Biodiversity and its Significance

Editors

Pramod Tandon
Yash P Abrol
Suman Kumaria

I.K. International

Chapter 13

Microbial Diversity: A Review

M. S. Dkhar, H. Kayang and M. Dkhar
Department of Botany, School of Life Sciences, North-Eastern Hill University, Permanent Campus, Umshing, Mawkynroh, Shillong – 793 022, Meghalaya

Microorganisms, which plays a vital role in the functioning of the ecosystem, occur virtually in every habitat in the biosphere. Microorganisms, including fungi and bacteria related to forests, agriculture, jhum, grasslands, protected and degraded forests of India and other parts of the world, have been reviewed. Comprehensive accounts of saprophytes or symbionts, including mycorrhiza, which are concerned with soil fertility, have been given and discussed.

INTRODUCTION

Microbial diversity is an unseen national, as well as international resource that deserves greater attention than it has bean receiving. It is the largest untapped resource, both for understanding how biological systems function as well as for new biotechnologies. It encompasses the spectrum of variability among all types of microorganisms in the natural world and as altered by human intervention. Microorganisms occur virtually in every habitat in the biosphere. In fact, recent discoveries have indicated their existence even on other planets too. They even occur in extreme environments even in abiotic conditions, unfavourable for most forms of life. Microorganisms represent by far, the richest repertoire of molecular and chemical diversity in nature. They underlie basic ecosystem processes, such as biogeochemical cycles and food chains as well as maintain vital and often elegant relationships between themselves and higher organisms. Microorganisms provide the fundamental base to all types of ecosystem. Without microorganisms, all life on earth would cease.

Focussing on microbial diversity is timely. Diverse microorganisms are essential for a sustainable biosphere. They are able to recycle nutrients, produce and consume gases that affect the global climate, destroy pollutants, treat wastes, and they can even be used for biological control of plant and animal pests. The study of microbial diversity is also important to treat new and emerging diseases and to advance biotechnology. New technologies, particularly in nucleic acid analysis, computer science, analytical chemistry and habitat sampling and characterization, place the study of microbial diversity at the cutting edge of science. Over the ages, humans have been highly successful in applying processes carried out by microorganisms to solve problem in agriculture, food production, human health, environmental quality and industry. They have played a pivotal role in the evolution of life on earth. Recent technologies developed in molecular biology and genetics offer great promise to develop the potential of microbial diversity. The world of microorganisms and their activities in nature are vast and therefore, it is not possible to deal with the entire microbial activity in nature. However, in the present study, we have tried to present an overview of the functional aspects of microorganisms in relation to environmental factors.

UNDERSTANDING FACTORS AFFECTING MICROBIAL DIVERSITY

Studies on microbial diversity are important in order to understand microbial ecology in soil and other ecosystems (Atlas, 1984; Reid, 1994). The information on microbial diversity from North-East India is sporadic, as compared to other parts of India and no comprehensive study has so far been made to explore and conserve the microbial diversity of North-East India as a whole. North-East India is known to possess diverse forest types, from tropical evergreen forests to moist alpine shrub forests which occupy 59.9% of its geographical area, which is much higher than the all India average of 28%. Its forests constitute a powerful ecological unit having vital environmental significance.

Studies on physico-chemical characteristics have generally been conducted in forests, agricultural and grassland soils. Various physico-chemical characteristics which affect microbial diversity are temperature, pH, moisture content, climate, vegetation, organic matter constituents, altitude, etc. (Singh, 1968; Mishra and Kanaujia, 1972; Das 1980; Dkhar 1983; Das and Mishra, 1986).

Soil microbial diversity in general, is influenced by the nature of the crop grown and the physico-chemical characteristics of soil viz., nature of the particles of which the soil is composed of, i.e., nutrients, aeration, temperature, precipitation, organic matter content, moisture, pH and depth (Waksman, 1927; Mishra and Kanaujia, 1972; Deka, 1981; Baruah 1983; Campbell, 1983; Behera and Mukherji, 1985; Tiwari *et al.,* 1986; Tiwari, *et al.,* 1987 a, b; Tiwari, 1988; Arunachalam *et al.,* 1997; Berg *et al.,* 1998; Coyne, 1999; Kayang *et al.,* 2000). The physico-chemical characteristics of soil regulate the microbial populations and their activities; the state of litter decomposition governs microbial diversity in the soil (Mishra, 1966; Tiwari *et al.,* 1987a). Therefore, due to their inseparable relationships, these parameters were widely investigated by various workers (Waksman, 1927; Thakur and Morris, 1928; Warcup, 1950).

Saksena (1955) stated that the high moisture content of soil was favourable for the growth of fungi, as long as there was no water logging. Brown (1958), Cook and Lawrence (1959), Pugh (1962) and Wohlrab *et al.,* (1963) reported that there is a shift in the species composition of soil mycoflora which parallels pioneer vegetational succession.

