrification in soils. *Commun. Soil Sci. Plant Anal.* 23: 1885-1891.

Taiwo, L.B., Nworgu, F.C. and Adatayo, O.B. 1999. Effect of Bradyrhizobium inoculation and phosphorus fertilization on growth, nitrogen fixation and yield of promiscuously nodulating soybean [Glycine max (L) Merr.] in a tropical soil. *Crop Res.* 18 (2): 169-177.

Tate R.L., III. 1977. Nitrification in histosols. A potential role for the heterotrophic nitrifier. *Appl. Environ. Microb.* 33: 911-914.

Tate R.L., III and Terry, R.E. 1980. Variation in microbial activity in histosols and its relationship to soil moisture. *Appl. Environ. Microb.* 40: 313-317.

Taylor, J.P., Wilson , B., Mills, M.S. and Burns, R.G. 2002. Comparison of microbial numbers and enzymatic activities in surface soils and subsoils using various techniques. *Soil Biol. & Biochem.* 34 (3): 387-401.

Thies, J. E., Woomer, P. L and Singleton, P. W. 1995. Enrichment of bradyrhizobium spp populations in soil due to cropping of the homologous host legume. *Soil Biol. & Biochem.* 27(4-5): 633-636.

Tilak, K.V.B.R., Saxena, A.R. and Naveen Datt 1995. Dynamic of microbes in Agricultural soil with different management practices. *J. Soil Biol. Ecol.* 15(2):117-126.

Tiwari, S.C. 1996a. Distribution of dehydrogenase, urease and phosphatase enzymes in a hilly sandy loam soil profile. *Journal of Hill Research.* 9: 321-324.

Tiwari, S.C, Tiwari, B.K. and Mishra, R.R. 1986. Temporal and Depth-wise Variation in CO_2 Evolution and Microbial Population in Pineapple-Plantation Soils. *J. Soil Biol. Ecol.* 6(2): 67-76.

Tiwari, S.C, Tiwari, B.K. and Mishra, R.R. 1987b. The influence of moisture regimes on population and activity of soil microorganisms. *Plant and Soil.* 101: 133-136.

Tiwari, S.C, Tiwari, B.K. and Mishra, R.R. 1988. Enzyme activities in soil: Effects of leaching, ignition, fumigation and autoclaving. *Soil Biol. & Biochem.* 20: 583-585.

Tiwari, S.C., Tiwari, B.K. and Mishra, R.R. 1989. Microbial populations, enzyme activities and nitrogen-phosphorus-potassium enrichment in earthworm casts and in the surrounding of soil of pineapple plantation. *Biol. Fertil. Soils.* 8: 178-182.

Tiwari, M.B., Tiwari, B.K. and Mishra, R.R. 1989. Enzyme activity and carbon dioxide evolution from upland and wet land rice soils under three agricultural practices in hilly regions. *Biol. Fertil. Soils.* 7: 359-364.

Tiwari, S.C. and Mishra, R.R. 1989. Seasonal variation in dehydrogenase and urease activity in hilly soils under grassland and forest. *J. Ind. Soc. Soil Science.* 43: 689-690.

Tiwari, S.C. 1996. Relationship between enzyme activities and microbial population and soil respiration in some Indian soils. *J. Soil Biol. Ecol.* 16(1): 17-26.

Tiwari, S.C. 1996a. Effects of organic manure and NPK fertilization on enzyme activities and microbial population in subtropical oxiol. *Journal of Hill Research.* 9: 334-340.

Tiwari, S.C., Sorokhaibam, S.S, Dkhar, M.S. and Mishra, R.R. 2002. Soil degradation effects dehydrogenase activity and microbial biomass C in humid tropical forest soils of Arunachal Pradesh, north-Eastern Indian. *Asian .J Micro. Biotech. and Environ.* Sc. 4: 143-148.

Trasar-Cepeda, M.C. and Gil-Sotres, F. 1987. Phosphatase activity in acid high organic matter soils in Galicia (NW Spain). *Soil Biol. & Biochem.* 19: 281-289.

