IMPACT OF SHIFTING CULTIVATION AND MINING ON LAND DEGRADATION AND SOIL BIOLOGICAL PROCESSES IN NOKREK BIOSPHERE RESERVE OF MEGHALAYA

by

VANLALHRUAII RALTE

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Dedicated to the
loving memory
of my father
late R. Siamkunga

NORTH-EASTERN HILL UNIVERSITY
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I, Ms. Vanlalhruaii Ralte, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of the 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 University / Institute.

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

(Vanlalhruaii Ralte)

27/9/04
(Head, Department of Botany
North-Eastern Hill University)

Head
Department of Botany
School of Life Sciences
N.E.H.U., Shillong-22

23/9/04
(Supervisor)

23/9/04
(Joint Supervisor)

Dr S K Barik
Reader in Ecology
Department of Botany
North-Eastern Hill University
Shillong-793 022

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Abbreviations:

BR = biosphere reserve
C = undisturbed core zone
J12 = 10-12-yr. old jhum fallow
J6 = 6-8-yr. old jhum fallow
J1 = 1-yr. old jhum fallow
CM = coalmine spoil
LM = limestone mine spoil
BD = bulk density
SMC = soil moisture content
SL = sandy loam
S = sandy
CL = clay loam
SCL = sand-clay-loam
WHC = water holding capacity
WSA = water-stable aggregate
MiA = microaggregate
MaA = macroaggregate
CEC = cation exchange capacity
SOC = soil organic carbon
SOM = soil organic matter
TKN = total Kjeldahl nitrogen
P = available phosphorus
K = exchangeable potassium
MBC = microbial biomass carbon
MBN = microbial biomass nitrogen
DHA = dehydrogenase activity
UA = urease activity
Mpot = mineralization potential
A_f = ammonification
N_f = nitrification
N_m = mineralization
LD = litter decomposition
SE = standard error

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Chapter 1

General introduction

Biosphere reserves (BRs), where human beings constitute an integral component of the conservation measures, are excellent sites for exploring the impact of anthropogenic activities on the vegetation, biodiversity and soil. BRs are meant for preserving and generating natural and cultural values, through management that is scientifically correct, culturally creative and operationally sustainable (UNESCO 1995). Each biosphere reserve exemplifies the characteristic ecosystem of one of the world's major bio-geographic regions. These are land areas and/or coastal marine areas involving human communities as integral component with objectives ranging from complete protection (core zone) to intensive yet sustainable development. Thus, the biosphere reserve concept is a key to achieving Man and Biosphere programme's objective of striking a balance between conserving biodiversity, encouraging economic and social development and preserving cultural values. Thirteen biosphere reserves have been established till date all over India (UNESCO 2001) (Table 1.1).

Each BR is intended to fulfill three basic objectives:

- *In situ* conservation of biodiversity (genetic resources, species and ecosystems) of natural and semi-natural ecosystems and landscapes.
- To foster sustainable economic development of the human population living within and around the BR.
- To provide facilities for long-term ecological studies, environmental education and training, and research and monitoring related to local, national and global issues of conservation and sustainable development.

Table 1.1. Biosphere reserves of India

Sl. No.	Name of the BR	State(s)/ U.T.	Date of notification	Area under BR (km^2)
1	Nilgiri	Karnataka, Kerala & Tamil Nadu	01/08/1986	5520 (1240)
2	Nanda Devi	Uttar Pradesh	18/01/1988 (revised on 07/02/2000)	5860.69 (624.62 + 87.5)
3	**Nokrek (Tura range)**	**Meghalaya**	**01/09/1988**	**820 (47.48)**
4	Great Nicobar	Andaman & Nicobar Island	06/01/1989	885 (520 + 185)
5	Gulf of Mannar	Tamil Nadu	18/02/1989	10,500 (560)
6	Manas	Assam	14/03/1989	2,837 (520)
7	Sundarbans	West Bengal	29/03/1989	9,630 (1700)
8	Similipal	Orissa	21/06/1994	4,374 (845)
9	Dibru-Saikhowa	Assam	28/07/1997	765 (340)
10	Dehang-Dubang	Arunachal Pradesh	02/09/1998	5,111.5 (4094)
11	Pachmarhi	Madhya Pradesh	03/03/1999	4,926.28 (524.37)
12	Khanchendzonga	Sikkim	07/02/2000	2619.92 (1784)
13	Agasthyamalai	Kerala	12/11/2001	1,701 ( )

* values in parentheses indicate area of the core zone

The functions/ objectives of each BR are fulfilled by dividing the BR into the following zones (UNESCO 1995):

(i) *Core zone*: One or more core zones, which are securely protected sites for conserving biological diversity, monitoring minimally disturbed ecosystems, and undertaking non-destructive research and other low-impact uses such as eco-tourism and education.

(ii) *Buffer zone(s)*: A well-defined buffer zone(s) usually surrounds or adjoins the core zone(s), and is used for cooperative activities compatible with sound ecological practices, including environmental education, recreation and applied and basic research.

(iii) *Transition area:* A flexible transition area or area of cooperation containing a variety of agricultural activities, settlements and other uses in which local communities, management agencies, scientists, non-governmental organizations, cultural groups, economic interests and other stakeholders work together to manage and sustainably develop the area's resources.

The Nokrek BR located in the western part of Meghalaya in the Garo Hills, having an area of 820 sq. km, has a core zone of 47.48 sq. km and a buffer zone of 772.52 sq. km. It lies between 90°13' E and 90°35' E longitudes, and 25°20' N and 25°29' N latitudes. The vegetation in the core zone comprises of evergreen forest, semi-evergreen forest and deciduous forest. The bamboo patches, secondary successional communities on jhum fallows, grassland and riverine forest occur in the buffer zone. The Nokrek BR has the following distinct and unique features:

1.1. Core zone: The highest point of the Garo Hills i.e. Nokrek Peak (1412 m) lies within the core zone. The area of national park i.e. the core zone, as well as the entire ridge of Tura range is very important because of the floral and faunal diversity and more importantly due to the fact that the ridge forms the primary catchment of all the major water systems in Garo Hills.

The area is very important from the point of view of ethnological and ethnobotanical studies and the undisturbed core zone of the BR is the last remnant of the representative primary vegetation of the region. During the course of study, 213 medicinal plants were recorded from this region. Among the recorded medicinal plants, *Taxus baccata* is critically rare. Many rare, endemic and threatened plant species were found in the core zone. It is the center of origin of rare and endangered species. Substantial size of *Citrus indica* population is found in the natural habitat with natural protective barriers of BR and it has also a gene pool of other rare *Citrus* spp.

The area of core zone is also large enough for the normal movement of the wildlife population.

1.2. Buffer zone: The Garo tribe with a total population of 39,432 inhabit in 129 villages distributed within the buffer zone. Major human activities in the buffer zone are, shifting cultivation, coal mining and limestone mining. Many villagers have raised plantations of orange, areca nut, cashew nut and pear in the buffer zone of BR. Orange orchards cover about 955 ha or 1.16 % of the total area of the BR.

1.2.1. Shifting cultivation

About 85 % of the population extensively practice slash and burn agriculture (locally called 'jhum') in the entire buffer zone. The average area under jhum in each village is 243.70 ha. It is estimated that 31,473 ha or 38.47 % area on the hill slopes of the biosphere reserve is influenced by slash and burn agriculture.

The practice of shifting cultivation is primarily based on the concept of conservation and economic use of natural resources. This is, however, only true when sufficient time is allowed for the regeneration of the forest and resumption of its normal ecological productivity. It is essential not to prolong the crop phase beyond the threshold time and leave the land until its fertility is completely restored.

The shifting cultivation is characterized by clearing of the entire vegetation in a plot of land and burning of dried slash during winter, followed by mono and mixed cropping for 1-2 years depending on the availability of land. Thereafter the field is abandoned for natural recovery of soil fertility. Though the length of the shifting cultivation cycles varies from village to village, it is remarkably short in the southern parts of the BR. In the northern part, it varies from 6-10 years, but in the southern parts, it has been reduced to 3-4 years. Extensive cutting and burning activities during shifting cultivation is the major cause of land degradation, habitat destruction and ultimately depletion of the biodiversity. Exploitation of various resources is also directly or indirectly affecting the soil condition and plant diversity of the area. Reduced jhum cycles could further aggravate the problem of soil reclamation through vegetation regrowth.

1.2.2. Coal and limestone mining

Besides slash and burn agriculture, substantial area of biosphere reserve has been affected due to coal and limestone mining. The extensive coal mining is going on in West Darrenggre, Siju, Pyndengru-Balphakram and Selsela Blocks in and around the BR leading to creation of a forested landscape dotted with mine spoils.

The limestone quarrying is being done around Dana-Adugiri village. The limestone quarries are located near the boundary of the BR, whereas the coalmines are in the villages very close to the core zone. Both, coal as well as limestone mining activities is causing tremendous loss to the vegetation and soil. It is estimated that 35,900 million tonnes of coal and 510 million tonnes limestone are present in and around the BR (Ashutosh 1998).

Surface mining of coal causes enormous damage to the flora, fauna, disrupts local hydrological cycle and alters characteristics of soil system due to destruction of the vegetal cover. Nutrient-deficient sandy mine spoils are generally hostile to plant growth and revegetation. Reclamation strategies, other than natural colonization, are very tardy process.

Shifting cultivation affects the physico-chemical and biological characteristics of soil in different ways. Cultivation reduces the proportion of water stable macro-aggregates and increases the proportion of micro-aggregates (Monreal and Kodama 1997). Soil aggregates, especially water stable aggregates, are of special importance for allowing high water infiltration and good soil structure. Any change in the aggregate structure is expected to alter soil properties and its fertility level.

Degradation of the soil system occurs through organic matter loss resulting from tillage (Balota *et al.* 2003) and clearing of natural vegetation (Srivastava and Singh 1989). This is primarily accelerated by microbial decomposition (Seybold *et al.* 1999). Soil degrading processes like erosion, leaching and mineralization have negative impact on organic carbon. Clearance of natural vegetation for agriculture changes the amount and quality of organic matter input into soil and alters soil temperature and moisture regimes, and biological processes affecting litter decomposition and soil organic matter dynamics.

Singh *et al.* (2002) found that high temperature and low moisture content of surface coalmine spoils are important factors that limit plant growth. Lunt and Hedger (2003) reported that vegetation growth on coalmine spoils is a slow process, mainly due to soil characteristics.

A proper understanding of the impact of these activities on the vegetation, biodiversity and soil of the BR is a pre-requisite for the effective management of the BR. The main objective of the present research thus was to study the impact of shifting agriculture and mining on the soils of the buffer zone of the Nokrek BR.

In order to achieve the objective of the research, various soil physico-chemical and biological properties, and soil biological processes were studied in the undisturbed core zone, as well as in jhum fallows of three different ages viz., 10-12-, 6-8- and 1-year old and mining sites in the buffer zone of the BR over a period of three years (2000-2002) on a seasonal basis. The thesis is divided into 8 chapters. Chapter 1 gives a general **introduction** to the study. Chapter 2 presents the **review of literature** on the subject related to the present research. Chapter 3 describes the **location, geology, climate, flora, fauna and demographic features**. Chapter 4 deals with the **physico-chemical properties of the soil**. Chapter 5 includes results of **soil microbial biomass carbon and nitrogen** and chapter 6 discusses **enzyme activities and nitrogen mineralization in soil**. Chapter 7 presents findings of **leaf litter decomposition**. The major findings of chapter 4-7 are critically discussed in an integrated manner under **general discussion** in chapter 8. **Summary** and list of cited **references** are appended in the end.

Land degradation is defined as "reduction or complete loss of natural capacity to produce healthy and nutritious crops resulting from erosional loss of nutrient-rich surface soil, leaching of nutrients, reduced water retention, surface sealing, hardpan formation and accumulation of toxic chemicals, etc. The loss of productivity occurs in spite of very favourable climatic and other non-edaphological factors" (Somasiri 1994).

Disturbance in the vegetation, which is a force, often abrupt and predictable, kills or damages the organisms, alters the availability of resources leading to erosional loss of soil and nutrients, and ultimately leads to degradation of land. Its role has been emphasized in many ecosystems such as tropical rainforests (Congdon and Herbohn 1993), temperate forests (Finzi *et al.* 1998), pasture communities (Lavorel *et al.* 1998), coral reefs (Karlson and Hurd 1993; Connell *et al.* 2004) and herbaceous vegetation (Tessier *et al.* 2003). Huston (1994) in his theoretical model of diversity variation postulated that 'disturbance' and 'competitive exclusion' are the two fundamental processes controlling diversity in the ecosystem. The intermediate disturbance hypothesis (Roxburgh *et al.* 2004) states that disturbances such as tree fall gaps lead to predictable successional sequence in which one tree species replaces another, and results in coexistence of many canopy tree species. If disturbances are rare, almost all the sites are dominated by late successional canopy species and total stand diversity is low. If disturbances are frequent, almost all sites are dominated by early successional pioneer species and diversity is again low. However, at intermediate rates of disturbance, there is a range of sites - some are newly disturbed, some are of intermediate age and some are old enough to be dominated by late successional canopy species. This allows full range of species traits to coexist and leads to maximal species diversity.

Loss of biodiversity, severe erosion and land degradation are associated with the destruction of forest and the practice of shifting cultivation (Srivastava 1997). Cultivation practice deteriorates soil structure, increases loss of soil organic matter (Garcia-Oliva *et al.* 1999) and reduces the proportion of macro-aggregates (Monreal and Kodama 1997) through the loss of the labile organic matter that is responsible for the formation of macro-aggregates. Inappropriate soil and water management under rainfed agriculture is one of the primary causes of land degradation (Scholes *et al.* 1994). Frequent perturbations caused by fire, weeding, hoeing and crop harvest lead to loss of soil structure and increase in soil compaction (Vasquez *et al.* 1996).

In shifting agriculture, depletion of fertility during cultivation is the prime cause of land abandonment. During the fallow period, fertility level is improved and the land becomes usable for further cultivation. Eight to ten years of fallow have been found sufficient to re-establish fertility level through a net transfer of nutrient back to the soil (Tiessen *et al.* 1992). Short jhum cycle of 5-years permit only partial recovery of soil fertility during the fallow period (Ramakrishnan and Toky 1981).

Soil texture is the most fundamental attribute of soil fertility. Soil fertility increases with clay content, but high clay-soils are prone to drought in dry areas and to flooding in wet areas (Scholes *et al.* 1994). Plant production is lower in clay soils than in the sandy soils in arid areas, but higher in wet areas because of the interacting effects of clay on soil water and nutrient status. The clay content has a controlling influence on the soil water retention (Scholes 1990). However, it is negatively related to the mineralization of nitrogen (Cote *et al.* 2000). Soil structure influences organic matter turnover and soil fertility, and plays a key role in the ability of soil to store organic matter (Balabane 1996).

Soil aggregation is the cementing of soil particles into secondary units (Unger and McCall 1980). Micro-aggregates are the building blocks of soil structure. It ranges in size from 50-250 µm in diameter and can unite to form macro-aggregates of a general size of 250 µm to 2 mm through the action of temporary and transient building agents (Beare *et al.* 1994). Soil aggregates, particularly water stable aggregates, are of special importance for allowing high water infiltration and good soil structure. Any change in the aggregate structure is expected to alter soil properties. Cultivation reduces the proportion of water stable macro-aggregates and increases the proportion of micro-aggregates (Monreal and Kodama 1997).

Soil organic matters store nutrients, improve nutrient cycling, increase cation exchange capacity, buffer against rapid change in pH, serve as energy source for micro-organisms, build the soil structure, increase water infiltration and reduce the effects of compaction. Soil degrading processes like erosion, leaching and mineralization have negative impact on organic carbon. Cultivation tends to increase the rate of organic matter loss in soils primarily by accelerated microbial decomposition (Seybold *et al.* 1999).

The microbial biomass in soil, a small (2-5 % by weight of soil organic matter) but most active and labile component of soil organic matter (Grant *et al.* 1993, Bosatta and Agreen 1994, van Ginkel *et al.* 1994, Ley *et al.* 2001 etc), is of particular importance in soil fertility considerations because it is more susceptible to various management practices than the bulk organic matter (Sparling 1992). It plays a crucial role in the mineralization of key nutrients from soil organic matter where it acts as a reactive agent to facilitate the processes of conversion of nutrients in dead organic mass to inorganic mass. It acts as a sink as well as a source of nutrients for plant growth (Seely and Lajtha 1997; Zogg *et al.* 2000). Garcia-Gill *et al.* (2000) opined that soil microbial biomass measurements could give an early indication of changes in soil organic matter long before changes in total soil carbon can be detected. Values of microbial biomass can provide satisfactory estimates of the restoration of soil microbial population (Raghubanshi and Singh 1992). It also serves as an ecological marker for predicting ecosystem recovery after disturbance (Hargreaves *et al.* 2003) and acts as a sensitive indicator of soil toxicity (Brookes and McGrath 1984). Studies in tropical forest ecosystem in relation to disturbance (Luizao *et al.* 1992; Henrot and Robertson 1994) have established that microbial diversity and its biomass decrease as a result of disturbance.

Enzyme activity measurements in soil have been increasingly used to investigate changes in microbial functions due to anthropogenic impacts. The activity can begin to change much sooner (1-2 years) than other properties (e.g. SOC), thus providing an early indication of the trajectory of soil quality with changes in soil management (Dick 1999). It has been shown in many investigations that increase in SOM content increases enzyme activities (e.g. Klose *et al.* 2003). The enzyme activities react readily to cultivation practices and change seasonally. The activities are affected by the microbial consertia, plants, animals, substrate availability, and physical and chemical characteristics (Vepsalainen *et al.* 2001).

Among the macronutrients, deficiency of nitrogen and phosphorus adversely affects re-establishment of species on degraded sites (Tyler and Olsson 1993). Nitrogen mineralization is of crucial importance in natural ecosystems where it is a limiting nutrient for plant growth. It has been suggested that N losses from forest ecosystems following tree cutting are caused either by increased N mineralization rates or reduced N uptake by plants after disturbance (Kaye and Hart 1997). Moisture-limited seasonality of N mineralization has been reported in dry tropical forests (Singh *et al.* 1991), in Scottish highlands (Morecroft *et al.* 1992) and in taiga forests (Clein and Schimel 1995). Positive correlation between soil moisture and N mineralization was reported in dry tropical (Srivastava 1992) and temperate (Orchard and Cook 1983) forest soils.

Litterfall and decomposition processes maintain and regulate energy flow and nutrient cycling in forest ecosystems (Fioretto *et al.* 2003). Both above ground litter and fine roots are important source of organic matter and nutrient input in forest soils. It has been established that the turnover rate of fine roots is faster than the litter in tropical forest ecosystems and they play a major role in nutrient absorption by plants and contribute substantially to the soil organic matter (Vogt *et al.* 1991). Fine roots also conserve nutrients by preventing leaching losses from the ecosystem (Arunachalam *et al.* 1996).

Leaf litter is a major component of the total litterfall in most ecosystems (Xiong and Nilsson 1997). Decomposition and nutrient release rates from decaying litter are determined by the resource quality of the organic material, environmental conditions and decomposer organisms (Swift *et al.* 1979). Much emphasis has been placed on the mass balance between leaf litter inputs and leaf litter decomposition (Xiong and Nilsson 1997) and on the effect of chemical composition of leaf litter on the rate of decomposition (Cadisch and Giller 1997). Clearance of natural vegetation for agriculture changes the amounts and qualities of organic matter inputs to soil, its moisture regimes, and biological processes that affect decomposition and organic matter dynamics.

Fungi, bacteria and invertebrates (Dighton 1997), rainfall and soil moisture content (Sujatha *et al.* 2003), and quality of litter in terms of its susceptibility to attack by decomposers are the main factors that affect litter decomposition. The rate of litter decomposition has been related to initial concentration of nitrogen (Quested *et al.* 2002), lignin (Sariyildiz and Anderson 2003), carbon to lignin ratio (Aber and Melillo 1982) and lignin/ N ratio (Melillo *et al.* 1982). Palm and Sanchez (1991) found that the polyphenol / N ratio was a better parameter than lignin to estimate the rate of litter decomposition process. Nitrogen availability in the soil-litter interfaces is believed to control the rate of litter decomposition (Prescott 1995, 1996). It is well known that enzyme activities in decomposing litter in soils are directly related to rates of litter mass loss (Sinsabaugh *et al.* 1992; Klose *et al.* 2003).

Mining brings about complete degradation of land and loss of fertile soil substratum. Though mining and use of minerals in India date back to the Indus-Valley Civilization, coal mining was first taken up in India in 1774 by Sumner and Heatly in Raniganj coalfield (Tandon 1990). In north-east India, coal mining was initiated by Medlicott (1869, 1874) followed by preliminary excavations by Fox (1935-38) in Garo Hills. Coalfields of Garo Hills were re-examined by Arogyaswami, Sen, Rao and Puri in 1949-50.

In the hills of Meghalaya, the coal bearing sedimentary formations are sub-horizontal to gentle dipping in nature. Coal occurs at various places in Meghalaya namely, Laitryew, Cherrapunji, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, East Darrangiri, Pynursla, Lungryrdem, Mawlong-Shella-Ishamati in Khasi Hills, West Darrangiri, Siju, Pyndengru-Balphakram, Salsella Block in the Garo Hills and Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioski in Jaintia Hills (Das Gupta 1999).

Large deposits of limestone of Shella formation of the Jaintia group (Eocene) occur along a belt following the southern border of the Khasi hills between Lamgaon to Chargaon in the Langrin area via Therriaghat, Shella and Mawsynram. In the Garo hills, prominent exposures of the upper Sylhet limestone (Shella formation) are found along the southern slope of the Tura range. The best development is seen near Siju-Arteka and Siju-Songmong in the Simsang valley. The chemical composition of limestone of Meghalaya (Shella formation) is CaO - 50.82 %, MgO - 1.07 %, R_2O_3 - 3.04 % and Insolubles - 3.1 % (Krishnaswamy 1988).

Destruction of the vegetal cover during surface coal mining is invariably accompanied by an extensive damage and loss to the flora, fauna and disruption of hydrology and soil biological systems. The disturbed and haphazardly mixed infertile, consolidated and unconsolidated materials overlying a coal seam, termed as overburdens, when dumped in unmined areas in the vicinity of the coalmines create **mine spoil**.