It is widely accepted that each of the vegetational communities harbours a characteristic soil fungal population, particularly the assemblage of more predominant species. However, there is no evidence that microfungi form discrete communities, rather they constitute a continuum, the species composition gradually changing with differences in the vegetational cover and soil characteristics (Wicklow and Whittingham, 1974). The changing climatic conditions at different altitudes are accompanied by differences in the composition of the vegetation. Thus, a microorganism that subsequently decomposes a little of this vegetation may require a different range of metabolic reactions than those utilised in other environments. Furthermore, a decrease in the diversity of fungal species at higher altitudes is paralleled by a decrease in plant species. As the decomposition of litter is also controlled by differences in the chemical composition of litter, so the spectrum of fungal species concerned with litter decomposition is likely to differ in the same way (Schinner, 1978). The pattern of distribution of fungi is also affected by nutritional conditions (Rehder and Schafr, 1978) and micro-climatic factors which have a decisive influence on the distribution of individual species.

Microbes are important organisms that drive the turnover of organic matter in soil and aquatic environments. They are the focal point of analysis when dealing with soil respiration, mineralisation, gas emissions or primary steps of the food web, known as the microbial loop (Azam *et al.,* 1983).

Soil microorganisms are largely hidden under ground populations; frequently have a greater mass than the plants and animals above ground (Jenkinson and Ladd, 1981; Sparling, 1985). It is also suggested that the total functional diversity of microorganisms in different soils may be similar and that a combination of environmental and plant factors influence microorganisms, which are active, and become culturable and proliferate under different conditions (Colwell *et al.,* 1985). Climatic regimes, seasonal variations in the year, type of vegetation, soil management practices and deforestation are the other important factors which influence the distribution and diversity of microorganisms in soil (Kauri, 1982; Lundgren, 1982; Behera and Mukherji, 1985; Bossio and Scow, 1995; Acea and Caraballas, 1996; Gorres *et al.,* 1998; Lupiwayi *et al.,* 1998; Zeller *et al.,* 2001).

The major underlying principle of diversity studies is probably the assumption that interactions between populations in a habitat lead to an organised and stable community (Atlas, 1984). Diversity can vary with a number of factors, such as disturbances and stress, in addition to ecological interactions. Microbial communities are inherently stable, but at the same time are also dynamic structures (Campbell, 1983; Bossio and Scow, 1995). The changes in microbial communities, resulting from agricultural practices, ecosystem management and global climate changes, can have profound impacts on ecosystem dynamics (Shukla and Mishra, 1992).

Behera *et al.,* (1991), while conducting an ecological investigation of some micro fungi in a tropical forest soil of Orissa, could isolate 36 fungal species and one sterile mycelium from the soil. They observed seasonal variations of fungal population to be pronounced in the upper layers of the soil. They also observed a positive correlation between fungal population, soil moisture and organic matter contents.

Microbial activity is an important key to understanding biological processes in soil. It is influenced by soil degradation, transformation of organic matter and soil structure. Changes in soil microbial activity, in response to stress, may eventually affect plant productivity and ecosystem functioning (Garcia *et al.*, 1994). Elliot and Lynch (1994), Pankhurst *et al.*, (1996) and Giller (1997) suggested that broad functional diversity might be additionally important in influencing the resilience residents of soil. Being the most important component of the soil environment, microorganisms exert considerable influence on soil fertility and plant growth (Tiwari *et al.*, 1991). The microbial population, as observed by Jha *et al.*, (1992), showed a positive and significant correlation with organic C in more degraded forest stands, and the disturbance to the soil and vegetation adversely affected the microbial populations and endogonaceous spores.

Berg *et al.*, (1998) investigated the abundance and micro stratification of bacteria and fungi inhabiting the organic layers of a scots pine forest. They suggested that the abundance of bacteria was influenced by water and that of fungi by water and temperature.

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

Soil microbial communities exist within a highly heterogeneous physical structure, which affects the spatial distribution of solutes, nutrients and of the communities, themselves (Young and Ritz, 1998). As a result, soil processes related to microbial activity often exhibit very high spatial variability (Parkin and Shelton, 1992; Robertson *et al.*, 1997; Rover and Kaiser, 1999; Stoyan *et al.*, 2000).

Generally, microbial populations and their activities in no tillage soil are greater than in conventional tillage soil. But environmental disturbances like clear cutting of forests affects the microbial populations and their activities. When the natural forest is cut completely the roots die, root decomposition takes place and the debris from leaves and branches on the soil surface enter into the soil, serving as food for microbial growth (Coyne, 1999). Thus, there is an increase in microbial growth and their activities in a short term. Soil disturbance activities, such as shifting cultivation and others related to agriculture and forestry have a considerable impact on the biological health of soil systems.

Sami *et al.*, (2000) stated that soil fungi and bacteria are the major organisms responsible for nutrient cycling and for controlling the amount of nutrients available to plants. Liu *et al.*, (2000) suggested that substrate availability was the most important factor affecting the diversity and activity of soil microorganisms within a season. Among the stress treatments soil moisture was not the factor causing differences in microbial diversity and activity, but it was a predictor for some microbial responses under particular kinds of stress.