Trolldenier, G. 1973. Secondary effects of potassium and nitrogen nutrition of rice. Change in microbial activity and iron reduction in the rhizosphere. *Plant and Soil.* 38: 267-279.

Trolldenier, G. 1981. Influence of plant nutrition on microbial activity in the rhizosphere. Agricultural Yield Potential in Continental Climates. *Proc. 16th Coll. Int. Potash Institute, Berlin.*

Turco, R.F., Kennedy, A.C. and Stott, D.E. 1994. Microbial indicators for soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B. A. (Eds.) defining soil quality for a sustainable environment. *Soil Science Society of America.* Madison. Wis. Pp. 73-90.

Upadhyay, R.S. and Rai, B. 1979. Ecological survey of Indian soil fungi with special reference to *Aspergilli, Peniciilia and Trichoderma. Rev. Eco. Biol. Soil.* 16: 39-49.

Upadhyay, V.P., Singh, R.P. and Rana, B.S. 1997. Soil respiration in disturbed forest ecosystem of central Himalaya. *Indian Forester.* 37: 77-82

Van Bruggen, A.C.H. and Semenov, A.M. 2000. In search of biological indicators for soil health and disease suppression. *Appl. Soil Ecol.* 15: 13-24.

Van Veen, J.A., Ladd, J.N., Martin, J.K. and Amato, M. 1987. Turnover of carbon, nitrogen and phosphorous through the microbial biomass in soils incubated with ^{14}C, ^{15}N and ^{32}P labeled bacterial cells. *Soil Biol. & Biochem.* 19: 559-565.

Van Veen, J.A., Marckx, R. and Van de Geijn, S.C. 1989. Plant and soil related controls of the flow of carbon from roots through the soil microbial biomass. *Plant and Soil.* 115: 179-188.

Van Veen, J.A. and Kulkman, P.J. 1990. Soil structural aspect of decomposition of organic matter by microorganisms. *Biogeochemistry.* 11: 213-233.

Vasilenko, Y.S. 1962. Urease activity in the soil. *Soviet Soil Sci.* 11: 1267-1272.

Ventura, W.B. and Yoshida, T. 1977. Ammonia volatilization from a flooded tropical soil. *Plant and Soil.* 46: 521-531.

Verma, L.N. and Thampan, P.K. 1995. Conservation and efficient use of organic sources of plant nutrients. *Organic-agriculture.* 101-143; 81 ref.

Vose, J.M., Elliot, K.J., Johnson, D.W., Walker, R.F., Johnson, M.G. and Tingey, D.T. 1995. Effects of elevated CO_2, and N fertilization on soil respiration from ponderosa pine (*Pinusponderosa* Doug. Ex Laws.) *Can. J. For. Res.* 25: 1243-1251.

Wagai, R., Brye, K.R., Gower, S.T., Normer, J.M. and Bundy, L.G. 1998. Land use and environmental factors influencing soil surface CO_2 flux and microbial biomass in natural and managed ecosystems in South-Eastern Winconsion. *Soil Biol. & Biochem.* 30: 1627-1637.

Wardle, D.A. 1992. A cooperative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. *Biological Reviews.* 67: 321-358.

Wardle, D.A. 1995. Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. *Adv. Ecol. Res.* 26: 105 – 185.

Waksman, S.A. 1922. Microbial analysis of soil as index of fertility III. Influence of fertilization upon number of microorganisms in soil. *Soil Science.* 141: 321-346.

Waksman, S.A. 1927. *Introduction to Soil Microbiology.* Academic Press, New York.

Waksman, S.A. 1952. *Soil Microbiology.* London. Chapman & Hall.

Waksman, S.A. and Starkey, R.L. 1924. Influence of organic matter upon development of fungi, actinomycetes and bacteria in soil. *Soil Science.* 12: 373-378.

Warcup, J.H. 1951. The Ecology of Soil Fungi. *Trans. Brit. Mycol. Soc.* 34: 376-379.

Wardle, D.A. 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soils. *Biological Reviews.* 67: 321-358.

Wardle, D. A. and Ghani, A. 1995. A critique of the microbial metabolic quotient (qCO_2) as a bioindicator of disturbance and ecosystem development. *Soil Biol. & Biochem.* 27(12): 1601-1610.