Coalmine spoils when freshly tipped have a great range of particle size ranging from large pieces of shale to silt and clay (Molyneux 1963). Specific soil-related constraints to mine soil reclamation are low pH, soil erosion, elemental toxicity (e.g. Al, Mn, etc) and non-availability of N, P and K in the spoil (Barnhisel and Hower 1997; Hossner *et al.* 1997). Richardson *et al.* (1971) reported that with high clay content, soils become water-logged, whereas with high silt content, the soils become compact forming crusts which often restrict seedling growth and entry of water and air into the soil system. Dollhopfs *et al.* (1981) reported similar results further stressing that water movement, unfavourable root growth and dispersed clay are noticeable with high sodium and low soluble salt contents resulting in nutrient loss. Lyngdoh (1995) reported lower bulk density in spoils in comparison to the unmined sites and Uma Shankar *et al.* (1993) reported higher proportions of sand in the mine-affected sites than the unaffected control site.

The pH of coalmine spoils ranges from 1.5 to 8.0. Exposure, abundance and neutralizing properties of minerals along with their combustion bring about such a variation in pH (Gemmell 1977). Bradshaw and Chadwick (1980) opined that freshly formed coalmine spoils are generally neutral or slightly alkaline in nature. The pyritic exposure and subsequent conversion to acids is a microbe-mediated process and iron-oxidising bacteria *Thiobaccillus ferro-oxidans* are known to aid the process (Chappell and Craw 2003).

Coalmine spoils represent extreme rigid substrata for plant growth and development where natural succession occurs at a slow pace (Lunt and Hedger 2003). Among the factors, which hinder the growth of plant species on these spoils, acidity merits special mention. Inhibition of root growth, reduced nutrient availability and poor soil structure are found to be associated with extreme acidity (Iverson and Wali 1992). The number of species colonizing mine spoils increases with the increase in pH of the substratum (Bradshaw and Chadwick 1980). Besides acids, coalmine spoils contain toxic level of soluble elements such as Fe, Al, Mn and Cu. The physical factors, which limit plant establishment and survival, include high temperature, moisture stress (Singh *et al.* 2002), soil particle size, surface instability leading to erosion and compaction (Adams 1998).

Though K, Ca and Mg contents may also become critical for growth of plants, N and P are the two principal limiting nutrients for plant growth in areas affected by mining (Singh *et al.* 2002). Leaching contributes to nitrogen deficiency in spoils and could lead to non-availability of N to plants growing on spoils (Palmer and Chadwick 1985). Total phosphorus content is often similar in acid and limestone soils, whereas easily exchangeable and soil solution concentrations of phosphate are very low in limestone minespoils (Tyler and Olsson 1993).

Due to water and wind erosion, the nutrient holding capacity is greatly reduced in the sloppy spoils since the litter layer, which is an exchange site for nutrients is lost from the system (Jha and Singh 1992). Among the macronutrients, deficiency of nitrogen and phosphorus adversely affects re-establishment of species on degraded sites.

Microbial biomass and enzyme activities that are responsible for mineralization of nutrients and its subsequent availability to plants are least studied on coal and limestone mine spoils, therefore, there was paucity of information in literature related to these aspects.

3.1. Location

Nokrek Biosphere Reserve is spread over an area of 820 sq. km covering parts of East Garo Hills, West Garo Hills and South Garo Hills districts of Meghalaya. It lies between 90°13' E and 90°35' E longitudes (Fig. 3.1). The Nokrek BR is situated on entirely hilly terrain of Tura ranges of mountain system ranging from 200 m to 1412 m altitude. The highest peak of this ridge called Nokrek Peak (1412 m a.s.l.) lies within the core zone of the Nokrek BR. The core zone, which is also designated as Nokrek National Park, comprises of 47.48 sq. km area of the ridge of Nokrek Hills, spread in east-west direction. The core zone supporting the virgin vegetation of the area is also the catchment area of the major rivers of the Garo Hills, namely Simsang, Dedari, Dareng and Ganol, which originate from the Nokrek BR. The buffer zone of the Nokrek BR has an area of 772.52 sq. km.

3.2. Climate

Garo Hills enjoy tropical climate with high rainfall, high humidity, mild summers and moderately cold winters. It has three seasons of which summer corresponds to the months from March to April, rainy season from May to October and winter from November to February.

Monsoon rains are received between April and October with highest rainfall occurring during June and August. Rainfall is scanty during November to March. The monthly rainfall data recorded at Sangsanggre, Tura town during last three years (2000-2002) yielded 3012 mm average annual rainfall (Fig. 3.2) spread over 117 days in the year.

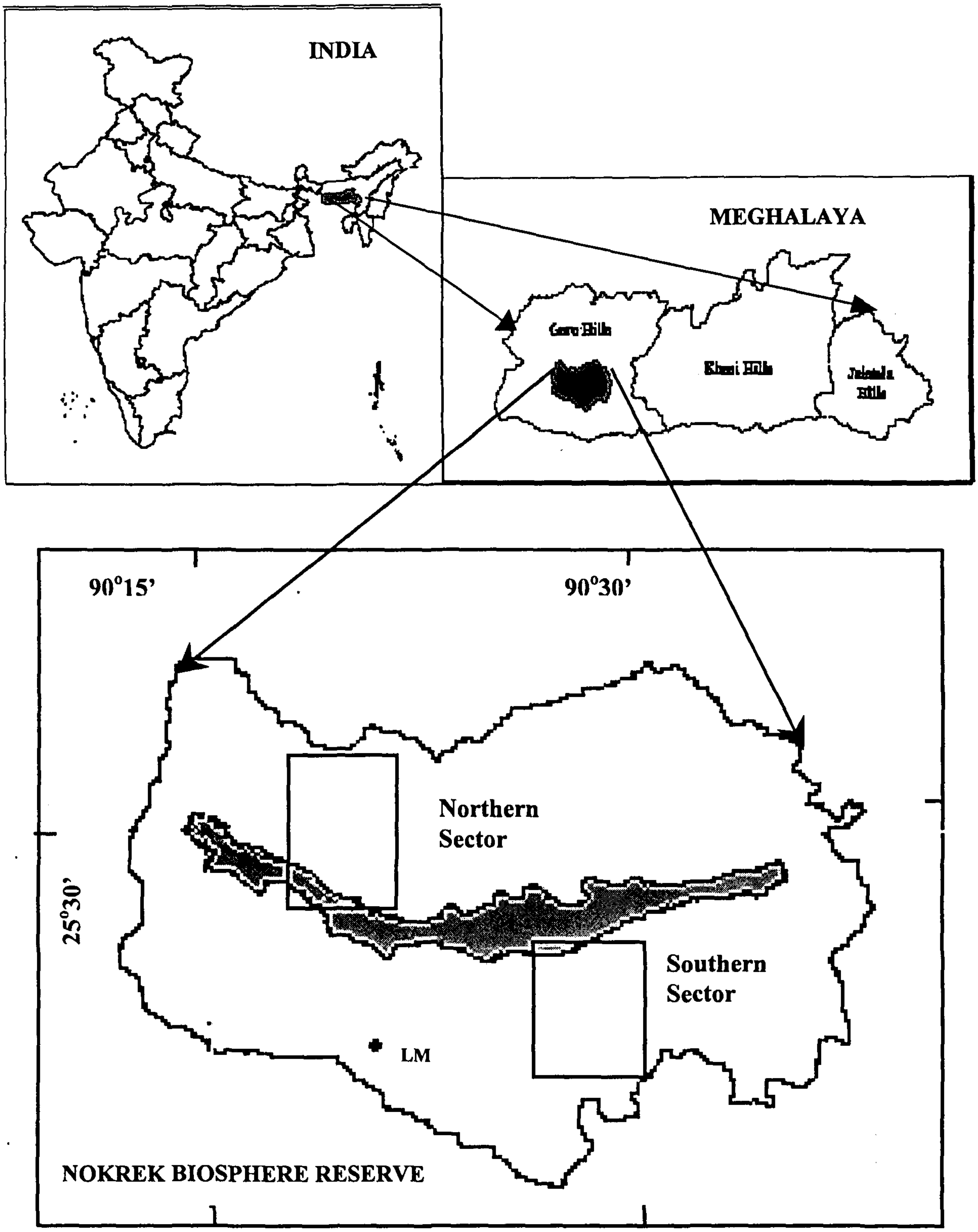

Fig. 3.1. Map showing the location of study sites in the Nokrek Biosphere Reserve, Meghalaya

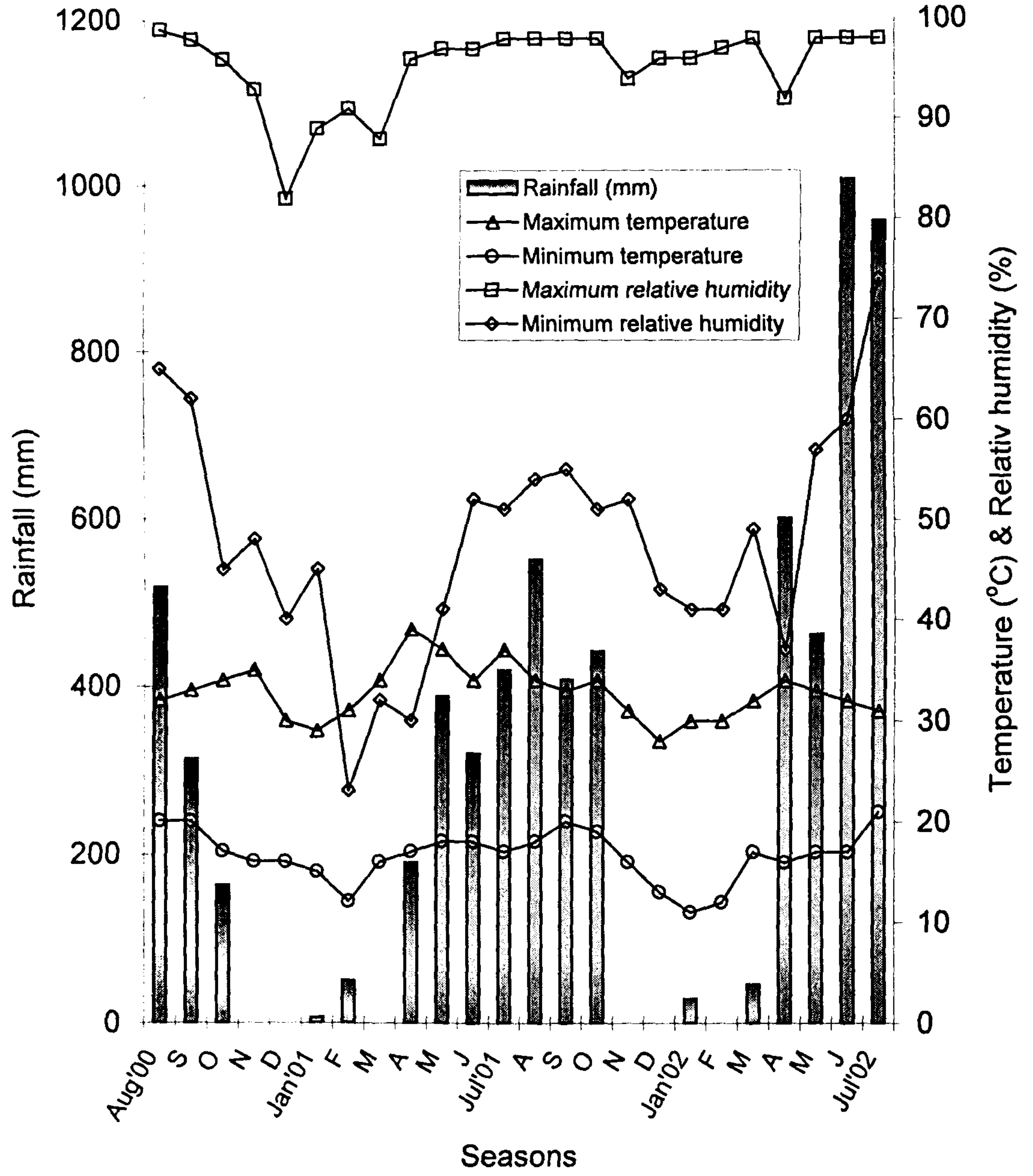

Fig. 3.2. Mean monthly rainfall, mean maximum and minimum temperatures and relative humidity at the study area

Temperature varies from place to place in the BR depending on aspect, altitude and vegetation type. The southern part of the BR is slightly warmer than the northern part, which is the coldest area of the Garo Hills. The average monthly temperature during the study period ranged from 33.4°C to 14.8°C. The highest temperature (39°C) was recorded in April and the lowest (10°C) in February (Fig. 3.2).

The average relative humidity during the same period varied from a minimum of 23 % to a maximum of 98 %.

3.3. Geology and soil

The Garo Hills region of the Meghalaya Plateau is an extensively dissected tract formed of gneissic rock with old inlier, Sela group, while some patches in the northern and southern parts are formed of recent alluvium and Jaintia Series/ Simsang Series rocks respectively. The basement of Gneissic Complex covering an area about 60 % of the Garo Hills of Pre-Cambrian age is the oldest litho unit exposed in central and northern parts of Garo Hills. It is composed of gneissic, granulites, migmatites, amphibolites and Bonded Iron-Formation (BIF) intruded by basic and ultra basic bodies. Over the Pre-Cambrian crest, sedimentary rock belonging to the Gondwana group comprising of pebble bed, sandstone and carboniferous shells with streak and lenses of coal occur in localized patches. Occurrences of basaltic trap rock and rhyolitic crystals tuff as detached sheet lenses, is indicative of Cretaceous-Paleocene volcanic activity in West Garo Hills districts. Sediments of tertiary age occur extensively around Siju, Adugre, Baghmara, Rongram and many other localities towards southern part of Garo Hills. The Shella formation is composed of sandstone, lithomargic clay, shells and coal seams. The important minerals found in the region are coal, limestone, pyrite, phosphorite gypsum, glass sand, clay and iron. A strip of vast coal deposit occurs in the southern part of the Garo Hills districts. This coal is of Lower Eocene geological horizon. The rocks concerned belong to the Jaintia Series. In the entire Garo Hills the total reserve of coal has been estimated to be 39,000 million tonnes, and West

Darenggre area comprises more than 35 % of it. A considerable portion of this deposit falls under the Nokrek BR, which lies in the southern and eastern sides of the buffer zone of the BR. Because of the ecological setting, peculiar land holding systems and lack of infrastructure, unscientific extraction of coal in unorganized sector is going on and the area affected by coal mining is increasing day-by-day (Sharma 2002).

The soil of the BR is sandy to sandy loam and red, brown to dark brown in colour. It is acidic in nature throughout the core zone except in the limestone mining areas. Within the buffer zone pH of the soil was lowest in the coalmine areas and highest in the limestone areas where the soil reaction was alkaline. The core zone soils are rich in organic matter and nutrients whereas buffer zone soils show sign of degradation especially in the nutrient content.

3.4. Demographic features

In total, 129 villages are located within the buffer zone of the BR. The total human population within the BR is 39,432 with an average density of 48 individuals per sq. km (Table 3.1). Ratio of female to the male population is 1106. The population of the children below 15 years of age is 15,591.

Table 3.1. Demographic features of the buffer zone of Nokrek BR

Number of villages	129
Human population	*ca.* 40,000
Population density / km^2	48.08
Number of primary schools	90
Number of middle schools	21
Current land area under jhum cultivation	*ca.* 31,473 ha*
Average land area under cultivation (jhum / village)	243.70 ha
Land area under orchards	955 ha*

(Source: Ashutosh 1998, *: Talukdar *et al.* 2001)

The Garos, the main indigenous tribe residing in the BR are Christian by faith, and only a small population (about 10 %) follows their traditional Garo religion. Garo society is matrilineal. They have traditional institutions to maintain the cohesive structure of family kinship and social relationships among the clans within their respective territorial jurisdictions called "*A'khings*". The major means of subsistence is shifting cultivation, though some families have started fruit trees plantation, tea gardens and settled paddy cultivation as the subsidiary sources of earning.

3.5. Fauna

The BR and its surrounding area are abode of large number of mammals, birds, fishes, reptiles, amphibians and invertebrates. The mammals found in the BR area are tiger, Indian elephant, Indian bison, leopard, leopard cat, sambar, barking deer, Indian wolf, common fox, wild pig, Malay bear, black bear, capped langur, Assamese macaque, pig tailed macaque, stump tailed macaque, Rhesus macaque, giant squirrel, binturong, slow loris, pangolin, flying squirrel, civet, five stripped palm squirrel, hare, Indian porcupine, mongoose, golden cat, hog badger, ferret badger, etc.

Among the birds, crested serpent eagle, great-pied hornbill, Indian pied hornbill, forest eagle owl, barn owl, scops owl, cuckoo shrike, Indian three-toed forest kingfisher, crow pheasant, Himalayan golden back woodpecker and Indian forest night jars are important. Besides, there are many varieties of ducks, parakeets, pigeons, doves, swifts, swallows, bee-eaters, wagtails, mynahs, barbets, etc. A variety of lizards and snakes are also found in the BR.

3.6. Vegetation

The following vegetation types were identified in the BR, based on the community characteristics and human activities:

A. Undisturbed natural ecosystems

    1. Subtropical evergreen forest
    2. Tropical evergreen forest
    3. Tropical semi-evergreen forest
    4. Tropical moist deciduous forest

5. Riverain forest

B. Disturbed / managed ecosystems

6. Successional communities on jhum fallows
7. Bamboo groves
8. Orchards
9. Paddy fields
10. Tea gardens
11. Coal mining areas
12. Limestone mining areas

All the above-mentioned ecosystems except riverain forests and tea gardens have been mapped in the BR using satellite imageries (Talukdar *et al.* 2001). The area occupied by different undisturbed and disturbed ecosystems in the BR is given in Table 3.2.

Table 3.2. Vegetation types and the area under each type in the Nokrek BR

Vegetation type	**Area in sq. km**	**Area in per cent**
I. Terrestrial		
(a) Forest:		
Sub-Tropical Evergreen Forest	30.54	3.70
Tropical Evergreen Forest	137.71	16.79
Tropical Semi-Evergreen Forest	109.25	13.52
Moist Mixed Deciduous	191.69	23.37
Bamboo groves	15.66	1.91
Total	**484.85**	**59.29**
(b) Non-forest:		
Orchard	9.55	1.16
Valley agriculture (paddy)	7.14	0.87
Abandoned jhum fallows	210.99	25.73
Current jhum field (2001)	103.38	12.61
Total	**331.06**	**40.37**
II. Lotic ecosystem (rivers)	**4.09**	**0.49**

The undisturbed subtropical and tropical forest ecosystems form the core zone. In the buffer zone, 421.71 sq. km (45.71 %) area is occupied by the natural ecosystems and 346.72

sq. km (44.88 %) area is covered by the semi-natural and modified ecosystems. Out of 346.72 sq. km, 40.69 % area is under shifting cultivation.

The undisturbed forest and the shifting cultivation sites are located in the northern side and the mining areas are in the southern side of the BR (Fig. 3.1)

Undisturbed forest

The undisturbed forests found at higher elevation of the core zone are evergreen in nature and may be grouped under subtropical broad-leaved hill forest described by Champion and Seth (1968). These forests cover an area of 30.54 sq. km, major portion (64.32 %) of which occur in the core zone. The dominant tree species in these forests are *Helicia nilagirica, Calophyllum polyanthum, Dysoxylum gobara* etc, which are densely interwoven by lianas. The shrub species include, *Dendrocnide sinuate, Piper griffithii, Rhynchotechum ellipticum*, etc (Table 3.4).

The ground vegetation is dominated by *Impatiens* spp., *Elatostemma* spp., *Ophiorrhiza* sp., etc. Ferns and other pteridophytes are common on the forest floor. The tree trunks and branches are covered with profuse growth of mosses, ferns, orchids and other epiphytes such as *Raphidophora* spp.

Shifting cultivation

In the buffer zone of the BR, 85 % of the Garo families practice shifting cultivation or 'jhum'. According to an earlier estimate, the total area under shifting cultivation was 150 sq. km (Ashutosh 1998). However, the present estimate shows that the area under the current jhum as well as abandoned jhum fallows is over 300 sq. km (Table 3.2).

The shifting agriculture involves alternation of a short cropping period with a relatively long fallow period. It is during the latter phase that recovery of soil fertility occurs, which in turn determines economic yield of the next cropping phase. The cycle of the shifting cultivation, *i. e.* length of the intervening fallow period between two cropping phases varies from village to village within the BR and depends on the availability of land and population of the village. It was observed that in the northern part of the BR the duration of jhum cycle was 6-10 years, while in the southern part it was only 3-4 years. The cropping period in majority of the villages was of two years. Paddy, maize, potato, tapioca, ginger and a variety of vegetables are cultivated in jhum fields.

The abandoned jhum fields pass through a series of successional stages; each dominated by different species, starting from weed dominated pioneer community to a more diverse pre-climax vegetation. Once the fields are abandoned, a dense cover of weeds such as *Eupatorium adenophorum, E. odoratum, Ageratum conyzoides, Blumea balsamifera* and grasses appear within a year. After about two years, tree coppice shoots from the existing stumps and root suckers begin to overtop the weed cover. Besides, early colonize tree species also invade the fallow lands by the end of the second year. Thus, a 2-3 years old fallow shows the abundance of *Macaranga indica* saplings. Further tree growth suppresses the weeds through shading and the community is dominated by *Macaranga indica, Eurya acuminata, Callicarpa vestita* and *Saurauia* spp. These communities have only one layer of densely packed trees composed of more or less even-aged individuals (Table 3.4).

Coal mining

Coal mining is restricted to the southern part of the BR between 200 m and 500 m elevations, where the forest is tropical evergreen to semi-evergreen type. Commercial extraction of the coal started in 1985 in Darenggre area. Since then the number of coalmines in the BR has increased many folds. At present, the activity is going on in eighteen villages. These are, Darenggre, Jetragre, Budugre, Budu Wathegre, Rongragre, Khamalgre, Rongmagre, Gopgre, Khibalamagre, Phamagre, Pharamgre, Anchenggre, Rongphakgre, Rongmigre, Rongrugre, Ruabangagre, Bandarigre and Rongdianchengre. The thickness of the coal seam ranges from 0.46 m to 2.13 m. Each of these villages has 50-300 quarries depending on the number of families in the village. Each quarry occupies an area within 30-50 m radius, while the spoils around each quarry have a radius of 20-25 m. Tree felling in the coal mine areas has adversely affected the forest cover and mine spoils are devoid of herbaceous cover (Table 3.4).

Limestone mining

Limestone mines are also located in the southern part just inside the boundary of the BR. The natural vegetation in this area varies from tropical semi-evergreen to moist deciduous forest. Compared to the coalmines, limestone mines occupy much less area within the BR and therefore have less impact.