Singh *et al.*, (2001) studied the effects of varying degrees of forest degradation on microbial communities, their activities and the various physico-chemical characteristics of the soil. Physico-chemical characteristics of the soil, viz., moisture content, water holding capacity, pH, organic carbon, total and available nitrogen and phosphorus contents declined with the increasing severity of forest degradation. Biological characteristics of the soil, such as soil respiration, bacterial and fungal populations, spore distribution and diversity of VAM fungi, microbial biomass and C and N contents also declined due to site degradation, suggesting the detrimental effect of *jhum* cultivation on soil fertility. Analysis of VAM fungal population revealed that degraded and moderately degraded sites exhibited lower indices of species diversity of VAM fungi, as compared to non-degraded sites suggesting higher levels of VAM fungi diversity at non-degraded sites. Microbial diversity at different sites analysed at molecular levels, using standard methodology, revealed that, in general, degradation caused a decline in microbial diversity.

Priha *et al.*, (1999) and Graystone *et al.*, (2001) pointed out that the structure and functional diversity of microbial communities in the soil is highly related to plant species composition above-ground, thus providing an important link between above and below-ground processes in terrestrial ecosystems. Bakermans and Madsen (2002) observed that the composition of microbial communities reflects the physical, chemical, geological and biological characteristics of their habitats.

Kourtev *et al.*, (2001) hypothesised that microbial communities in the initial soil will, in time, differentiate along with the different plant species and this will in turn lead to dangers in microbial functional capabilities. They further hypothesised that the various measures of community structure and function could be correlated with each other. Changes in microbial structure and function were accompanied by changes in ecosystem level, soil characteristics (nitrogen concentrations and pH) and processes (nitrogen mineralisation).

SIGNIFICANCE OF MICROBIAL DIVERSITY IN NATURE CONSERVATION

Only in the last decade mycologists and microbiologists started to pay attention to microorganisms as objects of nature conservation. Nowadays, knowledge of biodiversity and its conservation is receiving much attention all over the globe due to the politicisation of issue. On the other hand, microbiologists have not paid serious attention to microbes even though they exhibit far greater diversity than any other living organisms of the world. For planning the application of microbial diversity to biotechnology and for acquiring a better understanding of taxonomic approaches, it is necessary to study the ecology and distribution of the species in detail. Increased understanding of microbial species should lead to better conservation and management of whole ecosystem.

Knowledge of microbial diversity is important because of their role in regulating the population of other organisms and ecosystem processes, and of equal importance to microbial diversity itself, are variations in their own population that affect host-plant diversity and cycling. Microorganisms, however, are important, especially due to the fact that all life is dependent on microbial characteristics of the soil. Physico-chemical characteristics of the soil, viz., moisture content, water holding capacity, pH, organic carbon, total and available nitrogen and phosphorus contents declined with the increasing severity of forest degradation. Biological characteristics of the soil, such as soil respiration, bacterial and fungal populations, spore distribution and diversity of VAM fungi, microbial biomass and C and N contents also declined due to site degradation, suggesting the detrimental effect of *jhum* cultivation on soil fertility. Analysis of VAM fungal population revealed that degraded and moderately degraded sites exhibited lower indices of species diversity of VAM fungi, as compared to non-degraded sites suggesting higher levels of VAM fungi diversity at non-degraded sites. Microbial diversity at different sites analysed at molecular levels, using standard methodology, revealed that, in general, degradation caused a decline in microbial diversity.

Priha *et al.,* (1999) and Graystone *et al.,* (2001) pointed out that the structure and functional diversity of microbial communities in the soil is highly related to plant species composition above-ground, thus providing an important link between above and below-ground processes in terrestrial ecosystems. Bakermans and Madsen (2002) observed that the composition of microbial communities reflects the physical, chemical, geological and biological characteristics of their habitats.

Kourtev *et al.,* (2001) hypothesised that microbial communities in the initial soil will, in time, differentiate along with the different plant species and this will in turn lead to dangers in microbial functional capabilities. They further hypothesised that the various measures of community structure and function could be correlated with each other. Changes in microbial structure and function were accompanied by changes in ecosystem level, soil characteristics (nitrogen concentrations and pH) and processes (nitrogen mineralisation).

SIGNIFICANCE OF MICROBIAL DIVERSITY IN NATURE CONSERVATION

Only in the last decade mycologists and microbiologists started to pay attention to microorganisms as objects of nature conservation. Nowadays, knowledge of biodiversity and its conservation is receiving much attention all over the globe due to the politicisation of issue. On the other hand, microbiologists have not paid serious attention to microbes even though they exhibit far greater diversity than any other living organisms of the world. For planning the application of microbial diversity to biotechnology and for acquiring a better understanding of taxonomic approaches, it is necessary to study the ecology and distribution of the species in detail. Increased understanding of microbial species should lead to better conservation and management of whole ecosystem.