Widden, P. 1981. Pattern of phenology among Fungal populations. *The fungal community* edited by D.T. Wicklow and G.C. Caroll. Marcel Dekker Inc. 387-401.

Winogradsky, M.S. 1925. Etudes sur la microbilogie du sol. 1. Sur la methode. *Annls. Inst. Pasteur, Paris.* 39: 299.

Witter, E., Martesson, A.M. and Garcia, F.V. 1993. Size of the soil microbial biomass in a long term field experiment as affected by different N-fertilizers and organic manures. *Soil Biol. & Biochem.* 25: 659-669.

Witter, E. 1996. Soil C balance in a long-term field experiment in relation to the size of microbial biomass. *Biol. Fertil. Soils.* 23: 33-37.

Wolters, V. and Joergensen, R.G. 1991. Microbial carbon turnover in beech forest soils at different stages of acidification. *Soil Biol. & Biochem.* 23: 897-902.

Wong, M.H. 1975. Some edaphic factors influencing the distribution of the soil fungi. *Int. J. Ecol. Environ. Sci.* 1: 143-150.

Yan, F., Schubert, S. and Mengel, K. 1996. Soil pH changes during legume growth and pplication of plant material. *Biol. Fertil. Soils.* 23(3): 236-242.

Yeates, G.W., Bardgett, R.D., Cook, R., Hobbs, P.J., Bowling, P.J. and Potter, J.F. 1997. Faunal and microbial diversity in three Welsh grassland soils under conventional and organic management regimes. *J. App. Ecol.* 34: 453-470.

Zak, J.C., Willig, M.R., Moorhead, D.L., Wildman, H.G., 1994. Functional diversity of microbial communities: A quantitative approach. *Soil Biol. & Biochem.* 26, 1101-1108.

Zantua, M.I. and Bremner, J.M. 1976. Production and persistence of urease activity in soils. *Soil Biol. & Biochem.* 8: 369-374.

Zantua, M.I. and Bremner, J.M. 1977. Stability of urease in soils. *Soil Biol. & Biochem.* 9: 135-140.

Bio-Data

Name: Mr. R. Lalfakzuala

Father's Name: Rev. R. Hrangvunga

Address: Department of Botany
School of Life Sciences
North Eastern Hill University
Shillong - 793 022, Meghalaya
India

Permanent Address: Bethlehem Veng, Aizawl
Mizoram

Date of Birth: 2nd May 1973

Present Position: Research Scholar
North Eastern Biodiversity Research Cell & Department of Botany
North Eastern Hill University.

Qualifications:

Examination	*BoardUniversity*	*Year*	*Class*
B.Sc	North Eastern Hill University	1996	II
M.Sc	North Eastern Hill University	1998	I

Seminar, Conferences, Symposia, Workshops attended:

Name of the Seminar/ Conference/Symposia/Workshop	Sponsoring Agency	Place/Date	Nature of participation/ organisation
Workshop on Peoples Participation in Biodiversity Conservation, hosted by NEBRC, NEHU, Shillong.	NEBRC Shillong	4-6 March, 1999 Shillong	Participant
Seminar on Ethnobotany of North East India: Past, Present and Future, hosted by NEBRC, NEHU, Shillong	NEBRC	12th April, 2000 Aizawl	Organising Secretary

National Seminar on Intellectual Property Rights	Ministry of Human Resource Development, New Delhi	24 – 25 May, 2002 Shillong	Participant
Seventy Second Session of the National Academy of Sciences	National Academy of Sciences, India	25-27 October, 2002 Shillong	Paper Presentation
National Roving Seminar on Patenting in Biotechnology	DBT, New Delhi	26th October, 2002 Shillong	Participant
Seminar on Atomic Energy & Development in India	Dept. of Atomic Energy	17-18 September, 2002 Shillong	Participant
Regional Workshop on Evolving Stragedies for Conservation and Commercialisation of Medicinal and Aromatic Plants for North East India	NEC and NEBRC Shillong	15th July, 2003 Shillong	Participant