3.7. Site selection

Based on the field observations and vegetation characteristics, 14 sites – two in the core area (C-a and C-b), nine on jhum fallows, two in coal mining areas (CM-a, CM-b) and one site in limestone mining area (LM) were selected for the study (Plate 1-6). The sites on jhum fallows were grouped under three age groups *viz.*, 10-12-year old (J_{12}), 6-8-year old (J_6) and 1-year old (J_1). Each of these three groups was studied by selecting three sites (J_{12}a-c, J_6a-c, J_1a-c) (Table 3.3).

Table 3.3. Selected study sites in the BR and their altitudes

Ecosystems	Site codes	Altitude (m)
Undisturbed subtropical evergreen forest in the core zone	C-a	1300
	C-b	1300
10-12-yr.old jhum fallows	J_{12}a	1100
	J_{12}b	1228
	J_{12}c	1179
6-8-yr. old jhum fallows	J_6a	1160
	J_6b	1078
	J_6c	1133
1-yr. old jhum fallows	J_1a	972
	J_1b	1120
	J_1c	1291
Coalmine spoils	CM-a	250
	CM-b	314
Limestone mine spoil	LM	149

Plate 1a: An over view of undisturbed core zone

Plate 1b: Interior of undisturbed core zone

Plate 1c: Encroachment of core zone

Plate 2: 10-12-yr. old jhum fallow

Plate 3: 6-8-yr. old jhum fallow

Plate 4: 1-yr. old jhum fallow

Plate 5a: Rat-hole in the coal mining area

Plate 5b: Coalmine spoil

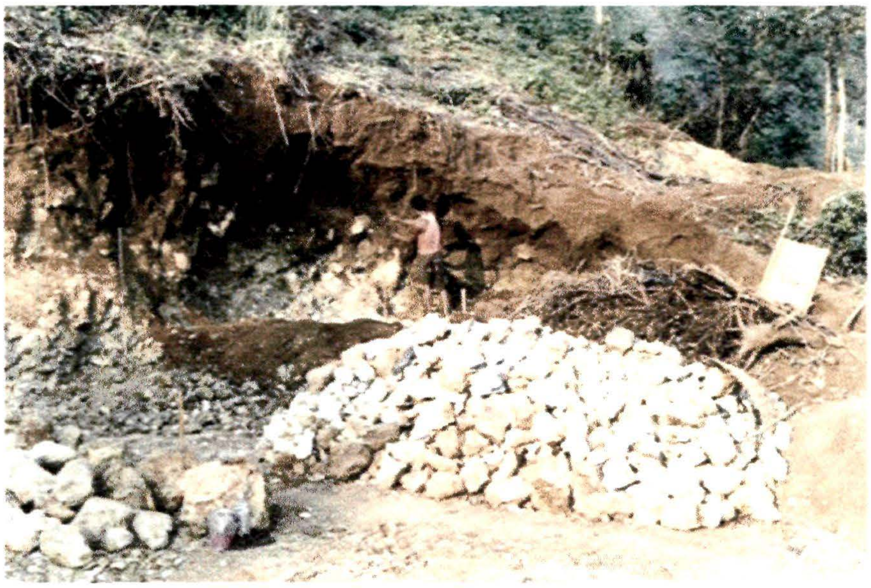

Plate 6a: Limestone extraction

Plate 6b: Limestone mine spoil

3.8. Vegetation characteristics

In each of the selected sites, ten quadrats of 10 m x 10 m were laid randomly for the study of woody (>5 cm CBH) individuals including tree, liana and shrub species. For the ground vegetation ten quadrats of 1 m x 1 m were studied randomly in two different seasons (dry and wet seasons). Importance value index (IVI) was calculated according to Misra (1968) and results are briefly presented in Table 3.4.

In the core zone, *Helicia nilagirica* was the dominant tree species while *Aphanamixis wallichii* and *Dysoxylum gobara* were the co-dominant species. *Macaranga indica* was the dominant species in the jhum fallows and *Eurya acuminata* and *Callicarpa vestita* were the co-dominant species. *Rhynchotechum ellipticum* was the dominant shrub species in the core zone and *Piper grifithii* and *Chasalia oxysporoides* were the co-dominant shrub species. Jhum fallows were dominated by *Solanum myriacanthum, Rubus khasianus* and *Clerodendrum viscosum. Desmodium triquetrum* was the dominant shrub species in the coalmine spoils and co-dominant species were *Cissampelos pareira* and *Ziziphus oenoplea.* Limestone mine spoil was dominated by *Smilax aspera* and the co-dominant species were *Trigonostemon semperflorens* and *Morinda angustifolia.* Among the herb species, *Pteris quadriaurita* was the dominant species in the core zone and jhum fallows were dominated by *Eupatorium adenophorum.* Coalmine spoils were dominated by *Paspalum* sp. and limestone mine spoil by *Pteris* sp.

Table 3.4. Dominant plant species, their IVI values and densities (individual ha^{-1}) at different sites of Nokrek BR*

Site	Trees			Shrubs			Herbs		
	Dominant species	IVI	Density (ha^{-1})	Dominant species	IVI	Density (ha^{-1})	Dominant species	IVI	Density (ha^{-1})
Core zone	*Helicia nilagirica*	19.64	342	*Rhynchotechum ellipticum*	24.60	8500	*Pteris quadriaurita*	25.81	13250
	Aphanamixis wallichii	15.73	35	*Piper griffithii*	17.37	5500	*Elatostemma sikkimense*	24.17	13000
	Dysoxylum gobara	13.47	100	*Chasalia oxysporoides*	13.76	4000	*Globba clarkei*	16.50	8000
10-12-yr. old jhum fallows	*Macaranga indica*	61.36	1475	*Solanum myriacanthum*	17.50	6630	*Eupatorium adenophorum*	23.56	35500
	Eurya acuminata	55.30	1625	*Rhynchotechum ellipticum*	14.02	4219	*Eragrostis unioloides*	16.64	22750
	Callicarpa vestita	24.31	355	*Rubus khasianus*	13.47	2712	*Abacopteris multilineata*	14.59	24500
6-8-yr. old jhum fallows	*Macaranga indica*	103.21	3520	*Clerodendrum viscosum*	32.01	10000	*Eupatorium adenophorum*	31.03	62250
	Eurya acuminata	50.13	1460	*Rubus khasianus*	21.04	4250	*Ageratum conyzoides*	13.50	26500
	Callicarpa vestita	42.56	780	*Leea edgeworthii*	11.46	2000	*Pogostemon auricularis*	12.24	23000
1-yr. old jhum fallows	*Macaranga indica*	-	-	-	-	-	*Eupatorium adenophorum*	23.57	147000
	Eurya acuminata	-	-	-	-	-	*Ageratum conyzoides*	16.41	900000
	Callicarpa vestita	-	-	-	-	-	*Borreria articularis*	16.40	104250
Coal-mine spoil	-	-	-	*Desmodium triquetrum*	31.02	2500	*Paspalum* sp.	41.42	26000
	-	-	-	*Cissampelos pareira*	20.32	1500	*Ageratum conyzoides*	21.82	9000
	-	-	-	*Ziziphus oenoplea*	18.70	1250	*Bidens pilosa*	16.53	6500
Lime-stone mine spoil	-	-	-	*Smilax aspera*	55.64	70	*Pteris* sp.	41.20	4750
	-	-	-	*Trigonostemon semperflorens*	40.16	45	*Axonopus compressus*	39.19	5750
	-	-	-	*Morinda angustifolia*	33.18	30	*Eragrostis artovirens*	31.26	4500

*Detailed study of floristic composition and structure of plant communities were carried out as a part of the project work along with the present study (Prabhu 2004)

Chapter 4

Physico-chemical properties of soil

4.1. Introduction

Soil physical properties play an important role in determining the physical conditions in soil where several biological processes take place (De Vos *et al.* 1994), while its chemical characteristics determine the quality of a particular soil (Hassink 1997). Physico-chemical characteristics such as soil temperature, moisture, bulk density, water holding capacity, pH, total organic C, N and P, ammonium-N and nitrate-N influence soil microbial population and their activities, and uptake of water and nutrients by roots (Arunachalam *et al.* 1997). Soil development and plant succession go hand-in-hand and factors of soil complex such as pH, organic matter and nutrient contents influence community development on degraded and disturbed lands (Aweto 1981; Pandey and Singh 1984/1985).

Nutrient regeneration in soil during revegetation of forest have been studied by Aweto (1981) and Pandey and Singh (1984/1985) in the tropical region and by Ramakrishnan and Toky (1981) and Mishra and Ramakrishnan (1983) in the humid subtropics of north-east India. They have found that the nutrient level increases with the increase in the age of the jhum fallows. Studies conducted by Barik *et al.* (1992) suggest that the microenvironmental conditions especially air temperature and soil moisture regime strongly influence survival and growth of tree seedlings on the forest floor after disturbance.

Changes in physical and chemical properties of soil of the BR as a result of a variety of human activities such as shifting agriculture and mining in the buffer zone were analyzed on the basis of several parameters such as bulk density and porosity, moisture content, texture, water holding capacity, water-stable aggregates, pH, cation exchange capacity, total organic C, total Kjeldahl N, available P and exchangeable K. The results of these analyses have been presented in this chapter.

4.2. METHODS

4.2.1. Soil sampling

Soil samples were collected in January (winter) and August (rainy) during 2001 and 2002 from the selected sites. At each site, three to five replicate samples were collected using a steel corer (6.3 cm diameter) from 0-10 and 10-20 cm depths. The replicated samples were mixed thoroughly to obtain one composite sample. Fresh samples were used for the analysis of soil moisture content and the rests were air-dried and sieved through 2 mm sieve and stored for further analysis.

4.2.2. Soil analysis

Soil texture and bulk density were determined by Bouyoucos hydrometer method and gravimetric method respectively (Allen *et al.* 1974), and porosity was calculated from the bulk density data. Water-stable aggregate structure was determined by following Elliot's (1986) method and water holding capacity (WHC) was determined by Keen's box method by using copper cups of 5.6 cm internal diameter and 1.6 cm height (Piper 1942). Soil moisture content was determined by taking 10 g fresh sieved soil (Allen *et al.* 1974) and pH was determined electrometrically by a digital pH meter (SYSTRONICS-335) in 1 : 2.5 w/v suspension of soil in deionised water (Anderson and Ingram 1993). Cation exchange capacity was determined after extracting the exchangeable bases from the soil with 1 M ammonium acetate solution (pH 7.0) followed by the replacement of ammonium-N with potassium chloride and distillation with magnesium oxide (Allen *et al.* 1974).

Organic carbon was determined by colorimetric method (Anderson and Ingram 1993). Soil organic matter content was obtained by multiplying the soil organic carbon content by 1.724 assuming that the SOM contains 58 % of carbon (Allen *et al.* 1974).

Total Kjeldahl nitrogen was determined by digesting air-dried soil samples with concentrated sulphuric acid using Kjeltabs (TECATOR) as catalysts, on a block digester. Distillation and titration were done simultaneously in a TECATOR KJELTEC AUTO 1030 ANALYSER. Available phosphorus was determined after extracting soil phosphorus in 0.5 M sodium bicarbonate solution by ammonium-molybdate blue method (Allen *et al.* 1974) and exchangeable potassium was determined by using flame photometer after extracting with 1 M ammonium acetate solution (pH 7.0) (Allen *et al.* 1974).

4.2.3. Statistical analysis

The data were analyzed using two-way and three-way analysis of variance (ANOVA) (fixed effect model) to test the effects of season, soil depth and/or site on various physico-chemical properties of the soil. Inter-relationship between different soil properties, and affect of climatic variables on soil properties were analyzed by computing coefficients of correlation (r) according to Zar (1974).

4.3. RESULTS

4.3.1. Physical properties of soil

Soil texture and bulk density (BD): The texture of the soil was sandy loam in the undisturbed core zone and jhum fallows of different ages, sandy in the coalmine spoil and sand-clay-loam to clay-loam in the limestone mine spoil. The clay content was generally higher at the lower depth (10-20 cm) except in the 10-12-yr. old jhum fallows and limestone mine spoil (Table 4.1). Two-way ANOVA revealed a significant variation ($p<0.01$) in the proportion of fine particles (silt + clay) in soils of different sites (Table 4.2). Bulk density of the soil showed a significant ($p<0.01$) variation due to site and soil depth. It gradually increased from 0.8 g/cm^3 in the limestone mine spoil to 1.8 g/cm^3 in the core zone (Table 4.1). The mean BD values for the upper soil layer (0-10 cm) were higher than the lower soil layer (10-20 cm) in jhum fallows and mine spoils. However, in the core zone, the BD of the soil was higher in the lower layer than the upper soil layer.

Table 4.1. Texture and bulk density of soil at the study sites

Sites	Depth (cm)	Proportion of soil particles			Textural class	BD (g/cm^3)
		Sand (%)	Silt (%)	Clay (%)		
Core zone*	**0-10**	**66.94**	**29.73**	**3.33**	**SL**	**1.20**
	10-20	**60.89**	**28.53**	**10.58**	**SL**	**1.79**
Jhum fallows:						
10-12-yr. old*	0-10	62.94	26.01	11.05	SL	1.14
	10-20	65.86	23.71	10.42	SL	1.18
6-8-yr. old*	0-10	75.05	19.37	5.58	SL	1.08
	10-20	61.78	26.14	12.08	SL	0.94
1-yr. old*	0-10	64.14	27.64	8.21	SL	1.09
	10-20	60.37	28.60	11.03	SL	1.00
Mean†	**0-10**	**67.38**	**24.34**	**8.28**	**SL**	**1.10**
	10-20	**62.67**	**26.15**	**11.18**	**SL**	**1.04**
Mine spoils:						
Coal*	0-10	92.74	3.52	3.74	S	1.70
	10-20	93.15	1.39	5.45	S	1.76
Limestone	0-10	37.94	32.18	29.88	CL	1.15
	10-20	50.64	25.05	24.30	SCL	0.79
Mean‡	**0-10**	**65.34**	**17.85**	**16.81**	**SL**	**1.43**
	10-20	**71.90**	**13.22**	**14.88**	**SL**	**1.28**

SL=sandy loam; S=sandy; CL=clay loam; SCL=sand-clay-loam

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

Table 4.2. Two-way ANOVA showing effect of sites and soil depths on fine particle (silt + clay) content in soils of the BR ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	13839.38	13839.38	...
Depth	1	4.13	4.13	0.11
Site	5	2448.22	489.64	12.59**
Residual	5	194.52	38.90	...
Total	**12**	**16486.25**	**1373.85**	**...**

Water holding capacity (WHC): Among the sites, WHC was highest in the core zone and lowest in the coalmine spoil, and it declined from upper (0-10 cm) to lower (10-20 cm) soil depth, except in case of limestone mine spoil (Fig. 4.1).

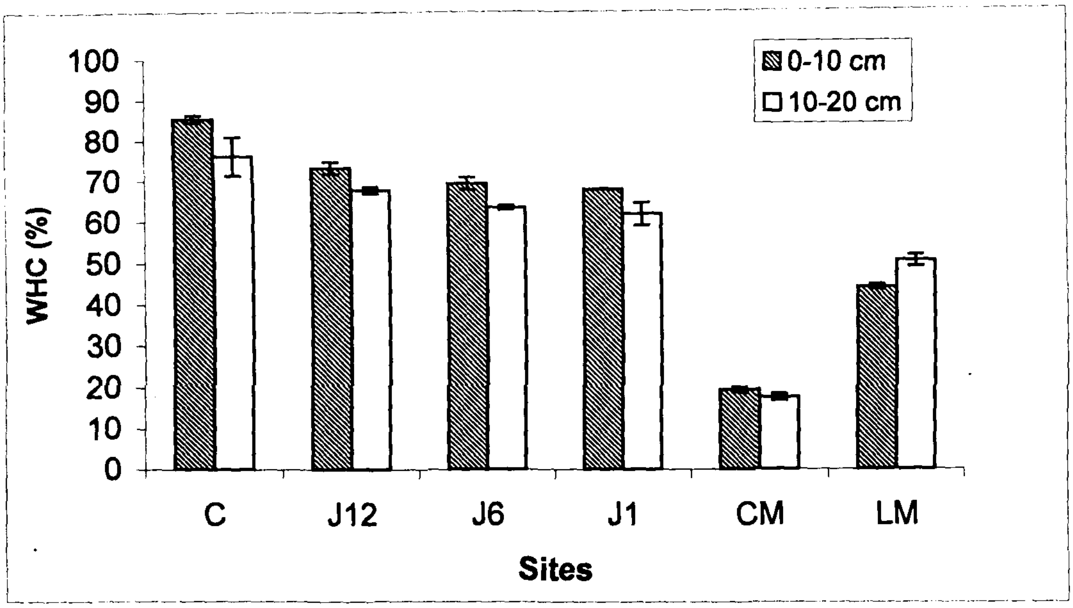

Fig. 4.1. Mean water holding capacity (WHC, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of 3-9 replicate sites.

Two-way ANOVA revealed a significant ($p<0.01$) difference between the different sites. It also increased significantly ($p<0.01$) with vegetation regrowth on jhum fallows (Table 4.3).

Table 4.3. Two-way ANOVA showing variation in water holding capacity (%) of soils due to sites and soil depths ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	40377.28	40377.28	...
Depth	1	41.22	41.22	2.78
Site	5	4988.82	997.76	67.25**
Residual	5	74.19	14.84	...
Total	**12**	**45481.51**	**3791.13**	**...**

Soil moisture content (SMC): Highest SMC was recorded in the undisturbed core zone followed by jhum fallows and lowest in the mine spoils (Table 4.4).

Table 4.4. Seasonal variation in soil moisture content (%, ±SE) at the study sites

Sites	Depth (cm)	2001			2002		
		Winter	Rainy	Mean	Winter	Rainy	Mean
Core zone*	**0-10**	**22.00**±0.47	**29.13**±0.79	**25.57**	**22.27**±0.07	**33.27**±0.83	**27.77**
	10-20	**25.15**±0.30	**28.03**±0.15	**26.59**	**22.53**±0.15	**28.60**±0.06	**25.57**
Jhum fallows:							
10-12-yr. old*	0-10	21.40±0.20	28.20±0.05	24.80	20.00±0.25	33.20±0.31	26.61
	10-20	24.17±0.55	22.72±0.39	23.45	23.80±0.49	28.10±0.20	25.95
6-8-yr. old*	0-10	13.60±0.75	26.43±0.03	20.02	16.67±0.07	26.60±0.26	21.64
	10-20	15.80±0.45	23.53±0.09	19.67	17.37±0.33	25.10±0.35	21.24
1- yr. old*	0-10	10.17±0.66	23.92±0.55	17.05	17.63±0.09	22.17±0.06	19.90
	10-20	11.30±0.41	22.04±0.22	16.67	17.70±0.06	17.90±0.06	17.80
Mean†	0-10	**15.06**	**26.18**	**20.62**	**18.10**	**27.32**	**22.71**
	10-20	**17.09**	**22.76**	**19.93**	**19.62**	**23.70**	**21.66**
Mine spoils:							
Coal*	0-10	5.90±0.77	12.83±0.20	9.37	7.20±0.12	11.23±0.12	9.22
	10-20	5.90±0.77	9.03±0.12	7.47	4.63±0.03	9.90±0.12	7.27
Limestone	0-10	6.27±0.60	18.60±0.44	12.44	10.30±0.10	20.87±0.38	15.59
	10-20	6.27±0.60	19.90±0.29	13.09	10.43±0.20	22.43±0.47	16.43
Mean‡	0-10	**6.09**	**15.72**	**10.90**	**8.75**	**16.05**	**12.40**
	10-20	**6.09**	**14.47**	**10.28**	**7.53**	**16.17**	**11.85**

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

The SMC varied significantly ($p<0.01$) between sites and soil depths (Table 4.5). During rainy season, values were higher in the surface soil and lower in the subsurface soil layer whereas the trend was reversed during winter season at most sites (Table 4.4 & Fig. 4.2).

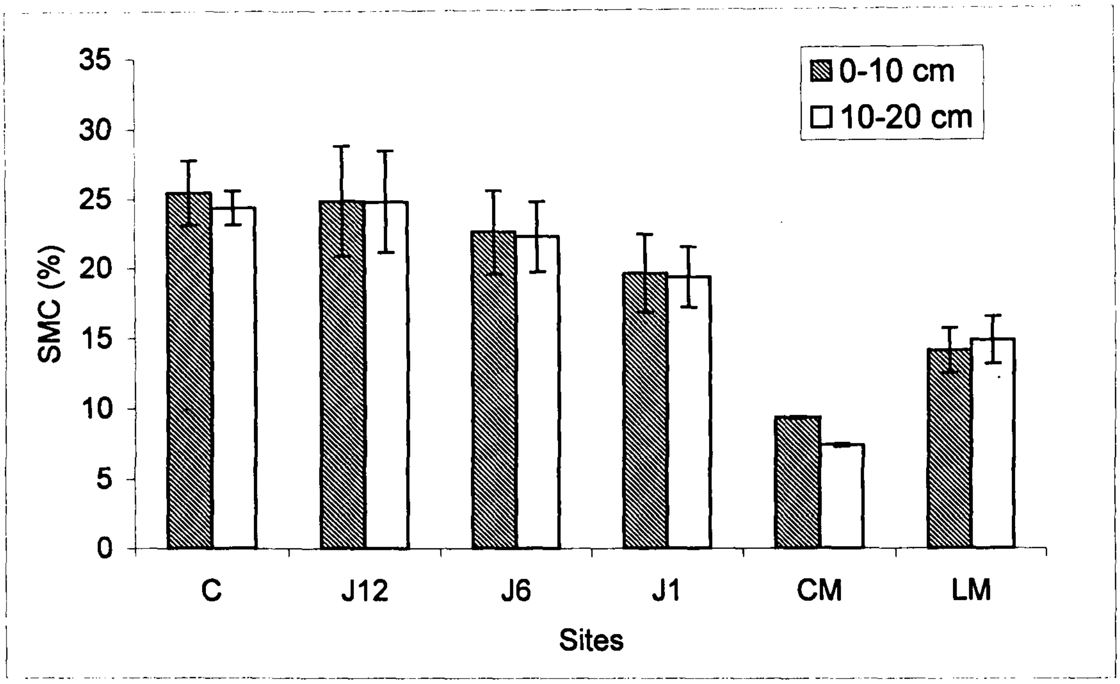

Fig. 4.2. Mean soil moisture content (SMC, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.5. Three-way ANOVA showing effects of site, season and depth on soil moisture content of the BR ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	16957.23	16957.23	...
Site	5	1853.88	370.78	52.21**
Season	3	37.31	12.44	1.75
Depth	1	715.10	715.10	100.70**
Site x season	15	28.39	1.89	0.27
Site x depth	5	72.47	14.49	2.04
Season x depth	3	36.51	12.17	1.71
Residual	15	106.52	7.10	...
Total	**48**	**19807.40**	**412.65**	**...**

Water-stable aggregates (WSA): Among different size classes of aggregates, the proportion of macroaggregates (0.3-2 mm) was maximum in all the stands (Table 4.6).