Knowledge of microbial diversity is important because of their role in regulating the population of other organisms and ecosystem processes, and of equal importance to microbial diversity itself, are variations in their own population that affect host-plant diversity and cycling. Microorganisms, however, are important, especially due to the fact that all life is dependent on microbial processes. The last decade has produced an extraordinary new awareness on microbial diversity (Dykhuisen, 1997).

Microbial communities, particularly bacteria and micro-fungi, constitute an essential component of biological characteristics in soil ecosystems. Directly or indirectly, animal wastes and the dead bodies of animals and tissues of plants eventually enter the soil. In time, they all disappear and are transformed into substances that enrich the fertility of the soil. Microorganisms are responsible for such transformations, converting dead plants and animal matter into simple organic substances that nourish the plants. Thus, by serving as a link amongst various components of energy, they play a key role in maintaining life on earth. In these processes, the microorganisms reform a variety of functions, e.g., biochemical transformation of nitrogen and nitrogenous compounds (nitrogen fixation, proteolysis, ammonification, nitrification, assimilatory nitrate reduction, denitrification), biochemical transformation of carbon dioxide and other carbon compounds (CO_2 fixation, degradation of organic carbon compounds), biochemical transformation of sulphur and sulphur compounds (oxidation and reduction of sulphur compounds), and the biochemical transformation of phosphorus, iron and essential elements, etc. Thus, such soil microbial processes play a key role in maintaining the atmospheric balance of various elements vital for life and also in mediating many natural functions in the ecosystem.

Degradation of natural ecosystems and consequent decline in vegetation cover is a major ecological concern. Soil physio-chemical properties can be improved by the manipulation of soil microbiological activities and the manipulation of microbial associations like mycorrhizae, *Rhizobia* and plant growth-promoting microorganisms, microbe residue association and biofertilisers, etc. Biofertilisers have been shown to possess a significant role in the restoration of soil fertility. Role of *Azotobacter, Azospirillium, Rhizobium, Frankia,* blue green algae, mycorrhizae in the restoration of degraded soils is well documented. These organisms have been exploited for the reclamation of degraded lands like coastal dunes, saline soils, eroded lands and mine spoils. In recent years, emphasis has been laid on the role of mycorrhizae in the revegetation of coal mine spoils. Mycorrhizae play a significant role in plant succession, thus, maintaining diversity of plant communities in such highly degraded ecosystems.

In response to the increased concern for environmental quality, innovative approaches need to be incorporated into agricultural systems. Management of VAM fungi is one important aspect of such an approach. However, the obligate symbiotic nature of VAM fungi continues to impede research on improving our understanding of these beneficial fungi. Furthermore, limited supply of VAM inocula has restricted field-testing. High production costs, as well as problems associated with soil-based pot cultures, have dampened the enthusiasm for commercial development. Nonetheless, the inability to presently use fermentation processes to produce VAM inocula should not deter further development of current technologies to produce these fungi in large quantities. Several areas of VAM inoculum production and application technology merit further investigation. Development of nutrient film and aeroponic culture technologies, along with sheared root processing of colonised roots produced in these systems, should make it possible for low cost, high quality inocula to be widely available for nursery inoculation and for moderate size field testing in the near future.

Much is unknown about the storage of VAM inocula. Further research on the storage properties of VAM inocula will definitely spur commercial production and the development of new formulations. Innovative inoculation technologies are needed to provide the most efficient application of available inocula in the wide array of crop production systems. Co-inoculation of VAM fungi with other beneficial organisms has great merit and should allow for a more holistic approach to rhizosphere health in the future. As inoculum production and inoculation technologies of VAM fungi undergo further development, involvement of all those concerned with crop production and plant health will ensure VAM inocula of consistent high quality and availability.

Microorganisms are essential components of biocoenoses by their functions as decomposers of organic matter, parasites of other organisms and mutualistic symbionts in mycorrhizae. Microorganisms can be excellent bio-indicators in view of their functions, niche differentiation and species diversity. For instance, many species of ectomycorrhizal fungi are indicators of the degree and kind of air pollution, wood-inhabiting fungi for the intensity of forestry practice, and grassland fungi for soil conditions, type of management and degree of disturbance.

Microorganisms possess many qualities that can be exploited for monitoring the presence of unwanted substances in the environment. The range of environmental extremes tolerated by microorganisms is much broader than that of other forms of life. Cells of bioluminescent bacterium (*Photobacterium phosphoreum*) have been used to detect air pollution.

Microorganisms are important (potential) sources of food and medicines, and they can be used for selective delignification of wood and straw, as well as for the degradation of xenobiotics. Their economic value can be counted in billions of US dollars, on account of their commercial uses, which include the production of amino acids, antibiotics, beer, biocontrol agents, cheese, enzymes, fermented foods, food (mushrooms), flavours, food colourants, fuel (ethanol, biogas), organic acids, preservatives, single cell protein, vitamins, herbicides, bio-pesticides and waste biodegradation.

Soil fertility is related to the soil parent material, litter types and the presence of basic microbial species richness. Therefore, within an ecosystem, species composition certainly matters, and changes in species diversity can therefore, lead to changes in soil fertility. Substantial alterations in soil fertility can be driven by changes in plant species composition, both within and among ecosystems. Disturbing the fungal diversity by several means, however, disturbs the microbial balance in nature. These include indiscriminate use of inorganic fertilisers and pesticides in agriculture to kill or suppress non-target microbes, air, water and soil pollutants, biotic activities, and collection for their use as food, medicines, etc. Therefore, useful fungal species are adversely affected, along with the harmful fungi affecting the whole biodiversity of ecosystems.

In natural habitats, microorganisms are an integral part of the biotic community, which interacts dynamically with the abiotic components to form ecosystems. Nowadays, particularly attention is given to soil functionality, largely to microbial activity, which is measured by determining both microbiological parameters and biochemical activities simultaneously (Bonmati *et al.*, 1991). However, in order to maximise the beneficial effects of microbial activity, there is a need for greater understanding of the factors influencing microbial diversity and activity. The abundance and activity of soil microorganisms are influenced by various environmental (e.g., soil type, nutrient status, pH and moisture) as well as plant (e.g., species and age) factors. They are not distributed uniformly in the environment, rather the abundance and activity of the organisms changes along environmental gradients. Biotic processes often result in the aggregation of organisms, even within homogeneous environments (Legendre and Fortin, 1989). Therefore, in order to maximise the beneficial effects of microbial activity, greater understanding of the factors influencing microbial diversity and activity is needed. Microbial growth in soil is carbon limited and therefore, the presence of organic matter has an influence on microbial populations (Lynch and Whipps, 1990; Wardle, 1992).

With increasing emphasis on environmentally friendly, low-input agricultural practices, there is growing interest in the management of soil microbial communities to enhance plant growth. Soil is rarely manipulated for microbial growth. However, if a soil is altered to affect plant growth, which is the essence of agriculture, these manipulations affect the distribution and types of microbial population. Thus, the microorganisms in turn, affect plant growth (Coyne, 1999).

Wardle and Giller (1996) pointed out that despite their comparable mass, we know much less about microorganisms than we do about higher plants and animals. Microorganisms have an enormous impact and role in our daily lives, including everything, right from maintaining the biosphere to improving our lifestyle (Hunter- Cevera, 1998).

The important functional attributes of soil microorganisms include population number, biomass, respiratory efficiency and diversity patterns. These microorganisms are responsible for the breakdown of organic matter, nutrient transformation (Das, 1980; Baruah, 1983; Tiwari 1988; Dkhar and Mishra, 1992; Kayang, 2001), influencing plants and are considered crucial to the functioning of soil ecosystems. Apart from their indispensable role in the biogeochemical cycling of nutrients, they are reported to be useful indicators of the fertility and quality of soil, since they are sensitive to changes occurring in the soil environment. In fact, 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 for mineral nutrients (Jenkinson and Ladd, 1981).

The analysis of the functional diversity of soil population is a very useful way for characterising and comparing the microbial communities. Little is known about 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 and Pankhurst *et al.*, 1996; Giller *et al.*, 1997). It has generally been hypothesised that the reduction in soil microbial diversity will result in the reduction of functional capability of soils (Giller *et al.*, 1997). A high degree of functional redundancy in soil microbial communities may result in there being no effect of the changes in microbial diversity on the function of communities (Andren *et al.*, 1995; Giller *et al.*, 1997). However, broad functional diversity may be additionally important in influencing the resilience of soil (Elliot and Lynch, 1994; Pankhurst *et al.*, 1996; Giller *et al.*, 1997).

The decomposition of dead plant material is an important process responsible for the release of nutrients from the litter and soil. It plays a major role in the structure and dynamics of ecosystems. It also helps in the transfer of elements and energy and in control mechanisms and feedback processes. It is a key process in all-terrestrial ecosystems, because it controls nutrient availability and hence, primary production. In addition, interactions of phylloplane, rhizosphere and rhizoplane microorganisms with plants are of much significance. In some cases, microorganisms may be keynote species which if lost, would lead to major changes in the ecosystem.

The relationships among microbial diversity, microbial activity, plant quality and ecosystem sustainability of disturbed and range lands are still poorly understood. Ecosystem functioning, before and after disturbance, can be governed by soil microbial population dynamics (Kennedy and Smith, 1995). The microbial communities in forest soils, rich in organic matter, may differ considerably from those found in grasslands and in arable soils, with lower organic matter content (Frostegard and Baath, 1996). Therefore, research on microbial diversity and activity may provide some advance evidence of ecosystem degradation. In managed ecosystems, the early detection of soil biological activity may allow for changes in the management system before the functioning of the entire ecosystem is impaired.