Table 4.6. Weight distribution (%) in different soil aggregate classes at different sites in the BR

Sites	Depth (cm)	Soil aggregate class (mm)						
		Macroaggregates				Microaggregates		
		>4.75	2-4.75	0.3-2	Total	0.063-0.3	<0.063	Total
Core zone*	**0-10**	**11.15**	**16.29**	**34.79**	**62.23**	**22.47**	**15.32**	**37.79**
	10-20	**11.81**	**16.04**	**42.75**	**70.60**	**17.27**	**12.14**	**29.41**
Jhum fallows:								
10-12- yr. old*	0-10	25.00	15.95	36.54	**77.49**	15.61	6.91	**22.52**
	10-20	23.84	16.61	41.93	**82.38**	13.87	3.76	**17.63**
6-8- yr. old*	0-10	18.07	12.94	45.37	**76.38**	16.8	6.83	**23.63**
	10-20	11.61	17.31	48.98	**77.90**	15.31	6.80	**22.11**
1- yr. old*	0-10	14.05	15.24	41.43	**70.72**	17.01	12.28	**29.29**
	10-20	13.15	10.11	49.22	**72.48**	20.08	7.46	**27.54**
Mean†	0-10	**19.04**	**14.71**	**41.11**	**74.86**	**16.47**	**8.67**	**25.14**
	10-20	**16.20**	**14.67**	**46.71**	**77.58**	**16.42**	**6.01**	**22.43**
Mine spoils:								
Coal*	0-10	7.86	5.00	38.60	**51.46**	38.77	10.69	**49.46**
	10-20	6.01	2.96	41.26	**50.23**	37.87	11.92	**49.79**
Limestone	0-10	28.13	17.31	35.15	**80.59**	8.78	10.65	**19.43**
	10-20	9.91	9.86	58.60	**78.37**	12.68	8.96	**21.64**
Mean‡	0-10	**18.00**	**11.16**	**36.88**	**66.04**	**23.78**	**10.67**	**34.45**
	10-20	**7.96**	**6.41**	**49.93**	**64.30**	**25.28**	**10.44**	**35.72**

Micro-aggregates = <0.3 mm; macro-aggregates = >0.3 mm

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

The proportion of micro-aggregates (<0.3 mm) in soil was more in the core zone than in the jhum fallows. On jhum fallows, it increased with the age of the fallow. The coalmine spoil had a high proportion of micro-aggregate and low proportion of macro-aggregate, but the trend was reversed in case of limestone mine spoil (Fig. 4.3).

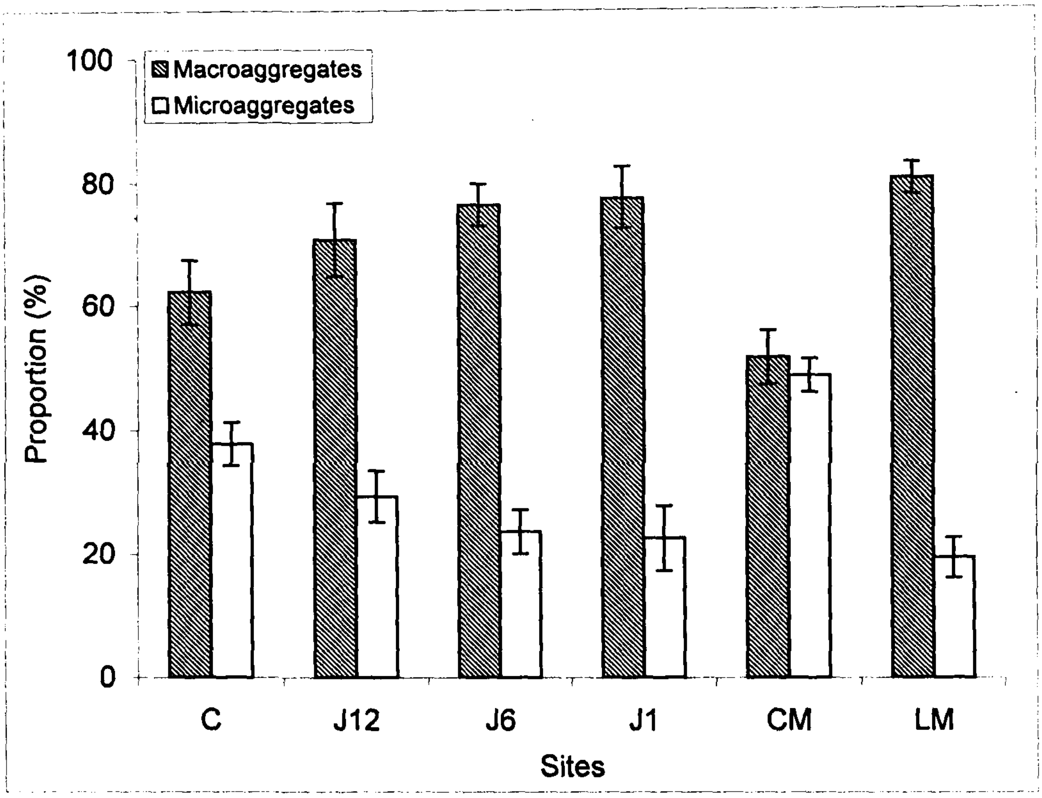

Fig. 4.3. Water-stable aggregates (±SE) in surface (0-10 cm) soil layer of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of 3-9 replicate sites.

4.3.2. Chemical properties of soil

Soil pH: The soil was acidic (pH=3.50 – 6.03) at all sites except in limestone mine spoil which was alkaline in nature (pH ≈ 8). The soil pH varied significantly among different sites (p<0.01) and varied between different seasons; the values were high during winter and low during rainy season (Table 4.7, Table 4.8 & Fig. 4.4). Lowest pH (3.50) was recorded in the coalmine spoil.

Table 4.7. Seasonal variation in pH (±SE) of the soil at the study sites in the BR

Sites	Depth	2001			2002		
	(cm)	Winter	Rainy	Mean	Winter	Rainy	Mean
Core	**0-10**	**6.00±0.10**	**5.91±0.01**	**5.96**	**6.03±0.05**	**5.29±0.02**	**5.66**
zone*	**10-20**	**5.88±0.02**	**5.77±0.07**	**5.83**	**5.93±0.01**	**4.41±0.02**	**5.17**
Jhum fallows:							
10-12-	0-10	5.82±0.01	5.75±0.05	5.79	6.05±0.09	5.44±0.03	5.75
yr. old*	10-20	5.55±0.01	5.27±0.02	5.41	5.46±0.05	5.13±0.01	5.30
6-8-	0-10	6.03±0.08	5.98±0.07	6.01	6.14±0.01	4.80±0.01	5.47
yr. old*	10-20	5.77±0.00	5.27±0.01	5.52	5.68±0.00	4.38±0.04	5.03
1- yr.	0-10	5.90±0.09	5.80±0.04	5.85	5.96±0.00	4.99±0.06	5.48
old*	10-20	5.58±0.02	5.53±0.04	5.56	5.61±0.003	4.28±0.08	4.95
Mean†	0-10	**5.92**	**5.84**	**5.88**	**6.05**	**5.08**	**5.56**
	10-20	**5.63**	**5.36**	**5.50**	**5.58**	**4.60**	**5.09**
Mine spoils:							
Coal*	0-10	3.50±0.04	5.72±0.03	4.61	4.89±0.03	4.73±0.03	4.81
	10-20	3.50±0.04	5.74±0.003	4.62	4.65±0.01	4.39±0.06	4.52
Lime-	0-10	8.02±0.12	8.31±0.003	8.17	7.84±0.01	7.80±0.02	7.82
stone	10-20	8.02±0.12	8.35±0.003	8.19	7.79±0.003	7.83±0.03	7.81
Mean‡	0-10	**5.76**	**7.02**	**6.39**	**6.37**	**6.27**	**6.32**
	10-20	**5.76**	**7.05**	**6.40**	**6.22**	**6.11**	**6.17**

*Mean of the replicate sites

†Mean of the jhum fallows

‡Mean of the mine spoils

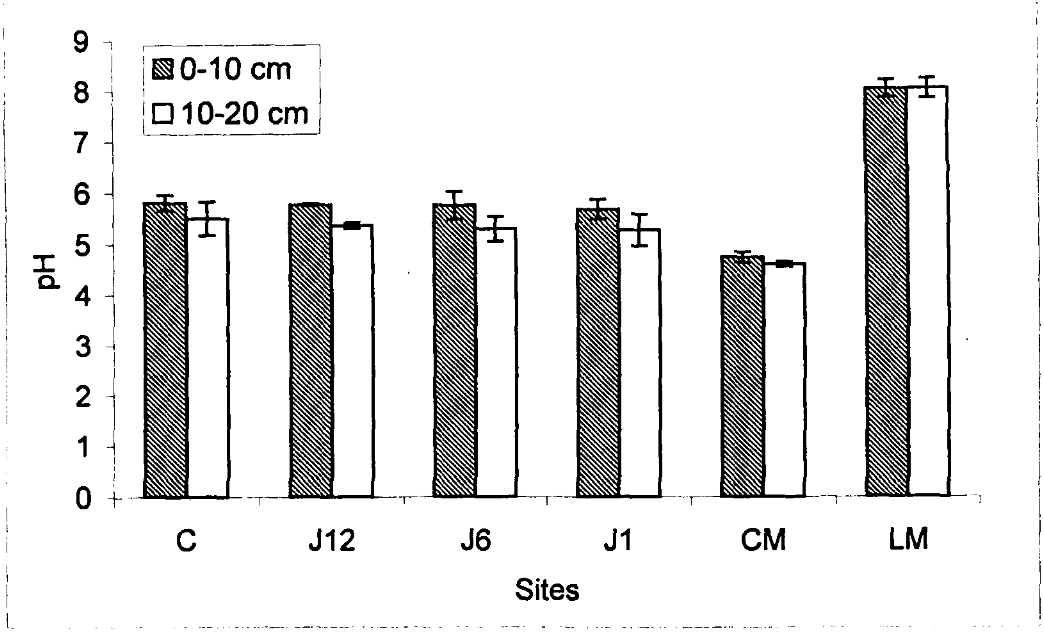

Fig. 4.4. Soil pH (±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers at different sites of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.8. Three-way ANOVA showing effects of site, season and depth on soil pH of the BR (p<0.01)**

Variation due to	d.f.	SS	MS	F
General mean	1	1615.53	1615.53	...
Site	5	51.58	10.32	88.26**
Season	3	2.24	0.75	6.39**
Depth	1	0.47	0.47	3.99
Site x season	15	0.98	0.07	0.56
Site x depth	5	4.61	0.92	7.89**
Season x depth	3	3.24	1.08	9.24**
Residual	15	1.75	0.12	...
Total	**48**	**1680.41**	**35.01**	**...**

Cation exchange capacity (CEC): Two-way ANOVA revealed a significant variation ($p<0.01$) in CEC between different sites (Table 4.9). The minimum value (2.92 meq/100g) was recorded in the coalmine spoil and maximum (19.23 meq/100g) in the limestone mine spoil. It increased significantly ($p<0.01$) from young to old jhum fallow (Fig. 4.5).

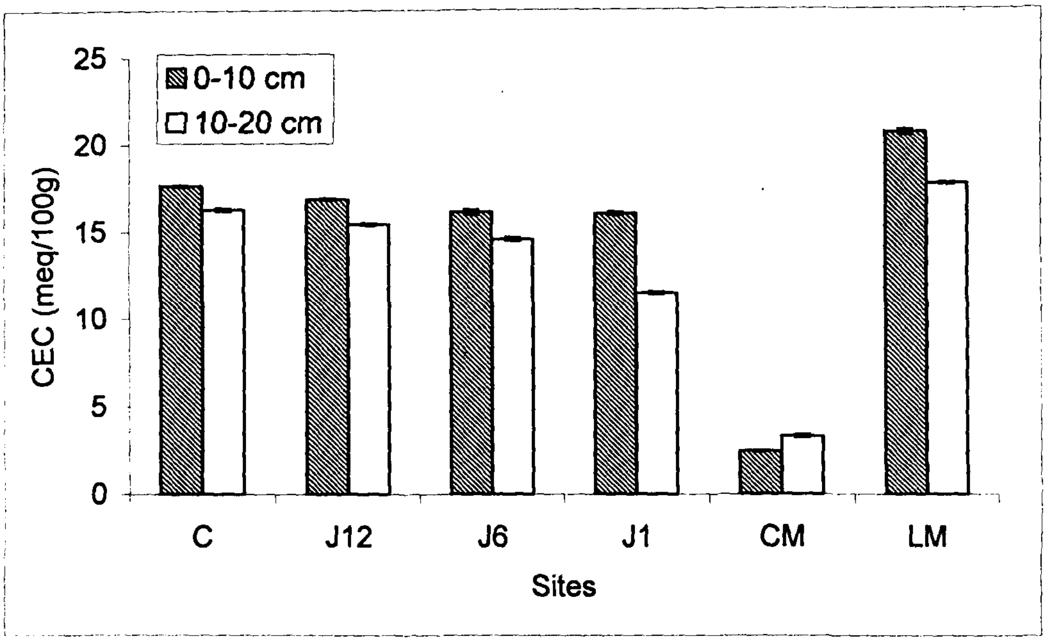

Fig. 4.5. Cation exchange capacity (CEC, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of 3-9 replicate sites.

Table 4.9. Two-way ANOVA showing effects of site and depth on cation exchange capacity in soils of the BR ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	2377.55	2377.55	...
Depth	1	10.07	10.07	6.19
Site	5	331.43	66.29	40.76**
Residual	5	8.13	1.63	...
Total	**12**	**2727.17**	**2455.54**	**...**

Total soil organic carbon (SOC): The SOC content was minimum during the winter season and maximum during the rainy season, and it declined significantly ($p<0.01$) with the increase in soil depth. Within the buffer zone, the 10-12-yr. old jhum fallow recorded a high value of 5.10 %, which gradually declined to 4.66 % in 6-8-yr. and 4.15 % in 1-yr. old fallow. The maximum value (5.78 %) was obtained in the core zone and minimum value (1.01 %) was recorded in the mine spoils (Table 4.10 & Fig. 4.6). Three-way ANOVA revealed significant variation in SOC content between sites and depths ($p<0.01$), and seasons ($p<0.05$) (Table 4.11).

Table 4.10. Seasonal variation in total soil organic carbon content (%, ±SE) in soils at the study sites

Sites	Depth (cm)	2001			2002		
		Winter	Rainy	Mean	Winter	Rainy	Mean
Core zone*	**0-10**	**5.45**±0.02	**6.70**±0.04	**6.08**	**4.69**±0.38	**6.86**±0.07	**5.78**
	10-20	**3.41**±0.05	**5.53**±0.05	**4.47**	**3.80**±0.37	**5.39**±0.02	**4.60**
Jhum fallows:							
10-12-yr. old*	0-10	4.50±0.03	5.89±0.00	5.20	4.33±0.04	5.68±0.03	5.01
	10-20	3.24±0.04	5.20±0.35	4.22	4.23±0.03	4.88±0.03	4.56
6-8- yr. old*	0-10	4.17±0.02	5.55±0.02	4.86	3.98±0.31	4.91±0.17	4.45
	10-20	2.39±0.06	4.30±0.01	3.35	2.89±0.02	4.16±0.07	3.53
1- yr. old*	0-10	4.29±0.23	4.23±0.01	4.26	2.72±0.01	5.35±0.00	4.04
	10-20	3.23±0.00	2.74±0.00	2.99	1.77±0.01	4.04±0.00	2.91
Mean†	0-10	**4.32**	**5.22**	**4.77**	**3.68**	**5.31**	**4.50**
	10-20	**2.95**	**4.08**	**3.52**	**2.96**	**4.36**	**3.66**
Mine spoils:							
Coal*	0-10	1.01±0.01	2.37±0.01	1.69	2.21±0.28	0.39±0.03	1.30
	10-20	1.01±0.01	1.02±0.04	1.02	2.11±0.31	0.33±0.01	1.22
Limestone	0-10	0.72±0.01	0.26±0.02	0.49	0.53±0.05	0.56±0.03	0.55
	10-20	0.72±0.01	0.84±0.02	0.78	0.37±0.02	0.64±0.02	0.51
Mean‡	0-10	**0.87**	**1.32**	**1.10**	**1.37**	**0.48**	**0.92**
	10-20	**0.87**	**0.93**	**0.90**	**1.24**	**0.49**	**0.88**

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

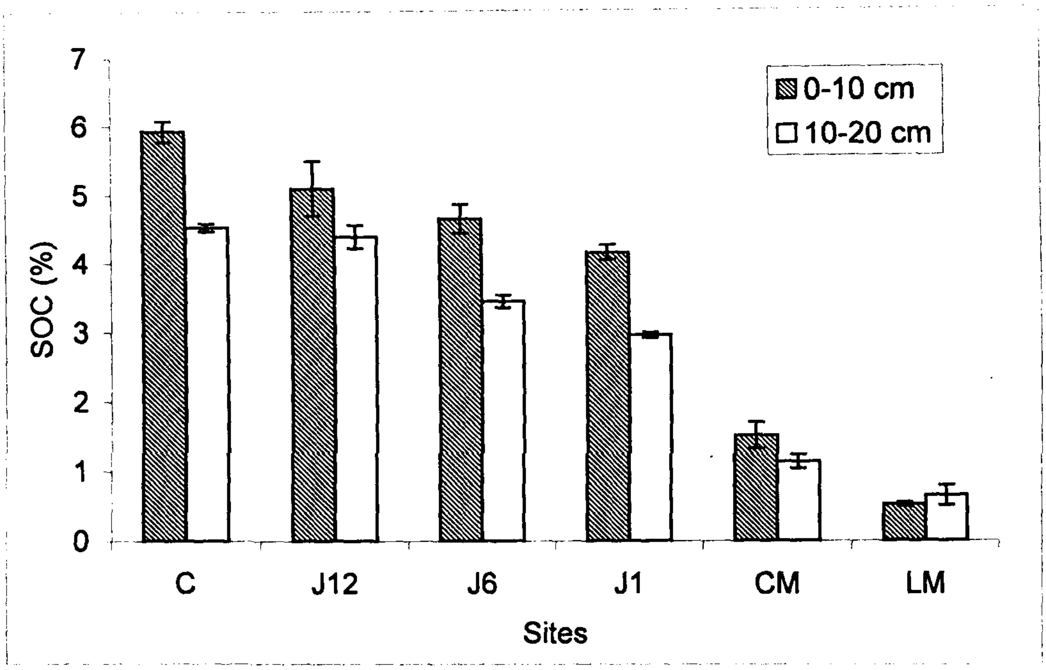

Fig. 4.6. Mean soil organic carbon (SOC, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.11. Three-way ANOVA showing effects of site, season and depth on organic carbon content in soils of the BR (*$p<0.05$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	504.34	504.34	...
Site	5	142.17	28.43	50.96**
Season	3	8.01	2.67	4.78*
Depth	1	8.38	8.38	15.01**
Site x season	15	3.65	0.26	0.46
Site x depth	5	8.31	1.66	2.98*
Season x depth	3	0.09	0.03	0.05
Residual	15	8.37	0.56	...
Total	**48**	**683.51**	**14.24**	**...**

Total Kjeldahl nitrogen (TKN): TKN content showed a significant ($p<0.01$) variation among sites, years, seasons and soil depths. The concentration was minimum during winter season and maximum during rainy season, declining significantly ($p<0.01$) with the increase in soil depth. Core zone had the highest concentration of TKN (0.34 %) and limestone mine spoil recorded the lowest value (0.02 %) (Table 4.12, Table 4.13 & Fig. 4.7).

Table 4.12. Seasonal variation in total Kjeldahl nitrogen (%, ±SE) in soils at the study sites

Sites	Depth (cm)	2001			2002		
		Winter	Rainy	Mean	Winter	Rainy	Mean
Core zone*	**0-10**	**0.29**±0.001	**0.35**±0.000	**0.32**	**0.36**±0.005	**0.34**±0.003	**0.35**
	10-20	**0.22**±0.000	**0.28**±0.003	**0.25**	**0.31**±0.005	**0.27**±0.003	**0.29**
<u>**Jhum fallows**</u>:							
10-12-yr. old*	0-10	0.22±0.004	0.26±0.005	0.24	0.28±0.001	0.30±0.001	0.29
	10-20	0.18±0.001	0.23±0.002	0.21	0.22±0.0003	0.23±0.001	0.23
6-8-yr. old*	0-10	0.21±0.002	0.25±0.003	0.23	0.22±0.002	0.27±0.002	0.25
	10-20	0.15±0.003	0.22±0.004	0.19	0.17±0.004	0.21±0.002	0.19
1- yr. old*	0-10	0.22±0.005	0.21±0.0003	0.22	0.27±0.0003	0.16±0.003	0.22
	10-20	0.18±0.0003	0.13±0.002	0.16	0.21±0.002	0.15±0.003	0.18
Mean†	0-10	**0.22**	**0.24**	**0.23**	**0.26**	**0.24**	**0.25**
	10-20	**0.17**	**0.19**	**0.18**	**0.20**	**0.20**	**0.20**
<u>**Mine spoils**</u>:							
Coal*	0-10	0.03±0.001	0.02±0.000	0.03	.0004±0.001	0.09±0.002	0.05
	10-20	0.03±0.001	0.05±0.0003	0.04	0.004±0.001	0.10±0.001	0.05
Limestone	0-10	0.03±0.0003	0.01±0.001	0.02	0.01±0.0003	0.04±0.001	0.03
	10-20	0.03±0.0003	0.05±0.0003	0.04	0.02±0.0003	0.04±0.001	0.03
Mean‡	0-10	**0.03**	**0.02**	**0.03**	**0.01**	**0.07**	**0.04**
	10-20	**0.03**	**0.05**	**0.04**	**0.01**	**0.07**	**0.04**

*Mean of the replicate sites

†Mean of the jhum fallows

‡Mean of the mine spoils

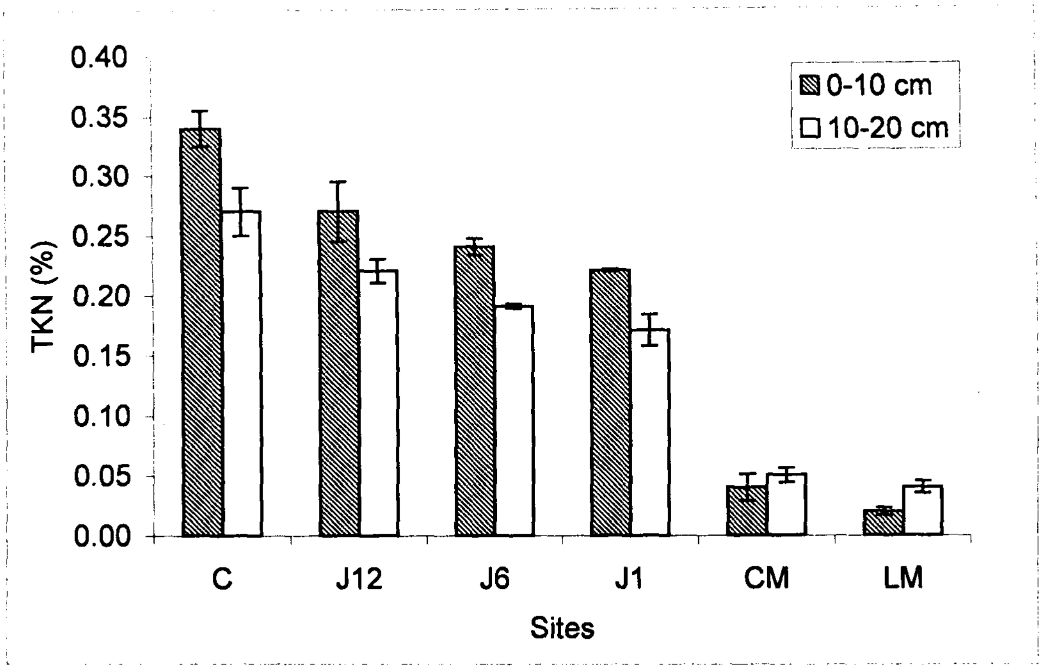

Fig. 4.7. Mean total Kjeldahl nitrogen (TKN, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.13. Three-way ANOVA showing effects of site, season and depth on total Kjeldahl nitrogen content in soils of the BR ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	1.376342	1.376342	...
Site	5	0.490431	0.098086	217.54**
Season	3	0.015924	0.005308	11.77**
Depth	1	0.019683	0.019683	43.65**
Site x season	15	0.014580	0.000972	2.16
Site x depth	5	0.002700	0.000540	1.20
Season x depth	3	0.001810	0.000603	1.34
Residual	15	0.006763	0.000451	...
Total	**48**	**1.928233**	**0.040172**	**...**

Available phosphorus (P): Available P showed a significant variation among sites and depths ($p<0.01$), and seasons ($p<0.05$). In the core zone and on jhum fallows, the maxima were recorded during winter and minima during the rainy season. At mining sites, a reverse trend was observed. The soil in the core zone had maximum concentration of available phosphorus (4.38 µg g^{-1}) while that of the mine spoils had the minimum concentration (1.55 µg g^{-1}). The concentration also declined with the increase in soil depth (Table 4.14, Table 4.15 & Fig. 4.8).