FUTURE PROJECTION

Microorganisms have enormous potential to make our life better on this earth. They are an integral part of our lives and possess a vast range of activities to support and improve the quality of our life; many of their properties are still unexplored and in future, we will largely depend on microorganisms to solve our natural as well as man-made problems. Conservation of the gene pools of microorganisms is needed in order to extend our understanding of evolutionary processes and the resulting diversity in taxa, morphological structures and ecological strategies.

Our knowledge of the relation between microorganisms and different management practices in forests and nature reserves is still very scanty. Therefore, such studies from different parts of North-East India are needed to explore, not only new fungal and bacterial diversity, but also to gather knowledge on their substrate relationship, culture and physiology, seasonal variations, quantitative estimations, decomposition biology, etc. Finally, the consequences of changes in microorganisms for the functioning of ecosystems are still poorly understood. Increased insight into these relationships will without doubt, contribute to a better appraisal of microorganisms as essential components of ecosystems.

REFERENCES

Acea M.J. and Caraballas T. (1996). Changes in physiological groups of microorganisms in soil, following wild fires. FEMS Microbiol Ecol 20: 33-39.

Andren O., Bengtsson J. and Clarholm M. (1995). Biodiversity and species redundancy in decomposed litter. In: The significant and regulation of soil biodiversity (Collins HP, Robertson GP and. Klug MJ eds), Kluver Acadamic Publishers, Dordrecht p 141-151.

Arunachallam A., Maithani K., Pandey H.N. and Tripathi R.S. (1997). The impact of disturbances on detrital dynamics and soil microbial biomass of *Pinus kesiya* forest in Northeastern India. Forest Ecology and Management 88: 273-282.

Atlas R.M. (1984). Diversity of microbial communities. In: Advances in Microbial Ecology (Marshall KC eds), Vol 7, Plenium Press, New York p 1-47.

Azam F., Fenchel T., Field J.G., Gray J.S., Meyer-Reil L.A., Thingstad F. (1983). The ecological role of water-column microbes in the sea. Mar Ecological Prog Ser 10: 257-263.

Bakermans C. and Madsen E.L. (2002). Diversity of 16S rDNA and Naphthalene Deoxygenase genes from coal tar waste contaminated aquifer waters. Microb Ecol 44: 95-106.

Baruah M. (1983). Studies on population dynamics and activity measurement of microbial communities of paddy field soils. Ph.D. Thesis, North Eastern Hill University, Shillong, India p 175.

Beare M.H., Coleman D.C., Crossley D.A.Jr., Henrix P.F. and Odum E.P. (1995). A hierarchical approach for evaluating the significance of soil biodiversity to biogeochemical cycling. Plant and Soil 170: 5-22.

Behera N. and Mukherji K.G. (1985). Seasonal variations and distribution of microfungi in the forest soils of Delhi (India). Folia Geobotanica Phytotaxton 20: 291-311.

Behera N., Pati D.P. and Basu S. (1991). Ecological studies of microfungi in a tropical forest soil of Orissa, India. Tropical Ecology 32(1): 136-143.

Berg M.P., Kniese J.P. and Verhoof H.A. (1998). Dynamics and stratification of bacteria and fungi in the organic layers of pine forest soil. Biology and Fertility of Soils 26: 313-322.

Bonmati M., Ceccanti B. and Nannipieri P. (1991). Spatial variability of phosphatase, urease, protease, organic carbon and total nitrogen in soil. Soil Biology and Biochemistry 23: 391-396.

Bossio D.A. and Scow K.M. (1995). Impact of carbon and flooding on the diversity of microbial communities in soils. Applied Environmental Microbiology 61: 4043-4056.

Brown J.C. (1958). Soil fungi of some British sand dunes in relation to soil type and succession. J Ecol 46: 641-664.

Cooke W.B. and Lawrence D.B. (1959). Soil mould fungi isolated from recently glaciated soils in South Eastern Alaska. J Ecol 47: 529-549.

Campbell R. (1983). Microbial ecology. In: Basic Microbiology (Wilkinson JF ed), Vol 5, Second Edition, Blackwell Scientific Publications, Oxford.

Colwell R.R., Brayton P.R., Grimes D.J., Roszak D.B., Huq S.A. and Palmer L.M. (1985). Viable but non-culturable *Vibrio cholera* and related pathogens in the environment: Implications for the release of genetically engineered microorganisms. Biotechnol 3: 817-820.

Coyne M. (1999). Soil microbiology. An explanatory approach. Delmer Publisher, New York p 462.

Das P.K. (1980). Microbial decomposition of pine (*Pinus kesiya* L) litter: An Ecological Study. Ph.D Thesis, North Eastern Hill University, Shillong, India p 233.

Das P.K. and Mishra R.R. (1986). Dehydrogenase activity and Co_2 evolution from *Pinus kesiya* Ex Gordon forest soils. Geobios 13: 12-15.

Deka H.K. (1981). Study on soil microbiological population of *jhum* fallows of different ages. Ph.D. Thesis, North Eastern Hill University, Shillong, India.

Dkhar M.S. (1983). Studies on the ecology of edaphic microbial populations and their activities in maize fields. Ph.D Thesis, North Eastern Hill University, Shillong, India p 158.