Table 4.14. Seasonal variation in available phosphorus (µg g^{-1}, ±SE) in soils at the study sites

Sites	**Depth (cm)**	**2001**			**2002**		
		Winter	**Rainy**	**Mean**	**Winter**	**Rainy**	**Mean**
Core zone*	**0-10**	**5.19±0.03**	**3.19±0.04**	**4.19**	**5.02±0.00**	**4.10±0.17**	**4.56**
	10-20	**4.01±0.06**	**2.61±0.07**	**3.31**	**3.57±0.03**	**3.17±0.03**	**3.37**
Jhum fallows:							
10-12-yr. old*	0-10	3.72±0.07	2.57±0.07	3.15	3.61±0.04	2.93±0.09	3.27
	10-20	2.60±0.01	2.00±0.04	2.30	2.21±0.04	1.73±0.15	1.97
6-8- yr. old*	0-10	2.36±0.01	1.66±0.07	2.01	2.19±0.07	2.60±0.12	2.40
	10-20	2.22±0.01	1.44±0.07	1.83	1.87±0.04	1.97±0.03	1.92
1- yr. old*	0-10	2.52±0.01	2.46±0.16	2.49	1.21±0.06	2.57±0.19	1.89
	10-20	1.69±0.04	1.83±0.06	1.76	1.15±0.04	2.00±0.00	1.58
Mean†	0-10	**2.87**	**2.23**	**2.55**	**2.34**	**2.70**	**2.52**
	10-20	**2.17**	**1.76**	**1.97**	**1.74**	**1.90**	**1.82**
Mine spoils:							
Coal*	0-10	1.46±0.03	1.73±0.00	1.60	1.56±0.03	0.90±0.00	1.23
	10-20	1.46±0.03	3.16±0.00	2.31	1.91±0.03	0.80±0.00	1.36
Lime-stone	0-10	0.91±0.05	1.04±0.04	0.98	2.51±0.07	2.27±0.03	2.39
	10-20	0.91±0.05	1.40±0.06	1.16	2.51±0.09	1.73±0.03	2.12
Mean‡	0-10	**1.19**	**1.39**	**1.29**	**2.04**	**1.59**	**1.81**
	10-20	**1.19**	**2.28**	**1.74**	**2.21**	**1.27**	**1.74**

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

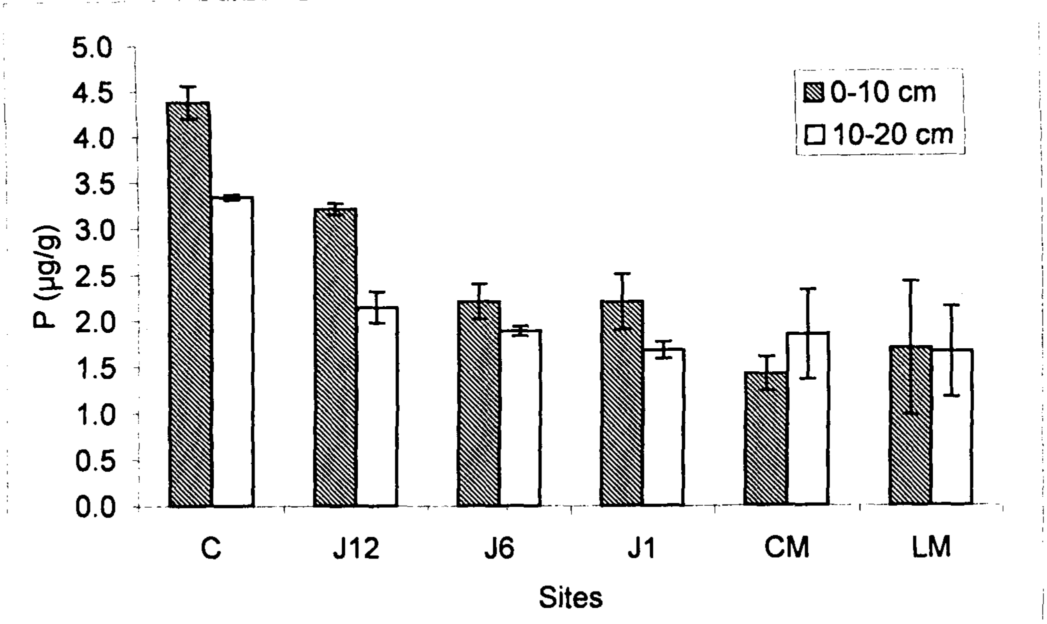

Fig. 4.8. Mean available phosphorus content (P, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.15. Three-way ANOVA showing effects of site, season and depth on available phosphorus in soils of the BR (*$p<0.01$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	253.09	253.09	...
Site	5	29.10	5.82	23.79**
Season	3	2.54	0.85	3.47*
Depth	1	3.11	3.11	12.71**
Site x season	15	7.83	0.52	2.13
Site x depth	5	1.97	0.39	1.61
Season x depth	3	0.63	0.21	0.85
Residual	15	3.67	0.24	...
Total	**48**	**301.94**	**6.29**	**...**

Exchangeable potassium (K): The core zone had the highest concentration of exchangeable K (248 μg g^{-1}) followed by jhum fallows and the coalmine spoils (60 μg g^{-1}) (Table 4.16 & Fig. 4.9). Among jhum fields, 1-yr. old fallow had a high concentration of K compared to the older fallows. Except at coalmine site, the concentration was significantly (p<0.01) higher in the upper soil layer than the lower layer at all the sites (Table 4.17). It was minimum during rainy season and maximum during the winter season. The exchangeable K also varied significantly (p<0.01) among the seasons and sites.

Table 4.16. Seasonal variation in exchangeable potassium (μg g^{-1}, ±SE) in soils at the study sites

Sites	**Depth (cm)**	**2001**			**2002**		
		Winter	**Rainy**	**Mean**	**Winter**	**Rainy**	**Mean**
Core zone*	***0-10***	***310±3***	***220±7***	***265***	***200±3***	***260±4***	***230***
	10-20	220±3	190±3	205	150±3	180±2	165
Jhum fallows:							
10-12-yr. old*	0-10	260±3	260±3	260	260±3	150±2	205
	10-20	150±3	150±0	150	180±0	130±3	155
6-8- yr. old*	0-10	290±7	180±3	235	180±9	180±3	180
	10-20	140±3	150±3	145	150±7	130±3	140
1- yr. old*	0-10	450±3	140±8	295	220±7	120±6	170
	10-20	270±6	110±3	190	210±9	110±2	160
Mean†	0-10	**333**	**193**	**263**	**220**	**150**	**185**
	10-20	**188**	**138**	**162**	**180**	**123**	**152**
Mine spoils:							
Coal*	0-10	80±3	70±3	75	50±4	40±2	45
	10-20	80±3	50±0	60	190±2	50±3	120
Limestone	0-10	200±3	170±7	185	150±10	140±6	145
	10-20	200±3	150±3	175	150±4	110±3	130
Mean‡	0-10	**138**	**120**	**129**	**100**	**90**	**95**
	10-20	**135**	**100**	**118**	**170**	**80**	**125**

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

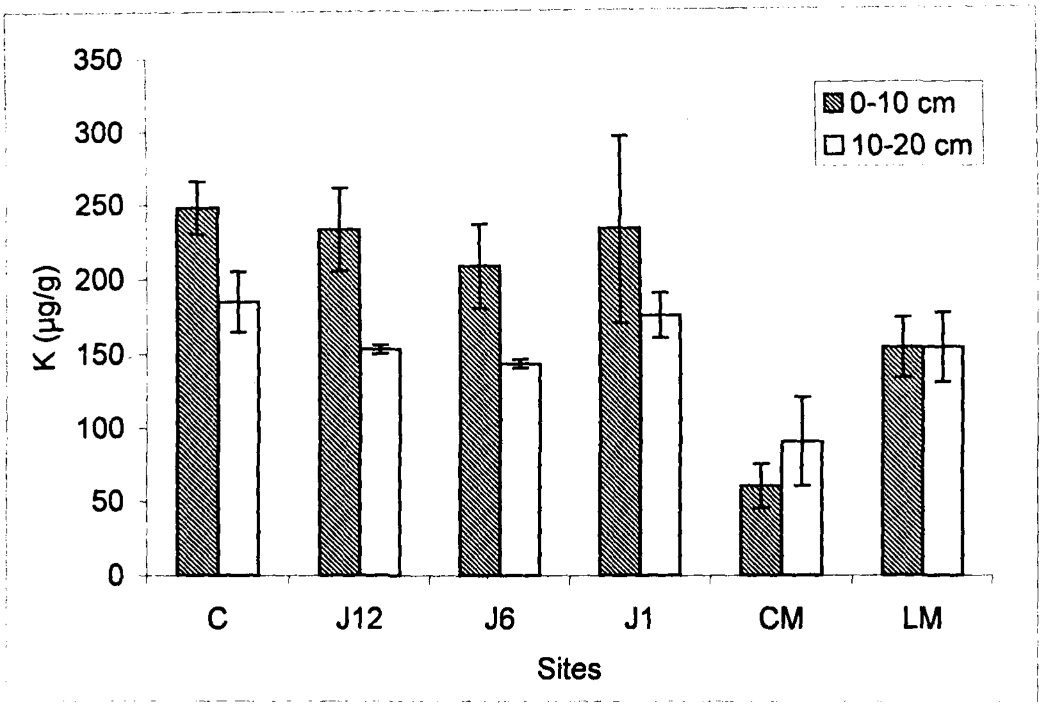

Fig. 4.9. Mean exchangeable potassium (K, ±SE) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 4.17. Three-way ANOVA showing effects of site, season and depth on exchangeable potassium in soils of the BR (*$p<0.01$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	1390602.00	1390602.00	...
Site	5	103685.40	20737.07	11.68**
Season	3	40189.50	13396.50	7.55**
Depth	1	45018.75	45018.75	25.36**
Site x season	15	31173.00	2078.20	1.17
Site x depth	5	27768.75	5553.75	3.13*
Season x depth	3	4439.50	1479.83	0.83
Residual	15	26623.00	1774.87	...
Total	**48**	**1669500.00**	**34781.25**	**...**

Carbon, Nitrogen and C/N ratio in water-stable aggregates: Organic carbon content in the micro-aggregate was found to be higher than the macro-aggregate structure in most of the cases (Table 4.18). Highest C and N concentrations in both micro- and macro-aggregates, were recorded the undisturbed core zone, followed in decreasing order by jhum fallows and mine spoils. C/N ratio was greater in the micro-aggregates than the macro-aggregates in the undisturbed core zone and jhum fallows. This trend was reversed in case of coalmine spoil (Table 4.18).

Table 4. 18. Total soil organic carbon, total Kjeldahl nitrogen contents and C/N ratio in macro (MaA)- and micro (MiA)-aggregates in soils of the BR

Sites	Depth	SOC (%)		TKN (%)		C/N	
	(cm)	MaA	MiA	MaA	MiA	MaA	MiA
Core zone	0-10	3.06	4.11	0.42	0.41	7.24	9.96
	10-20	2.25	3.47	0.36	0.31	6.25	11.37
Jhum fallows	0-10	3.10	3.51	0.35	0.44	8.91	7.95
	10-20	2.56	3.31	0.29	0.36	8.81	9.10
Minespoils	0-10	0.38	0.30	0.07	0.09	5.61	1.67
	10-20	0.23	0.34	0.07	0.08	3.15	4.28

4.4. DISCUSSION

4.4.1. Effect of shifting cultivation on physical properties of soil

The results presented in the foregoing pages clearly reveal that shifting agriculture in the buffer zone of the Nokrek Biosphere Reserve have led to changes in several physical and chemical characteristics of the soil system. The effect starts with the removal of vegetal cover from above the soil system. It has been reported that canopy harvesting in the forest results in erosion of the topsoil due to extreme rainfall events (Scholes *et al.* 1994), and increase in bulk density (Hajabbasi *et al.* 1997).

However, an examination of the mean values of BD reveals a marginal decrease from the core zone to jhum fallows.

A gradual decline in WHC from the core zone to jhum fallows was related to decrease in the proportion of silt particles in soil as is evident from the positive relation between WHC and proportion of silt particles (r=0.68, $p<0.05$) (Fig. 4.10).

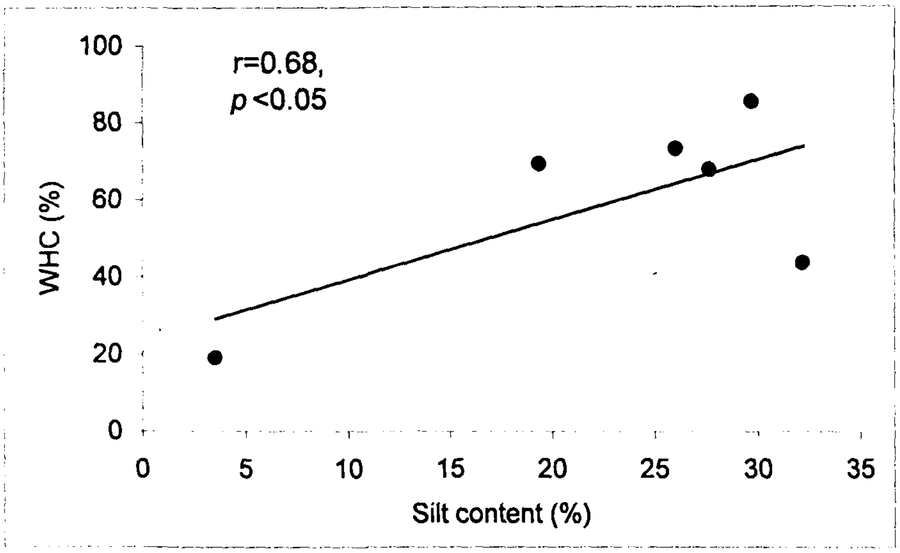

Fig. 4.10. Relationship between WHC and Silt content in soils of the BR

Another important factor that contributed to decrease in WHC was soil organic matter, which also showed a positive relationship with WHC (r=0.83, $p<0.05$) (Table. 4.19).

Table 4. 19. Correlation coefficients (r) between different physical and chemical properties of soil (n=24; $p<0.05$)

	CEC	pH	SOM	TKN	P	K
BD	-0.92	-0.46	-0.44	-0.52	-	-0.63
Silt	0.96	0.65	-	-	0.42	0.57
Clay	0.53	0.84	-0.59	-0.53	-	-
Sand	-0.86	-0.86	-	-	-	-
MiA	-0.83	-0.65	-	-	-	-
MaA	0.83	0.64	-	-	-	-
SMC	0.46	-	0.76	0.78	0.48	-
WHC	0.69	-	0.83	0.91	0.72	0.69

Congdon and Herbohn (1993) and Scholes *et al.* (1994) have reported a positive correlation between clay content and WHC. In the present study, however, the clay content was higher in the lower soil layer whereas WHC was more in the upper soil layer, which had greater accumulation of organic matter thereby indicating a stronger influence of SOM on WHC than the clay particles. Higher WHC has been reported from deodar forest soil in Uttar Pradesh, India (Yadav and Badolka 1973) and older forest regrowth in north-eastern India where SOM was as high as 11 % (Arunachalam *et al.* 1996 and Maithani 1996).

Similarly, greater moisture content in the surface soil layer may be ascribed to greater accumulation of litter on the forest floor that check evaporation losses and higher SOM that helps in retention of moisture. On the other hand, lower SMC in the surface soil layer during dry winter season could be the result of higher evapotranspiration from the soil and plant surfaces and percolation and infiltration of water to the lower depths (Tiwari *et al.* 1992). The lower SMC in the 1-yr. old jhum fallows as compared to the undisturbed core zone could be the result of greater loss of water as run off from the hill slopes and high evaporation from the exposed soil in the absence of tree cover.

Deleterious effects of cultivation on water-stable aggregates leading to decline in the macro-aggregates in soil have been reported by Malmer and Grip (1994). However, in the present study, higher values of macro-aggregates were recorded at the cultivation sites than the undisturbed core zone, where proportion of micro-aggregates was more than the macro-aggregates. Greater amount of microaggregates was responsible for higher concentration of organic carbon as well as higher C/N ratio in the core zone soil (Table 4.18). They are more stable than macroaggregates because of binding by humus, iron and aluminium oxides and clay particles (Wild 1996) and contain about 12 % more SOC than macroaggregates and have higher C / N ratios (Ashman *et al.* 2003).

4.4.2. Effect of shifting cultivation on chemical properties of soil

The soils of the undisturbed core zone and the jhum fallows were acidic (pH=4.28 - 6.03) in nature, but the jhum fallow soils were more acidic than the undisturbed core zone. This finding is similar to Juo *et al.* (1995) who observed a linear decrease in the soil pH up to 4 after forest clearing. Acidic nature of soils under shifting cultivation was recorded by Nayak and Srivastava (1995) in Arunachal Pradesh, where acidity increased with increasing soil depth. However, in some cases higher pH was recorded in younger jhum fallows than the undisturbed core zone. Singh *et al.* (1995) recorded higher soil pH in jhum fallows than bamboo forest and natural forests of north-eastern India. Since acidic reaction of the soil is due to presence of exchangeable Al^{+3} and intensive leaching of bases (Fitzpatrick 2003), drop in the pH during rainy season could be the result of excessive leaching of basic cations by rainwater (Wild 1996).

CEC that did not vary markedly between the undisturbed core zone and the jhum fallows was negatively correlated ($r=0.86$, $p<0.05$) to the percentage of sand particles and positively correlated ($r=0.53$, $p<0.05$) with the clay content of the soil (Table 4.19). This corroborates the findings of Scholes *et al.* (1994) who found a linear relationship between clay particles and CEC. However, a decline in CEC with the increase in soil depth where the proportion of clay was higher than the surface soil layer suggested that it was also influenced by organic colloids in the soil (Scholes *et al.* 1994). The significant positive relationship between CEC and pH ($r=0.68$, $p<0.05$) also explains the effect of pH on the exchangeable bases in soils of the BR (Fig. 4.11).

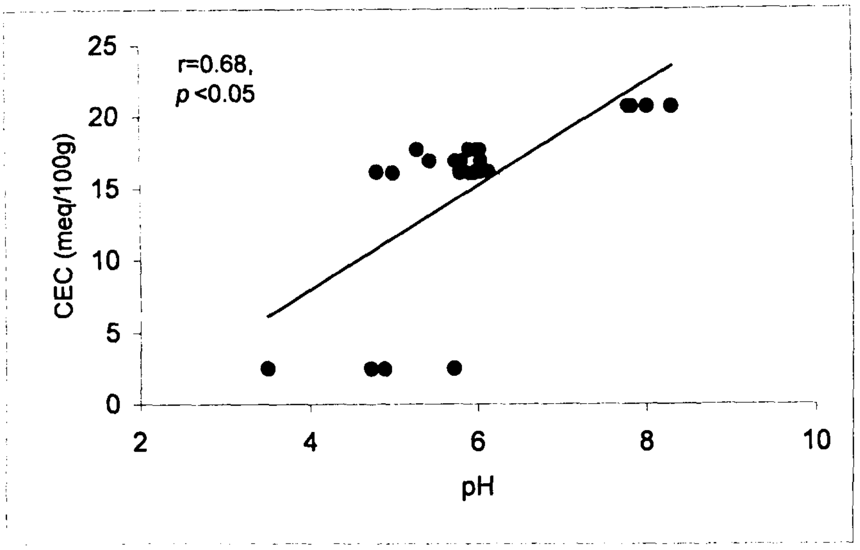

Fig. 4.11. Relation between CEC and pH in soils of the BR

Greater accumulation of organic carbon in the surface layer is ascribed to slow microbial decomposition of litter in acidic soils as reported by Nayak and Srivastava (1995) from humid sub-tropical soils under shifting cultivation in north-east India. In strongly seasonal climate where decomposition rate is fast, highly varied composition of litter protects the soil surface throughout the year and promotes organic matter accumulation (Brown *et al.* 1994). Higher nutrient status of the undisturbed core zone soil as compared to the jhum fallows is in conformity with findings of Agbenin and Goladi (1997) who recorded 38 % reduction in organic carbon, 41 % in TKN and 39 % in organic nitrogen, following continuous cultivation without fertilization. Garcia-Oliva *et al.* (1999) reported that slash and burn could result in significant disruption of soil carbon cycling in forest ecosystem and recorded 32 % decrease in organic carbon associated with macro-aggregates due to conversion of tropical deciduous forests into pastures by burning. Significant reduction in soil organic matter and organic carbon following conversion of tropical forests into pastures, agricultural fields, and shifting cultivation and tillage practices have been reported by Brown *et al.* (1994) and Henrot and Robertson (1994). Loss could even reach up to 50 % in organic matter and total nitrogen contents in comparison to the undisturbed natural forests sites (Hajabbasi *et al.* 1997; Saikh *et al.* 1998). Brand and Pfund (1998) noted a net loss of 20-22 % soil fixed carbon and nitrogen after burning in shifting cultivation systems. In the present study, a 30 % drop in SOC was recorded in 1-yr.old field compared to the core zone soil as a result of slash and burn agriculture.

Higher concentration of TKN in the surface layer of both the undisturbed core zone and jhum fallows of different ages could be due to the higher organic matter concentration in this layer. A sharp decline in TKN concentration from 0.35 % in the undisturbed core zone to 0.15 % in the 1-yr. old jhum fallow may also be due to runoff losses caused by heavy rainfall, besides low SOM content. Deka (1981) reported lower values of TKN during dry winter period. Similar results were obtained at the present study sites as well.

SOC was also positively correlated with available phosphorus ($r=0.93$, $p<0.0001$), therefore signifying the role of the organic matter in the availability of P, which is often present at low concentration in the soils of north-eastern region of the country. Though some workers (*e.g.*, Arunachalam *et al.* 1998; Saikh *et al.* 1998; Singh 2002) observed insignificant seasonal variation in total phosphorus and available phosphorus contents in regenerating jhum fallows, cultivated field, grassland and natural forests, the present findings are at variance with results obtained by these workers since available P showed a significant ($p<0.01$) variation due to season, site and depth. Available phosphorus was higher during winter and lower during the rainy season. Greater input of phosphorus through litter during winter and spring seasons in the 7, 13 and 16 years old forest regrowth has been reported by Arunachalam *et al.* (1998) in humid subtropical region.

High potassium concentration (450 $\mu g\ g^{-1}$) observed in the 1-yr. old jhum fallow could be the result of ash content left in soil after burning of slash during preceding winter and its subsequent loss through rainwater. Potassium concentration further declined in the next rainy season in 1-yr. old fallow due to excessive leaching and run off losses. A greater fluctuation in the concentration of K than the other nutrients is because K cycles through vegetation and soil solely as an unbound ion, and is easily leached from living and decomposing plant tissues compared to other nutrients. The exchangeable K concentration in the core zone was higher than other sites in the buffer zone possibly because K is retained and cycled more dynamically in the forest ecosystem (Bradley *et al.* 2001).

4.4.3. Changes in soil characteristics during vegetation regrowth on jhum fallows

Physical and chemical attributes and nutrient status of soil following abandonment of jhum field in the buffer zone showed a gradual recovery during regrowth of vegetation. The recovery was differential in different attributes. For instance, SMC and WHC recorded 69-96 % and 80-86 % increase respectively from 1-yr. to 10-12-yr. old fallow; CEC, SOC, TKN and available P recorded 91-96 %, 70-86 %, 65-79 % and 50-73 % increase respectively during the same period (Fig. 4.12 a & b). The increase in SMC during regrowth of vegetation on jhum fallows could be the result of greater infiltration and reduction in the losses due to run off and evaporation. Most of these changes were related to gradual build up of organic matter in soil (Maithani *et al.* 1998). Tiessen *et al.* (1992) reported that organic matter in the topsoil approaches to the level of mature forest by the end of the tenth year of secondary succession in the forest ecosystem. In the present study, SOM, TKN and available P content in 10-12-yr. old jhum fallow were comparable to the mature forest in the core zone.

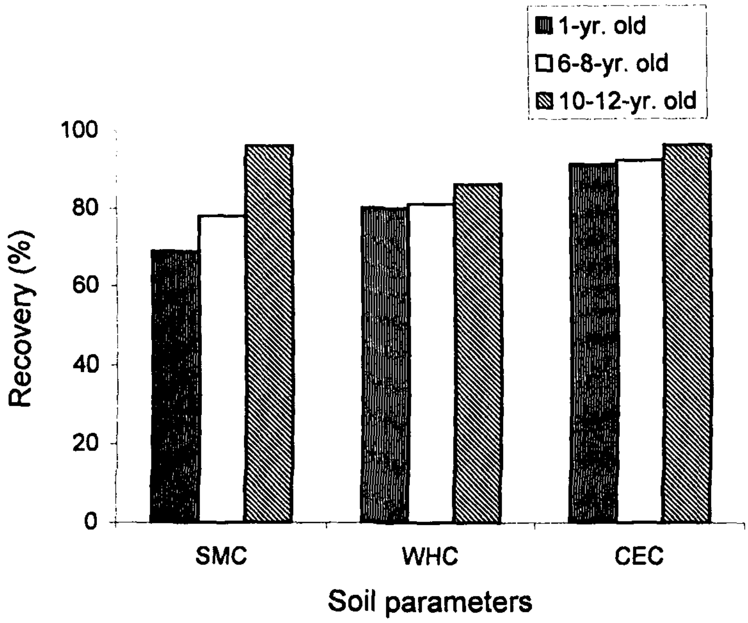

Fig. 4.12a. Recovery of SMC, WHC and CEC in surface soil layer during secondary succession on jhum fallows

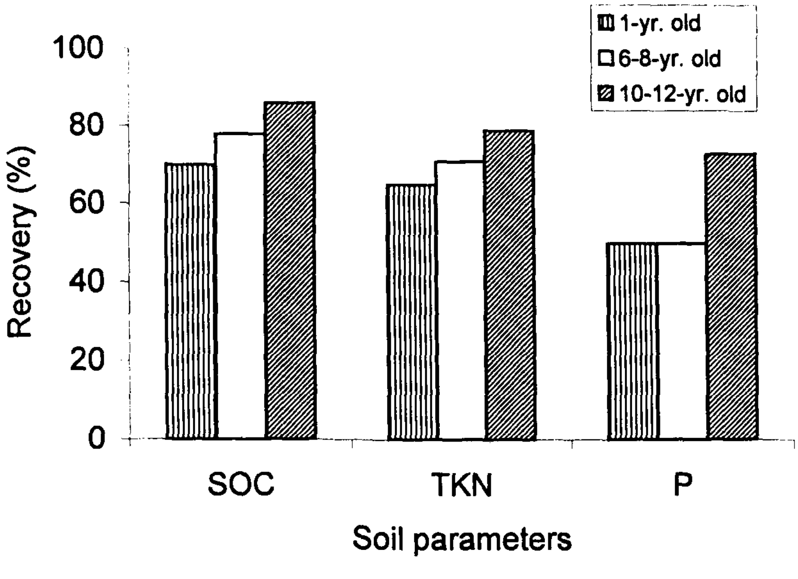

Fig. 4.12b. Recovery of organic carbon, TKN and P in surface soil layer during secondary succession on jhum fallows

4.4.4. Effect of mining activities on physico-chemical properties of soil

The physico-chemical properties of mine spoils were different from those of jhum fallows and core zone of the BR. The effect of these activities started with the removal of vegetal cover and dumping of the mine spoil on top of the natural soil. The BD registered a marked increase in the surface soil at mining sites especially at the coal mining sites. This is attributed to a significant decrease in silt particles as well as organic matter content. Loss of finer soil particles, especially the clay component from the soil after disturbance has been reported by Eyre (1968).

Similarly decline in WHC from the core zone to mining sites particularly at coal mining sites is attributed to increase in the proportion of sand particles and decrease in organic matter content. However relatively high WHC at limestone mine spoil was due to high proportion of clay as compared to the coalmine spoils (Das Gupta 1999).

The soils of mining sites were almost without any vegetal cover, coarse textured with low SOM content, therefore had very low SMC particularly at coal mining sites. Higher evaporation from the soil in the absence of tree cover and low water retention due to higher proportion of sand were the reasons for low SMC of mine spoils.

The percentage of macro-aggregates in the limestone mine spoils was higher and that in the coal mine spoil was significantly lower ($p<0.01$) than the undisturbed core zone. This has a strong influence on pH and CEC as is evident from positive relationships between macroaggregates and pH & CEC (Table 4.19).

The coalmine spoil was highly acidic primarily due to the oxidation of iron pyrites in the overburden (Singh *et al.* 2002). These minerals, when exposed to air and moisture, oxidize to produce acid and soluble salts. Lowering of pH on one hand strongly hampers the availability of a number of essential nutrients in the soil (Hossner *et al.* 1997), and on the other increases the availability of iron, aluminium and manganese to plant (Iverson and Wali 1992). Therefore under very acidic condition these elements become toxic to plants. Low concentrations of cations such as Ca, Mg, etc also cause acidity (Eyre 1968).

The mine spoils are poor in organic carbon, TKN, available P and exchangeable K. Das Gupta (1999) has also reported low percentage of organic carbon in freshly formed coalmine spoil of northeast India. In contrast, Toy and Shay (1987) did not get significant difference in organic matter content between the mine spoils and natural soils in Northern Great Plains.

Low N and P in the mine spoils have been attributed to leaching and lack of binding power of phosphorus (Singh *et al.* 2002). Lunt and Hedger (2003) also reported lack of macronutrients in the mine wastes where phosphorus is a limiting factor during early succession and colonization.

Chapter 5

Microbial biomass carbon and nitrogen

5.1. Introduction

The soil microbial biomass constitutes a transformation matrix for all natural organic materials in the soil and acts as a labile reservoir of plant available nutrients (Seely and Lajtha 1997; Zogg *et al.* 2000). Since it constitutes a significant part of the potentially mineralizable N and serves both as the transformation agent and source-sink of N (Bonde *et al.* 1998), it plays an important role in N cycling due to rapid turnover rate. Garcia-Gill *et al.* (2000) concluded that microbial biomass is a much more sensitive indicator of changing soil conditions than the total organic matter content. It increases with forest productivity (Myrold *et al.* 1989) and is influenced by forest management (Bauhus and Barthel 1995; Pietikainen and Fritze 1995). Since microbial biomass is critical in regulating soil ecosystem level processes, such as nutrient cycling, and organic matter transformations, there is much interest in understanding the factors, which regulate its size, activity and structure (Grayston *et al.* 2001; Zeller *et al.* 2001) and the factors which influence them both in natural and managed systems.

The present chapter analyzes the seasonal and spatial distribution pattern of soil microbial biomass carbon and nitrogen in the undisturbed forests (core zone); and attempts to evaluate the effects of shifting cultivation and mining activities on microbial biomass carbon (MBC) and nitrogen (MBN) in the buffer zone of the BR.

5.2. METHODS

5.2.1. Soil sampling

Soil samples were collected in winter, spring, rainy and autumn seasons during 2000, and in winter (January) and rainy (August) seasons during 2001 and 2002. In each stand, three to five replicate samples were collected using a steel corer (6.3 cm diameter) from two soil depths (0-10 and 10-20 cm). The replicated samples of a given depth were thoroughly mixed to obtain one composite sample. The composite samples were passed through a 2 mm mesh sieve and were used in field moist condition for the determination of microbial biomass carbon and nitrogen.

5.2.2. Analysis

MBC was determined by chloroform fumigation method (Vance *et al.* 1987). Six sub-samples of 10 g ± 0.01 g each were drawn from each composite sample, three of them were fumigated by saturating with 10 ml (alcohol-free) chloroform liquid and kept for 24 hours and remaining three were not fumigated. After fumigation, chloroform was removed from the samples by evaporation. Microbial biomass was extracted from both fumigated and non-fumigated samples with 50 ml of 0.5 M K_2SO_4 by shaking for 30 minutes. The extracts were filtered through Whatman filter paper No. 42 and the filtrates were used for the determination of microbial biomass.

The organic C in the extracts of fumigated and non-fumigated soil samples was determined by digesting 4 ml filtered extract with 0.0667 M $K_2Cr_2O_7$ (1 ml) and 5 ml of H_2SO_4 (98 % acid) for 30 minutes. The digested sample was titrated with acidified ferrous ammonium sulphate solution using 0.3 ml (3 - 4 drops) of indicator (o-phenanthroline monohydrate and ferrous sulphate hexahydrate). The MBC was calculated as

$$\text{MBC} = 2.64\ \text{Ec}$$

Where, Ec is the difference between the amount of organic C in the K_2SO_4 extract of fumigated and non-fumigated soils, both expressed as $\mu g\ g^{-1}$ dry soil and 2.64 is the relationship between biomass C as measured by fumigation incubation method and amount of C extracted by 0.5 M K_2SO_4 after chloroform treatment.

MBN was determined by fumigation extraction method (Brookes *et al.* 1985) slightly modified by Okalebo *et al.* (1993). For the estimation of N, 10 ml of the filtrate was digested at 350°C with 4.4 ml of digestion mixture (0.42 g selenium powder + 14 g lithium sulphate + 30 ml of 30 % H_2O_2 + 420 ml conc. H_2SO_4) in a micro-Kjeldahl digestion tube till it becomes whitish or colourless. The mixture was extracted with distilled water in a 50 ml volumetric flask. The solution was either centrifuged or filtered through Whatman No. 1 filter paper to get a clear solution for the estimation of MBN. Ten ml of clear extract was used to determine ammonium-N released as a result of reaction with 40 % NaOH *solution in the micro-Kjeldahl digestion chamber. The ammonium-N* released was collected in 5 ml of 1 % boric acid solution till permanent green colour develops. Then, a few drops (2-4 drops) of bromocresol green indicator solution was added into the solution mixture and was titrated with N/140 HCl till it turns into pink colour which is the end point.

$$\text{MBN } (\mu g\ g^{-1} \text{ dry soil}) = N_f - N_o$$

Where, N_f = biomass N of fumigated sample; N_o = biomass N of non-fumigated sample)

5.2.3. Statistical analysis

The data were analyzed using 2-way and 3-way analysis of variance (ANOVA) (fixed effect model) to test the effects of season, soil depth and/ or site on the soil microbial biomass C and N. These were correlated with other properties of soil by computing coefficients of correlation (r) according to Zar (1974).

5.3. RESULTS

5.3.1. Seasonal and spatial variation in MBC and MBN

5.3.1.1. Microbial biomass carbon (MBC)

The MBC concentration in the surface soil layer ranged from 1273 to 1867 µg g^{-1} in the core zone, 212 to 1117 µg g^{-1} in jhum fallows and 87 to 339 µg g^{-1} in the mine spoils. The values peaked during the rainy season and they were at their minimum level during winter in the core area and jhum fallows, whereas it gradually increased from 2001 winter to 2002 rainy season in the mine spoils. The surface soil had significantly

($p<0.01$) higher values at all the sites except in limestone mine spoil, where a reverse trend was obtained (Table 5.1 & Fig. 5.1). Three-way ANOVA revealed a significant variation ($p<0.01$) between sites, seasons and soil depths (Table 5.2). The data also indicate that there was a marked recovery in MBC during regrowth of vegetation from 1-yr. old fallow to 12-yr. old field.

Table 5.1. Seasonal variation in soil microbial biomass carbon (µg g^{-1}, ±SE) at different sites in the BR

Sites	Depth (cm)	2001			2002		
		Winter	Rainy	Mean	Winter	Rainy	Mean
Core zone*	**0-10**	**1273±48**	**1633±30**	**1453**	**1545±98**	**1867±30**	**1706**
	10-20	**580±36**	**680±60**	**630**	**1023±50**	**1079±123**	**1051**
Jhum fallows:							
10-12-yr old*	0-10	600±37	930±55	763	904±69	1117±113	1011
	10-20	231±24	430±22	330	766±46	823±13	795
6-8-yr old*	0-10	345±10	440±53	392	490±46	973±24	732
	10-20	149±45	348±64	248	319±14	403±59	361
1-yr old*	0-10	212±51	334±49	273	463±20	663±36	563
	10-20	135±36	178±51	156	293±33	372±28	332
Mean†	0-10	**386**	**566**	**476**	**619**	**918**	**768**
	10-20	**171**	**319**	**245**	**459**	**533**	**496**
Mine spoils:							
Coal*	0-10	93±21	114±17	103	253±19	339±10	296
	10-20	93±21	114±23	103	190±10	288±10	239
Limestone	0-10	87±24	89±38	88	225±43	233±69	229
	10-20	87±24	116±26	101	321±11	336±34	329
Mean‡	0-10	**91**	**102**	**96**	**239**	**286**	**263**
	10-20	**91**	**115**	**103**	**256**	**312**	**284**

*Mean of the replicate sites

†Mean of the jhum fallows

‡Mean of the mine spoils

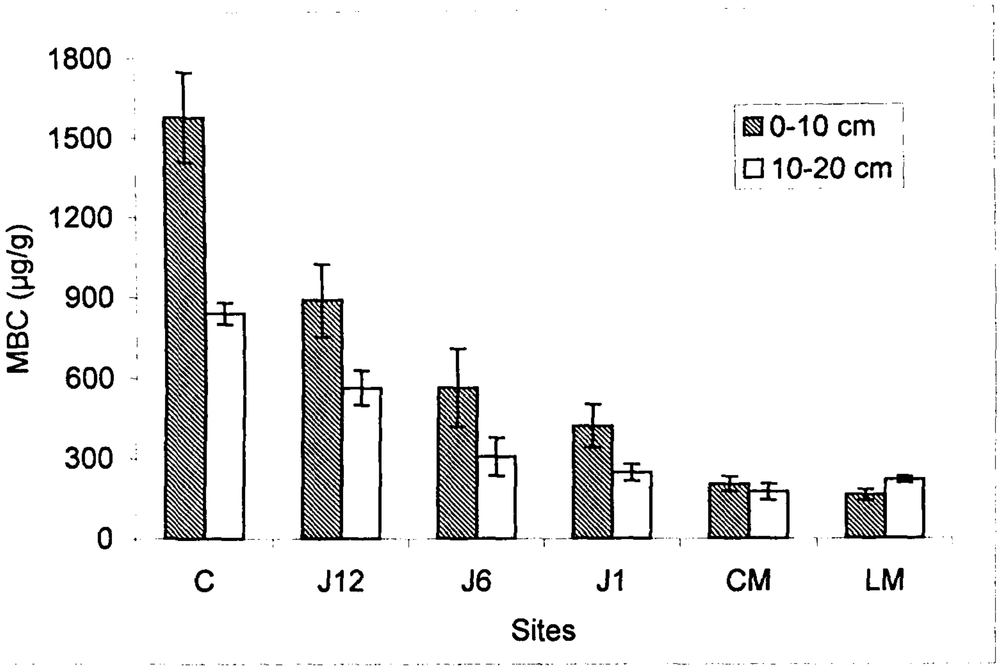

Fig. 5.1. Microbial biomass carbon (MBC) in surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

Table 5.2. Three-way ANOVA of the data showing effects of site, season and depth on soil MBC in the BR (n=24, **p*<0.05, ** *p*<0.01)

Variation due to	d.f.	SS	MS	F
General mean	1	12572680.00	12572680.00	...
Site	5	6266409.00	1253282.00	252.84**
Season	3	1465828.00	488609.40	98.57**
Depth	1	215203.00	215203.00	43.42**
Site x season	15	924632.00	61642.14	12.44**
Site x depth	5	74986.00	14997.20	3.03*
Season x depth	3	40795.00	13598.33	2.74
Residual	15	74352.00	4956.80	...
Total	**48**	**21634880.00**	**450726.70**	**...**

5.3.1.2 Microbial biomass nitrogen (MBN)

At all the sites, microbial biomass nitrogen (MBN) was minimum during winter (January) and maximum during autumn (October); the increase from January to October was sharp in the surface soil layer of the core zone and 10-12 yr. old community in the buffer zone. In the subsoil layer, the increase was gradual at all sites. The soil of the undisturbed primary forest in the core zone had maximum concentration (up to 384 µg g^{-1}) of MBN followed in descending order by 10-12-yr. old fallow (up to 219 µg g^{-1}), 6-8-yr. old fallow (up to 108 µg g^{-1}) and 1-yr. old fallow (up to 100 µg g^{-1}) in the buffer zone. It also declined significantly ($p<0.01$) from the surface to the subsurface soil layer at all sites (Table 5.3 & Fig. 5.2). The variation among the sites and seasons were also significant (Table 5.4).

Table 5.3. Seasonal variation in soil microbial biomass nitrogen (µg g^{-1}, ±SE) at the study sites

Sites	**Depth (cm)**	**2000**			
		Winter	**Spring**	**Rainy**	**Autumn**
Core zone*	**0-10**	**239±11**	**268±12**	**294±11**	**384±20**
	10-20	**61±6**	**85±3**	**93±5**	**111±9**
Jhum fallows:					
10-12- yr. old*	0-10	143±9	179±5	184±11	219±19
	10-20	55±4	87±6	90±5	105±7
6-8- yr. old*	0-10	52±4	90±4	92±5	108±9
	10-20	40±2	64±4	75±4	85±7
1- yr. old*	0-10	37±2	78±4	83±3	100±3
	10-20	29±3	49±3	61±3	80±4
Mean†	0-10	**78.14**	**115.48**	**119.68**	**142.53**
	10-20	**41.37**	**66.63**	**75.25**	**90.27**

*Mean of the replicate sites

†Mean of the jhum fallows

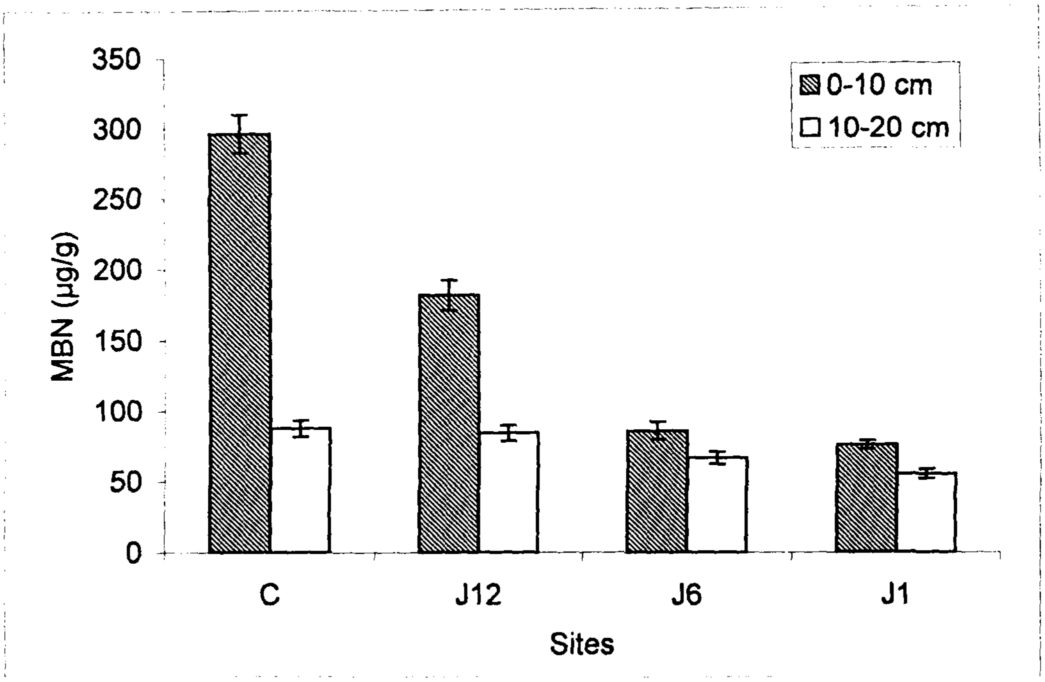

Fig. 5.2. Microbial biomass nitrogen (MBN) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows}. The values are means (±SE) of seasonal data and 6-9 replicate sites.