Dkhar M.S. and Mishra R.R. (1992). Changes in chemistry during the decomposition of maize residues. Proc Nat Acad Sci India 62(B): 437-440.

Dykhuisen D.E. (1997). Santa Rosalia revisited: Why are there so many species of bacteria? Antonie Van Leewenhoek 73: 25-33.

Elliot L.F. and Lynch J.M. (1994). Biodiversity and soil resilience. In: Soil Resilience and Sustainable Land Use (Greenland DJ and Sza Boles I eds), CAB International, London p 353-364.

Frostegard A. and Baath E. (1996). The use of phospholipid fatty acid analysis to estimate bacterial and fungal biomass in soil. Biology and Fertility of Soil 22: 59-65.

Garcia C., Hemandez T. and Costa F. (1994). Microbial activity in soil under Mediterranean environmental conditions. Soil Biol Biochem 26: 1185-1191.

Graystone S., Griffith G., Mawdsley J., Campbell C. and Bardgett R.D. (2001). Accounting for variability in soil microbial communities of temperate upland grassland ecosystems. Soil Biol Biochem 33: 533-551.

Giller K.E., Beare M.H., Lavelle R., Izac A.M.N. and Swift M.J. (1997). Agricultural intensification, soil biodiversity and agro system functions. Applied soil Ecology 6: 3-16.

Gorres J.H., Dichia M.J., Lyons J.B. and Amadon J.A. (1998). Spatial and temporal patterns of soil biological activity in a forest and or an oil field. Soil Biol Biochem 30: 219-230.

Hunter-Cevera J.C. (1998). The value of microbial diversity. Curr Opinion Microbial 1: 279-285.

Jenkinson D.S. and Ladd J.N. (1981). Microbial biomass in soil measurement and turnover. In: Soil Biochemistry (Paul and Ladd JN eds), Vol 5, Marcel Dekker Inc, New York and Basel p 415-471.

Jha D.K., Sharma G.D. and Mishra R.R. (1992). Ecology of soil microflora and mycorrhizal symbionts in degraded forests at two altitudes. Bio Fertil Soils 12: 272-278.

Kauri T. (1982). Seasonal fluctuations in the number of aerobic bacteria and their spores in four horizons of a beach forest. Soil Biol Biochem 14: 185-190.

Kayang H. (2001). Fungal and bacterial enzyme activities in *Alnus nepalensis* D. Don. European Journals of Soil Biology 37(2): 175-180.

Kayang H., Sharma G.D., Laloo R.C. and Mishra R.R. (2000). Weight loss and concentration of nutrients during the decomposition of leaf litter of *Alnus nepalensis* D. Don in subtropical forests of North East India. Vasundhara 5: 1-10.

Kennedy A.C. and Smith K.L. (1995). Soil microbial diversity and the sustainability of agricultural soils. In: The significance and regulation of soil biodiversity. Kluwer Dordrecht p 75-86.

Kourtev P.S., Ehrenfeld J.G. and Haggblom (2001). Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. Soil Biol Biochem 35: 895-905.

Legendre P. and Fortin M.J. (1989). Spatial pattern and ecological analysis. Vegetation 80: 107-138.

Liu X., Lindemann W.C., Whilford W.G. and Steiner R.L. (2000). Microbial diversity and activity of disturbed soil in the Northern Chihuahuan Desert. Biol Fertil Soils 32: 243-249.

Lundgren B. (1982). Bacteria in a pine forest soil as affected by clear cutting. Soil Biol and Biochem 14: 537-542.

Lupiwayi N.Z., Rice W.A. and Clayton G.W. (1998). Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. Soil Biol Biochem 30: 1733-1741.

Lynch J.M. and Whipps J.M. (1990). Substrate flows in the rhizosphere. Plant Soil 129: 1-10.

Mishra R.R. (1966). Seasonal variation in fungal flora of grasslands of Varanasi (India). Tropical Ecology 7: 100-113.

Mishra R.R. and Kanaujia R.S. (1972). Studies on certain ecological aspects of soil fungi. Tropical Ecology 13: 5-11.

Moore R., Anderson A.R., Ray D., Walker C., Pyatt D.G., Evans H.F., Carter C.I., Straw N.A., Wairhouse D. and Winter T.G. (1995). Soil biodiversity: A literature review. Scottish Natural Heritage, No.17.

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.

Parkin T.P. and Shelton D.R. (1992). Spatial and temporal variability of carbon furan degradation in soil. J Environmental Qualitative 21: 672-678.

Priha O., Graystone S., Pennaner T. and Smolandes A. (1999). Microbial activities related to C and N cycling and microbial community structure in the rhizospheres of *Pinus sylvestris, Picea aber* and *Betula pendula* seedlings in an organic and mineral soil. FEMS Microbiol Ecol 30: 187-199.

Pugh G.J.F. (1962). Studies on fungi in coastal soil. II Fungal ecology in a developing salt marsh. Trans Br Mycol Soc 45: 560-566.