Table 5.4. Three-way ANOVA of data showing effects of site, season and depth on soil MBN in the BR (n=24, ** *p*<0.01)

Variation due to	d.f.	SS	MS	F
General mean	1	432450.00	432450.00	...
Site	3	81849.00	27283.00	164.71**
Season	3	72000.25	24000.09	144.89**
Depth	1	6728.00	6728.00	40.62**
Site x season	9	49986.75	5554.08	33.53**
Site x depth	3	425.00	141.67	0.86
Season x depth	3	684.25	228.08	1.38
Residual	9	1490.75	165.64	...
Total	**32**	**645614.00**	**20175.44**	**...**

5.3.2. Percentage contribution of MBC to SOC

The percentage contribution of MBC to SOC in the surface soil layers ranged from 2.34 to 3.29 in the undisturbed core zone; 0.51 to 2.09 in jhum fallows; 0.48 to 8.69 in coalmine spoil and 1.21 to 4.25 in limestone mine spoil. In the subsurface soil layer, maximum contribution (9.68 %) was observed in the limestone mine spoil and minimum (0.41 %) in 10-12 yr. old jhum fallow (Table 5.5).

Table 5.5. Percentage contribution of microbial biomass carbon to total soil organic carbon content at different sites in the BR

Sites	Depth (cm)	2001			2002		
		Winter	Rainy	Mean	Winter	Rainy	Mean
Core zone*	**0-10**	**2.34**	**2.44**	**2.39**	**3.29**	**2.72**	**3.01**
	10-20	**1.70**	**1.23**	**1.47**	**2.69**	**2.00**	**2.35**
Jhum fallows:							
10-12-yr. old*	0-10	0.51	0.60	0.56	1.16	1.98	1.57
	10-20	0.62	0.41	0.52	1.10	0.97	1.04
6-8- yr. old*	0-10	1.33	1.57	1.45	2.09	1.97	2.03
	10-20	0.71	0.83	0.77	1.81	1.69	1.75
1- yr. old*	0-10	0.80	1.04	0.92	1.80	1.24	1.52
	10-20	0.42	1.27	0.85	1.65	0.92	1.29
Mean†	0-10	**0.88**	**1.07**	**0.98**	**1.68**	**1.73**	**1.71**
	10-20	**0.58**	**0.84**	**0.71**	**1.52**	**1.19**	**1.36**
Mine spoils:							
Coal*	0-10	0.92	0.48	0.70	1.14	8.69	4.92
	10-20	0.92	1.11	1.02	0.90	8.72	4.81
Lime-stone	0-10	1.21	3.44	2.33	4.25	4.15	4.20
	10-20	1.21	1.38	1.30	9.68	5.26	6.97
Mean‡	0-10	**1.07**	**1.96**	**1.51**	**2.70**	**6.42**	**4.56**
	10-20	**1.07**	**1.25**	**1.16**	**4.79**	**6.99**	**5.89**

*Mean of the replicate sites; †Mean of the jhum fallows; ‡Mean of the mine spoils

The overall percentage contribution of MBC to SOC was highest in the mine spoils followed by undisturbed core zone and lowest in the jhum fallows (Fig. 5.3). In the limestone mine spoils, contribution of MBC to SOC in the lower soil layer was higher than in the upper layer. At other sites, the proportion of MBC was always more in the upper soil layer.

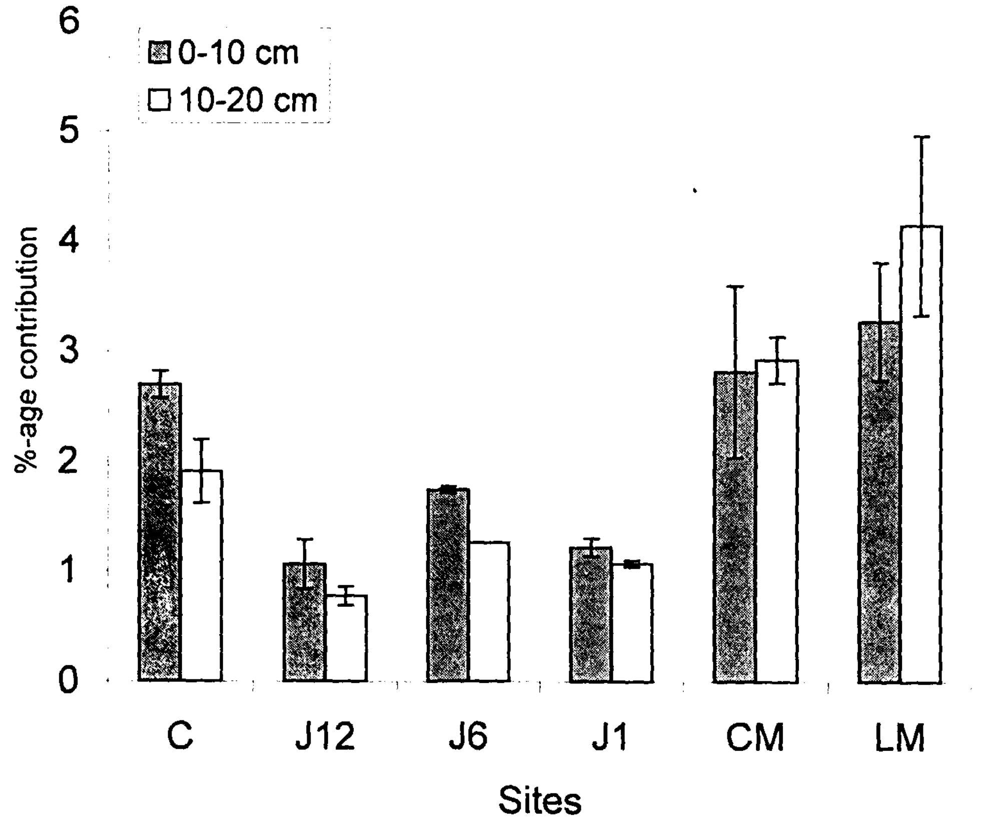

Fig. 5.3. Percentage contribution of MBC to SOC in surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

5.3.3. Percentage contribution of MBN to TKN

In the surface soil layer, percentage contribution of MBN to TKN varied between 8.24 and 8.40 in the undisturbed core zone, and 1.86 and 7.81 in jhum fallows. In the subsurface soil layers, maximum contribution (3.87 %) was recorded in 10-12 yr. old jhum fallow and minimum (2.23 %) in 1-yr. old jhum fallow (Table 5.6). The values were significantly ($p<0.01$) higher in undisturbed core zone as compared to the jhum fallows (Fig. 5.4). The percentage contribution was significantly higher during rainy season than the winter at all the sites at both the soil depths.

Table 5.6. Percentage contribution of microbial biomass nitrogen to total Kjeldahl nitrogen content in soils at different sites in the BR

Sites	Depth (cm)	Winter	Rainy
Core zone*	**0-10**	**8.24**	**8.40**
	10-20	**2.77**	**3.29**
Jhum fallows:			
10-12- yr. old*	0-10	6.45	7.81
	10-20	3.00	3.87
6-8- yr. old*	0-10	2.48	3.68
	10-20	2.67	3.41
1- yr. old*	0-10	1.86	3.77
	10-20	2.23	3.39
Mean†	**0-10**	**3.60**	**5.09**
	10-20	**2.63**	**3.56**

*Mean of the replicate sites

†Mean of the jhum fallows

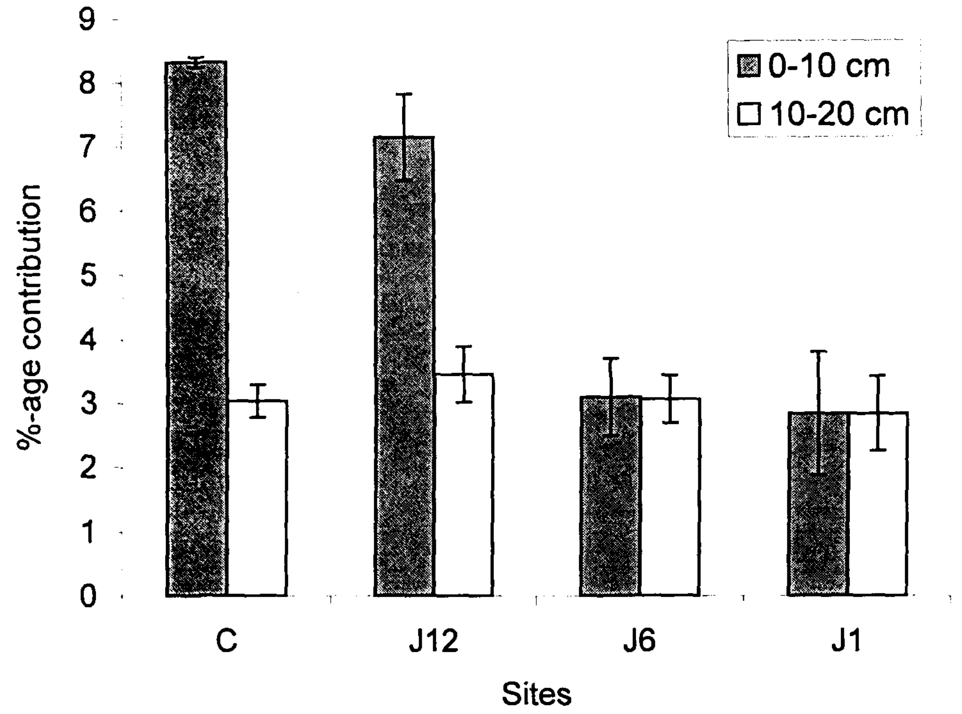

Fig. 5.4. Percentage contribution of MBN to TKN in surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows}. The values are means (±SE) of seasonal data and 6-9 replicate sites.

5.4. DISCUSSION

5.4.1. Seasonal and spatial dynamics of MBC

The concentration of MBC obtained in the present study is well within the reported range (61-2000 µg g^{-1}) for various temperate and tropical forest soils (Vance *et al.* 1987; Henrot and Robertson 1994; Diaz-Ravina *et al.* 1995). The low value during winter is in accordance with the findings of Lynch and Panting (1982) and Sarathchandra *et al.* (1989). Higher values of microbial biomass during rainy season have also been reported from pasture and dry tropical forest soils (Sarathchandra *et al.* 1984; Singh *et al.* 1989). Piao *et al.* (2000) reported greater accumulation of soil MBC in the winter when soil moisture was higher than other seasons, with drying-rewetting cycles not frequently occurring. In our case, minima and maxima of SMC and MBC were observed during winter and rainy season, respectively. These results are in conformity with those of Singh (2002) who reported higher MBC during warm-wet months and lower during dry-cool period, while working in undegraded forests of Arunachal Pradesh. A close relationship between SMC and MBC is evident from a positive correlation ($r=0.68$, $p<0.05$) between the two (Fig. 5.5).

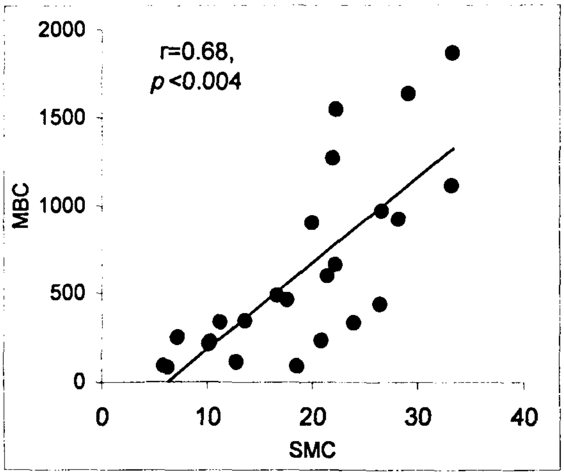

Fig. 5.5. Relationship between MBC and SMC

Nutrients derived from litter that accumulate on the soil surface during dry season are immobilized by microorganisms as water availability during rainy season allows microbial growth (Mao *et al.* 1992). Apart from the soil moisture, detrital material on the forest floor and relatively high temperature are important factors that favour growth of microbial population in soil during rainy season. Contrary to these conditions, when soil moisture and temperature decline during winter, conditions become unfavourable for microbial growth, though some amount of partially decomposed detrital material is still available on the forest floor. This suggests greater role of soil moisture and ambient temperature in seasonal variation of MBC on the forest floor. Besides seasonal variation, the amount of microbial biomass differed significantly between depths and sites

($p<0.05$). Comparatively higher MBC in the upper soil layer may be attributed to greater amount of organic matter content in this layer (Singh 2002), which increases with time owing to greater accumulation of plant-derived organic matter and microbial products (Maithani *et al.* 1998). Lavahun *et al.* (1996) have also reported significant variation in the distribution of MBC at different depths of grassland and two arable soils, and attributed it to the decline in organic carbon content.

Diaz-Ravina *et al.* (1995) reported significant variation of microbial biomass in forest soils due to soil type and seasonal fluctuations. Their study confirmed that variation in the microbial biomass in forest soils is mainly due to the type of soil, which explained 71 % of the total variation, rather than the season that accounted only 18 % variation; the interaction between the soil type and season explained only 8 % variation. They concluded that the type of soil was the most important factor for observed variation in microbial biomass in forest soils. Singh (2002) observed significant impact of site management on microbial biomass accumulation in forest soils and abandoned fallow. However, the findings of Zeller *et al.* (2001) suggest that influence of site and sampling time is stronger than the management regime or abandonment.

5.4.2. Effect of shifting cultivation on MBC and its recovery during vegetation regrowth on jhum fallow

MBC showed a marked recovery during secondary succession on jhum fallows. This trend is similar to the results obtained by Bauhus *et al.* (1998). Gradual build up of detrital mass on the soil surface during regrowth of vegetation appears to be the main reason for greater microbial biomass in the old regrowth and the undisturbed forest. Reduction in MBC in soils as a result of shifting cultivation and selective logging of forest trees in Arunachal Pradesh has been observed by Singh (2002). Tiwari *et al.* (2002) also reported decline in MBC in humid tropical hill forest soils of north-eastern India after soil disturbance by shifting cultivation and selective logging practices. They observed that

MBC in the topsoil layer was reduced by 50 % at degraded site and 35 % at moderately degraded site in comparison to undegraded forest site. In the present study, there was 74 % reduction in MBC in the surface soil of 1-yr. old fallows in comparison to primary forest in the core zone. The recovery started with the growth of plants and the MBC values in 10-12-yr. old-field was 44 % less than the core zone. Henrot and Robertson (1994) reported marked decline in MBC because of vegetation removal in humid subtropical soils. Chang *et al.* (1995) reported higher MBC in old-growth forests than 3- and 10-year-old forest plantations in British Columbia. Similar findings of MBC were obtained from the mixed secondary monsoon forest of tropical China by Mao *et al.* (1992). They demonstrated that removal of litter altered soil microbial biomass content and accelerated loss of carbon and nutrients. Srivastava and Singh (1991) noted remarkable decline in the amount of soil MBC following conversion of tropical forests into other land use systems. They found higher biomass nutrients in forests, followed by savanna, cropland and lowest in mine spoils. Taylor *et al.* (1999) investigated the microbial biomass in northern hardwood forest stands ranging in age from 3 to more than 120 years after clear felling. They observed greater values in early and late successional stands than mid-successional stand. They found that microbial biomass was not very responsive to the environmental factors; however, moisture content was most often contributed to variation in microbial biomass and concluded that the lower soil microbial biomass in the mid-successional stand is not controlled by factors directly related to forest harvesting.

5.4.3. Effect of mining on MBC

There was 87 % reduction of MBC in coalmine spoil and 90 % in limestone mine spoil in comparison with the forest in the core zone. In a study on coal mines in Meghalaya, Das Gupta (1999) observed mine spoils always had a lower bacterial and fungal population than the unmined control site and concluded that the lowest microbial population in the newly formed mine spoil was probably due to the harsh environmental conditions like direct sunlight, low relative humidity, very low organic carbon content and low WHC of the spoil. Srivastava (1992) recorded minimum microbial biomass nutrients (C, N and P) in a 5-year-old mine spoil and maximum in the native mixed forest soil. He found consistently higher biomass C, N and P in dry summer periods, which decreased significantly to a minimum level in the rainy season indicating pulsed turnover of microbial biomass in the soil. Wardle (1998) stressed that the temporal variability in soil microbial biomass is an important component of its turnover, which contribute to definite patterns of soil nutrient and mineralization. The temporal variability in MBC was closely related to soil N content in forest, pH and latitude in arable ecosystems, and pH, latitude and soil C contents in grasslands. Heavy metal toxicity and low pH in coalmine spoil have been shown to result in reduction of soil microbial biomass (Fliebach *et al.* 1994).

5.4.4. Seasonal and spatial dynamics of MBN

Ecosystems with high organic matter input and easily available organic compounds tend to have higher microbial biomass contents and activities because they are preferred energy source for the microorganisms (Hassink 1994), and the quantity and composition of microbial biomass is sensitive to changes in the soil chemical and physical environment (Wolters and Joergensen 1991; Wardle 1992; Bauhus and Khanna 1994). The high concentration of organic matter in the upper soil layer (0-10 cm) that increases the availability of nutrients seem to be an important factor responsible for high MBN in the core zone soil. This is clearly evident from strong positive correlations between MBN and SOC ($r=0.68$, $p<0.05$), MBN and TKN ($r=0.89$, $p<0.05$), and MBN and available P (Fig. 5.6).

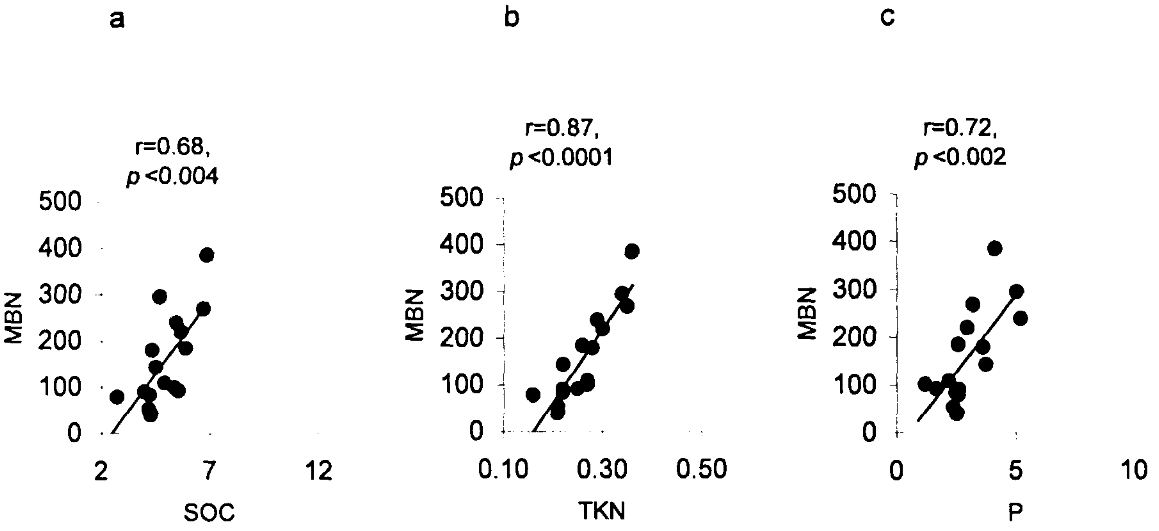

Fig. 5.6. Relationship between MBN and (a) SOC (b) TKN and (c) available P in soils of the BR

Fraser *et al.* (1988), have also observed a direct relationship between microbial activities and the amount and quality of carbon and other nutrients available from plant residues and root exudates. Witter and Kanal (1998) found close relationship between the amounts of MBC and C concentrations in different soils, but the ratio of MBC to organic carbon did not remain constant. They concluded that differences in MBC to organic carbon ratio between the soils were mainly due to differences in the quality of soil organic matter rather than due to intrinsic differences in microbial efficacy of substrate utilization. Grayston *et al.* (2001) reported increase in microbial biomass with decrease in soil fertility from the improved to unimproved grasslands. Groffman *et al.* (2001) also observed strong relationships between soil organic matter and microbial biomass and activity.

The microbial population is generally high in the upper soil layer owing to higher organic matter content, better aeration and greater nutrient availability. Significant decline in MBN from the surface (0-10 cm) to the subsurface (10-20 cm) soil layer is therefore ascribed to these factors. Similarly, significantly higher MBN in the undisturbed core zone supporting primary subtropical semi-evergreen forest than the developing communities on jhum fallows and mine spoils in the buffer zone could be attributed to the availability of high SOM and inorganic nutrients in the soil and prevailing favourable microenvironment for microbial growth at the former site.

It has been reported that seasonal changes in soil moisture, soil temperature and available residue could have a strong effect on soil microbial biomass and its activity (Insam 1990; Diaz-Ravina *et al.* 1995). The seasonal trend of MBN observed in the present study is at variance with those reported from the tropical deciduous forests, savanna and temperate pastures where peak values of microbial nutrients were observed during early spring and summer (Diaz-Ravina *et al.* 1993) but it is in accordance with the findings of von Lutzao *et al.* (1992) in the spruce forest soils who recorded the highest microbial biomass-N in autumn. The increase in MBN from winter through spring, rainy to autumn seasons may be ascribed to the gradual rise in temperature from January to September, favourable soil moisture content and greater availability of nutrients such as N due to decomposition of litter during the preceding rainy season as is evident from the positive correlation between MBN and SMC ($r=0.66$, $p<0.05$), and TKN ($r=0.89$, $p<0.05$) (Fig. 5.7 and 5.6b).