Rehder H. and Schafer A. (1978). Nutrient turnover studies in alpine ecosystems. IV. Communities of the Central Alps and a comparative survey. Oecologia (Berl) 34: 309-327.

Reid W.V. (1994). Setting objectives for conservation evaluation. In: Systematics and Conservation evaluation (Forey PL, Humphries CJ and Vane–Wright RI eds), Systematics Association special Vol 50, Clarenden Press, Oxford p 1-13.

Robertson G.P., Klingensmith K.M., Klug M.J., Paul E.A., Crum J.R. and Ellis B.G. (1997). Soil resources, microbial activity and primary production across an agricultural ecosystem. Ecol Appl 7: 158-170.

Rover M. and Kaiser E.A. (1999). Spatial heterogeneity within the plough layer, low and moderate variability of soil properties. Soil Biol Biochem 31: 175-187.

Saksena S.B. (1955). Ecological factors governing the distribution of soil microfungi in some forest soils of Sagar. J Ind Bot Soc 34: 262-268.

Sami A., Vare H. and Strommer R. (2000). Soil microbial activity and biomass in the primary succession of a dry heath forest. Soil Biol Biochem 32: 1091-1100.

Schinner F. (1978). Streuabbauunter suchungen inder Alainegion oberen subalpinen. Stufe. In: Okologische Analsen von Almflachen in Gasteiner Tal (Cernusca A ed), Universitatsuer lag wags Innsbruck p 251-258.

Shukla A.K. and Mishra R.R. (1992). Influence of soil management systems on the microfungal communities of potato fields. Cryptogamie Mycol 13(2): 135-144.

Singh K.P. (1968). Litter production and nutrient turnover in two deciduous forests of Varanasi. Proc Symp Recent Adv Trop Ecol 655-665.

Singh S.S., Tiwari S.C. and Dkhar M.S. (2001). Evaluation of soil degradation, using physicochemical, biochemical and biological parameters in the humid tropics of Arunachal Pradesh. Ann For 9(2): 287-292.

Sparling G.P. (1985). The soil biomass. In: Soil organic matter and Biological activity (Vaughan and Malcolm RE eds), Martinus, Nihoff/Dr W Junk, Dordrecth, Boston, Lancaster p 223-262.

Stoyan H., De-Polli H., Bohm S., Robertson G.P. and Paul E.A. (2000). Spatial heterogeneity of soil respiration and related properties on the plant-scale. Plant Soil 222: 203-214.

Thakur A.K. and Morris (1928). A biochemical study of some soil fungi with special reference to ammonia production. J Indian Inst Sci All p 141.

Tiwari S.C. (1988). Studies on microbial communities and their activities in soil of pineapple (*Ananas comosus* L.) plantations. Ph.D. Thesis, North Eastern Hill University, Shillong, India.

Tiwari S.C. and Sharma G.D. (1998). Altitudunal variations in dehydrogenase and urease activity and microbial population in soils of the Eastern Himalayas. Journal of Hill Research 11(1): 22-25.

Tiwari S.C., Tiwari B.K. and Mishra R.R. (1986). Temporal and depth-wise variations in carbon dioxide evolution and microbial population in pineapple plantation soils. Journal of Soil Biology and Ecology 6: 67-76.

Tiwari S.C., Tiwari B.K. and Mishra R.R. (1987a). The influence of soil 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. (1987b). Temporal and depth-wise variations in urease and dehydrogenace activities and bacterial population in pineapple plantation soils. Proceeding Indian Academy Sciences 53(B): 173-176.

Tiwari S.C., Tiwari B.K. and Mishra R.R. (1991). Seasonal variations in microfungal population in pineapple (*Ananas comosus.* L) orchard soils. Acta Botanica Indica 19: 55-61.

Waksman S.A. (1927). Principles of Soil Micorobiology. Bailliere Tindall and Co, London.

Warcup J.H. (1950). The soil plate method for the isolation of fungi from soils. Nature (London) 166: 117-118.

Wardle D.A. (1992). A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in the soils. Biological Reviews 67: 321-358.

Wardle D. and Giller K. (1996). The quest for a contemporary ecological dimension to soil biology discussion. Soil Biochemistry 28: 1549-1554.

Wicklow D.T. and W.F. Whittingham (1974). Soil microfungal changes among the profiles of disturbed conifer-hardwood forests. Ecology 55: 3-16.

Wohlrab G., Tuveson R.W. and Olmstead C.E. (1963). Fungal populations from the early stages of succession in Indian dune sand. Ecology 44: 734-740.

Young I.M. and Ritz K. (1998). Can there be a contemporary ecological dimension to soil biology without a habitat? Soil Biol Biochem 30: 1229-1232.

Zeller V., Bardgett R.D. and Tapeiner U. (2001). Site and management effects on soil microbial properties of sub-alpine meadows, a study of land abandonment along a north-south gradient in the European Alps. Soil Biol Biochem 33: 639-649.