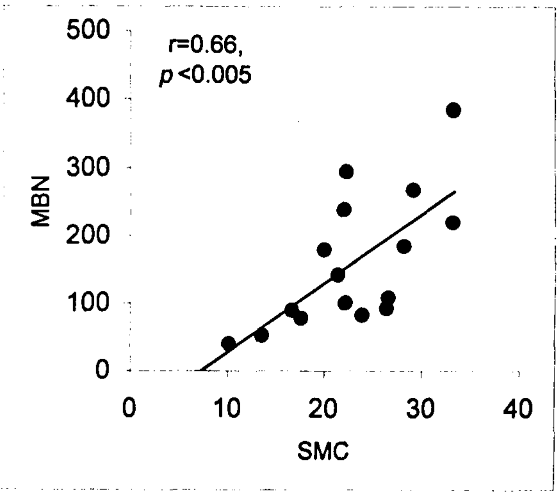

Fig. 5.7. Relationship between MBN and SMC in soils of the BR

Taylor *et al.* (1999) found similar result in northern hardwood successional sequence. Singh (2002) also observed higher MBN during warm-rainy months and lower MBN during dry-winter.

5.4.5. Contribution of microbial biomass to SOC and TKN

The MBC and MBN values, expressed as percentages of SOC and TKN, respectively, give estimates of the quantities of nutrients present in the microbial biomass, substrate availability, and organic matter dynamics in soils (Sparling 1992). The contribution of MBC to the soil organic carbon varied widely from 0.51 % to 8.69 % in the present study as compared to the tropical forests (1.5-5.3 %; Theng *et al.* 1989 and Luizao *et al.* 1992) and temperate forest soils (1.8-2.9 %; Vance *et al.* 1987). The proportion of MBC to SOC (3.01 %) in the undisturbed core zone was well within the reported range for the tropical forests. Diaz-Ravina *et al.* (1993) reported that a relatively high amount of nutrients is present in the biomass of microorganisms in forest soils and concluded that the contribution of microbial biomass to available plant nutrients was large for N, important for P, K and Mg, insignificant for Na and they could not reach any conclusion about Ca. Jenkinson and Ladd (1981) reported that MBN may be up to 5 % of total soil N. However, in the present case, the percentage contribution of MBN to TKN was 8.40 % in the core zone and 7.81 % in the 10-12- yr. old jhum fallow, suggesting that microbial communities at these sites have evolved a more complex system of substrate-use efficiency with the heterogeneous input of organic matter, enabling them to fix a greater proportion of the N in their biomass (Moore *et al.* 2000).

5.4.6. Effect of shifting cultivation on MBN and its recovery during vegetation regrowth on jhum fallow

The MBN sharply declined after clearing the vegetation for shifting cultivation as is evident from very low value in 1-yr. old-field than the core zone. It steadily increased following abandonment of field. This increase is attributed to the build up of organic matter and nutrients and improvement in moisture level in the soil during secondary succession. This is evident from significant ($p<0.05$) positive correlations between MBN with SOC, TKN and SMC. The change in microbial biomass in soil has been related to ecosystem development by Singh *et al.* (2002), and low microbial activity in the mid-successional communities has been ascribed to the greater competition for nutrients by rapidly growing vegetation (Taylor *et al.* 1999). This may be true in the present case too, since MBN was low in 6-8-yr. old stand than 10-12-yr. old fallow. Moore *et al.* (2000) also reported greater MBN content in 4-year rotation than in 2-year rotation with corn or soybean monocultures. However, Bending *et al.* (2000) reported insignificant variation in distribution of MBN under different management practices following crop harvesting. They suggested that management practice had no effect on soil biomass N, probably because there was no change in the total organic matter content, or the size of most of the labile organic matter pools, which could be considered to represent important energy source for the soil microbes.

5.4.7. Interrelationship between microbial biomass and other soil properties

A strong positive relation between MBC and MBN ($r=0.96$, $p<0.0001$) indicated that dynamics of N in the soil is intimately linked with that of C (Fig. 5.8). Such a relationship has been reported by several workers e.g., Moore *et al.* (2000) from the Clarion-Webster Research Center in Kanawha, Iowa; Arunachalam and Pandey (2003) from subtropical humid forest ecosystem; Joergensen (1995) under different management systems, etc.

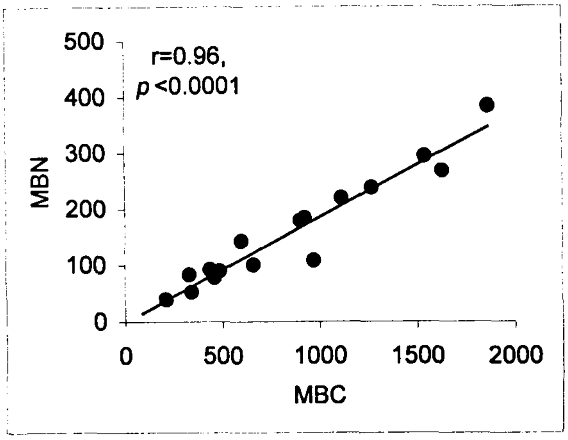

Fig. 5.8. Relationship between MBC and MBN in soils of the BR

Besides SOC, TKN and available P, other physico-chemical properties of soil like bulk density, silt content, micro-aggregates, water holding capacity and cation exchange capacity affected microbial biomass C and N (Table 5.7).

Table 5.7. Correlation coefficients (r) between microbial biomass and other soil properties in the BR (n=24; *p*<0.05)

	BD	Silt	MiA	WHC	CEC
MBC	0.89	0.52	0.65	0.91	0.90
MBN	0.93	0.68	0.64	0.92	0.93

Chapter 6

Enzyme activities and nitrogen mineralization

6.1. Introduction

Soil enzymes are essential for catalyzing reactions necessary for organic matter decomposition (Ajwa *et al.* 1999) and their activities are strongly influenced by organic matter content of the soil (Speir 1997). The enzyme activities have often been used as indices of microbial activity and soil fertility (Dick and Tabatabai 1992). Human activities that minimize addition of the organic matter to the soil may reduce enzyme activities and could alter the availability of nutrients for plant uptake (Dick *et al.* 1998). Therefore, the study of soil microbial biomass and their potential activity are important for understanding early changes in biological quality of soil following changes in the land management. Among the different types of soil enzymes, oxidoreductase (dehydrogenase) and hydrolases (phosphatase and urease) are thoroughly studied due to their specific importance in organic matter transportation processes, phosphorus cycle and agricultural practices.

Mineralization is a process of nutrient release from the organically bound materials into inorganic or plant-available forms. Potential mineralization measures the component of SOM that is likely to be mineralized (Hassink 1997) and can therefore be considered to provide a useful measure of fertility (Antil *et al.* 2001). Nitrogen mineralization is the rate at which mineral nitrogen in the soil becomes available for uptake by plants through decomposition of organic matter and has been shown to be an important factor limiting production in non-fertilized forest ecosystems (Nadelhoffer *et al.* 1984; Pastor *et al.* 1984). It is of crucial importance in natural ecosystems where it is a limiting nutrient for plant growth since the breakdown product of organically combined nitrogen in the soil is most readily assimilated by the plants. It has been suggested that nitrogen losses from forest ecosystems following tree cutting are caused either by increased nitrogen mineralization rates or reduced nitrogen uptake by plants after disturbance (Vitousek and Melillo 1979). Nitrogen availability in the soil-litter interface is believed to control the rate of litter decomposition (Prescott 1995, 1996).

Urease and dehydrogenase activities in soil were measured in the core zone and in jhum fallows in the buffer zone to evaluate the effect of shifting cultivation on the activities of these enzymes. Nitrogen mineralization potential and mineralization pattern in the soils of core and buffer zones were studied under laboratory condition and the patterns of recovery in enzyme activity as well as N-mineralization during secondary succession on jhum fallows were also examined.

6.2. METHODS

6.2.1. Soil sampling

Enzymes activity was measured in the soil samples collected in winter (January), spring (April), rainy (August) and autumn (October) during 2000. For mineralization studies, soils were collected during winter (January) and rainy (August) seasons of 2001 and 2002. On each sampling date, five soil samples were randomly collected from 0-10 cm and 10-20 cm depths at each site using a steel corer and mixed thoroughly to obtain a composite sample for each depth at a given site. The samples were passed through 2 mm sieve to remove stone and larger root particles.

6.2.2. Analysis

6.2.2.1. Dehydrogenase activity (DHA) and Urease activity (UA)

Dehydrogenase activity was determined by 2, 3, 5-triphenyl-tetrazolium chloride (TTC) reduction technique (Casida 1977). Five grams of soil was placed in a test tube (15 x 2 cm dia.) and carefully mixed with 0.1 g $CaCO_3$ and 1.5 ml of distilled water. The tubes were incubated at 30°C for 24 h after adding 1 ml of 1 % TTC solution and plugged with cotton wool. The resulting slurry was transferred on Whatman No. 1 filter paper and triphenyl formazan (TPF) was extracted with successive aliquots of concentrated methanol in a 50 ml volumetric flask. The extinction of the pink colour was read out with the help of a spectrophotometer (Systronics-106) at 486 nm using methanol as control (without soil).

$$\text{Dehydrogenase activity (g TPF g}^{-1}\text{ dry soil 24 h}^{-1}) = \frac{C \times 50}{W}$$

{Where, C = corrected reading of g TPF g^{-1} from the standard curve; 50 = volume of extractant (ml); W = dry weight of soil}

Urease activity was determined by urea reduction method of McGarity and Meyers (1967). Ten grams of fresh soil was placed in a 100 ml volumetric flask and treated with 1 ml of toluene, 10 ml buffer (pH 7) and 5 ml of 10 % freshly prepared urea solution. After a thorough mixing, the flask was incubated for 3 h at 37°C in dark. For the control, 5 ml of 10 % urea solution was replaced by 5 ml of sterile distilled water. After incubation, the volume of the flask was made up to 100 ml with distilled water, shaken thoroughly and the filtrate was transferred through Whatman No. 5 filter paper. The ammonia released because of urease activity was measured by indophenol blue method. The filtrate (0.5 ml) was taken into a 25 ml volumetric flask and 5 ml of distilled water was added to it. Then 2 ml of phenolate solution {mixture of 20 ml of stock A (62.5 g phenol crystals dissolved in minimum volume of methanol and made up the volume up to 100 ml with ethyl alcohol after adding 18.5 ml acetone) and 20 ml of stock B (27 g NaOH dissolved in 100 ml distilled water and kept in freezer} was added. Thereafter, 1.5 ml of sodium hypochlorite solution was added. The final volume of the flask was made to 25 ml with distilled water and absorbance of the resulting blue colour was measured with the spectrophotometer at 630 nm.

$$\text{Urease activity (mg NH}_4^+\text{-N g}^{-1}\text{ dry soil 3 h}^{-1}) = \frac{C \times 25 \times 100}{W}$$

{Where, C=corrected reading of mg NH_4^+-N ml^{-1} from the standard curve; 25 = volume of extractant (ml); 100 = total volume of solution (ml); W = dry weight of soil}

6.2.2.2. Nitrogen mineralization potential

For the determination of mineralization potential of soils, nitrogen mineralization was studied by method given by Sanchez *et al.* (1997). For this experiment, the inorganic nitrogen concentration was used as a determinant of the mineralization potential of the soil. Fresh soil samples collected during winter in 2001 were kept in the incubator at 25°C for 2-15 weeks. Before incubating soil, coarse roots and small and large fragments of organic debris were removed, as recommended by several authors (Nadelhoffer *et al.* 1991; Klemmedson and Weinhold 1992; Raghubanshi 1993). The moisture content of the incubated soil samples was kept constant throughout the experiment by periodic addition of deionised water. The concentrations of NH_4^+-N and NO_3^--N in soil were measured colorimetrically after 2, 4, 6, 8, 10, 13 and 15 weeks of incubation following the method outlined by Allen *et al.* (1974). The net mineralized N during each interval was calculated by adding NH_4^+-N and NO_3^--N concentrations. The net N mineralization rate was calculated by subtracting the initial inorganic N (NH_4^+-N plus NO_3^--N) present in the soil from the N accumulated in the soil during the respective incubation period: All the results are expressed on an oven-dry (105°C for 24 hours) soil basis.

N mineralization rate (µg g^{-1} day^{-1})

$$= \frac{\text{Final inorganic N concentration} - \text{Initial inorganic N concentration}}{\text{Incubation time (days)}}$$

6.2.2.3. N mineralization rates

Soil samples collected during winter and rainy seasons in 2001 were incubated at 25°C for 8 weeks as most of the soils exhibited peak potential during this time. Concentration of ammonium nitrogen (NH_4^+-N) was determined by molybdenum blue method and that of nitrate nitrogen (NO_3^--N) by phenoldisulphonic acid method (Allen *et al.* 1974). Inorganic nitrogen as well as the mineralization rates were computed following the formula used in the previous experiment.

6.2.3. Statistical analysis

The data were analyzed using 2-way and 3-way analysis of variance (ANOVA) (fixed effect model) to test the effects of season, soil depth and / or site on the dehydrogenase and urease activities and the effects of season and / or site on the inorganic nitrogen concentration, N-mineralization potential and N-mineralization rates. These were correlated with other properties of the soil by computing coefficients of correlation (r) according to Zar (1974).

6.3. RESULTS

6.3.1. Dehydrogenase activity (DHA) and urease activity (UA)

Dehydrogenase activity varied significantly ($p<0.01$) among different seasons; it steadily increased from a minimum level during winter to maximum level during autumn (Table 6.1 & Fig. 6.1). It also showed significant ($p<0.01$) variation among the sites and soil depths (Table 6.2). Highest activity was recorded in the core zone and lowest in 1-yr. old jhum field. On the jhum fallows, it gradually increased from the 1-yr. old to 10-12-yr. old fallow. In all the stands, the activity was significantly ($p<0.01$) higher in the upper soil layer. The trend of urease activity was similar to that of dehydrogenase activity (Table 6.3 & Fig. 6.2). It varied significantly ($p<0.01$) among the sites, declining sharply from the core zone to 1-yr. old-field and then gradually increasing during the regrowth of vegetation on jhum fallows. In all stands, activity was high in the upper soil layer than the lower layer (Table 6.4).

Table 6.1. Seasonal and spatial variation in dehydrogenase activity (TPF released, μg g^{-1} $24h^{-1}$, ±SE) in soils of the BR

Sites	Depth (cm)	Winter	Spring	Rainy	Autumn
Core	**0-10**	**0.43**± 0.05	**0.75**± 0.01	**0.84**± 0.01	**0.94**± 0.01
zone*	**10-20**	**0.25**± 0.01	**0.36**± 0.02	**0.41**± 0.01	**0.42**± 0.02
Jhum fallows:					
10-12-	0-10	0.36± 0.08	0.63± 0.02	0.68± 0.01	0.74± 0.01
yr. old*	10-20	0.25± 0.01	0.33± 0.02	0.41± 0.01	0.44± 0.01
6-8- yr.	0-10	0.29± 0.02	0.53± 0.05	0.55± 0.05	0.57± 0.06
old*	10-20	0.18± 0.04	0.35± 0.03	0.33± 0.04	0.27± 0.01
1- yr.	0-10	0.23± 0.05	0.44± 0.05	0.47± 0.04	0.50± 0.01
old*	10-20	0.10± 0.02	0.36± 0.04	0.34± 0.04	0.31± 0.04
Mean†	**0-10**	**0.29**	**0.53**	**0.57**	**0.60**
	10-20	**0.18**	**0.35**	**0.36**	**0.34**

*Mean of the replicate sites; †Mean of the jhum fallows

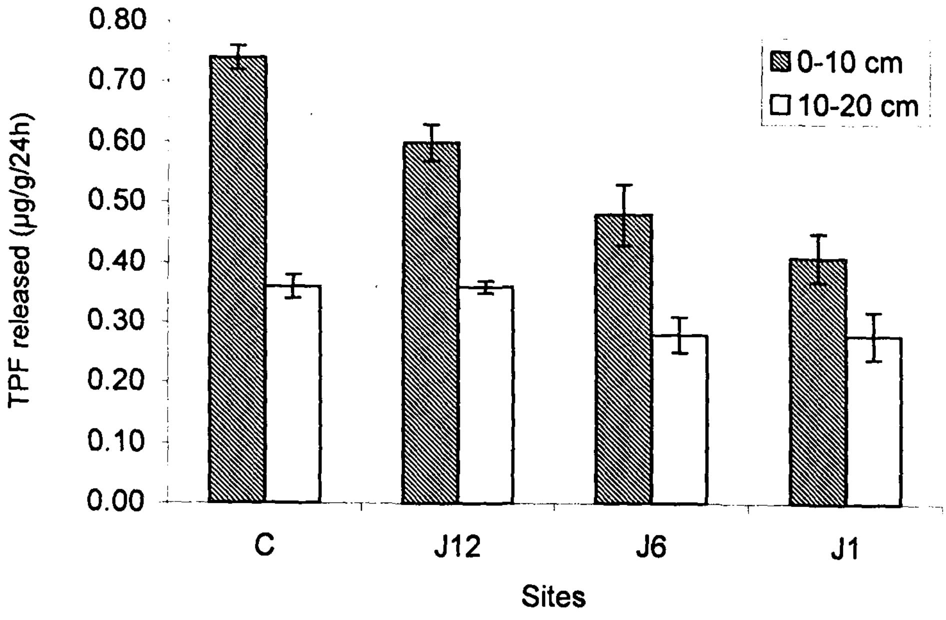

Fig. 6.1. Dehydrogenase activity (DHA) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows}. The values are means (±SE) of seasonal data and 6-9 replicate sites.

Table 6.2. Three-way ANOVA showing effects of site, season and depth on dehydrogenase activity of soils of the BR (*$p<0.05$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	6.177613	6.177613	...
Site	3	0.209012	0.069671	39.16**
Season	3	0.576430	0.192004	107.92**
Depth	1	0.183012	0.183012	102.87**
Site x season	9	0.071263	0.007918	4.45*
Site x depth	3	0.014513	0.004838	2.72
Season x depth	3	0.093162	0.031054	17.46**
Residual	9	0.016012	0.001779	...
Total	**32**	**7.340600**	**0.229394**	**...**

Table 6.3. Seasonal and spatial variation in urease activity (NH_4 released, µg g^{-1} $24h^{-1}$, ±SE) in soils of the BR

Sites	Depth (cm)	Winter	Spring	Rainy	Autumn
Core zone*	**0-10**	**19.83±** 0.50	**32.58±** 1.58	**38.49±** 1.36	**40.65±** 1.25
	10-20	**13.10±** 1.01	**16.90±** 1.59	**22.52±** 1.32	**25.16±** 1.51
Jhum fallows:					
10-12- yr. old*	0-10	18.86± 0.86	26.75± 1.76	30.41± 1.34	35.00± 0.98
	10-20	11.33± 1.07	16.00± 1.17	17.74± 1.06	21.67± 1.33
6-8- yr. old*	0-10	11.26± 0.29	20.25± 0.82	25.06± 0.91	31.83± 0.59
	10-20	8.15± 0.82	11.99± 0.67	15.51± 0.92	16.16± 1.17
1- yr. old*	0-10	5.74± 0.52	9.66± 0.56	15.42± 0.45	20.33± 1.23
	10-20	4.25± 0.22	6.66± 0.86	8.36± 0.94	9.00± 0.86
Mean†	**0-10**	**11.95**	**18.89**	**23.63**	**29.05**
	10-20	**7.91**	**11.55**	**13.87**	**15.61**

*Mean of the replicate sites

†Mean of the jhum fallows

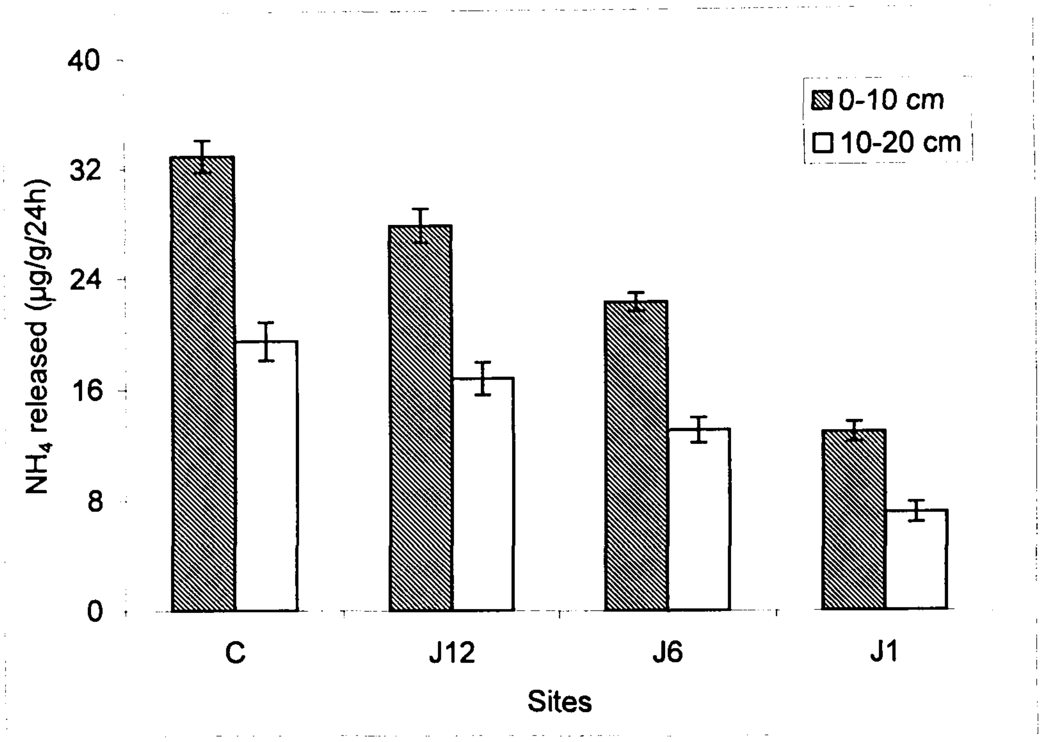

Fig. 6.2. Urease activity (UA) of surface (0-10 cm) and subsurface (10-20 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows}. The values are means (±SE) of seasonal data and 6-9 replicate sites.

Table 6.4. Three-way ANOVA showing effects of site, season and depth on urease activity of soils of the BR (*$p<0.05$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	11499.61	11499.61	...
Site	3	1168.16	389.39	154.43**
Season	3	977.12	325.71	129.17**
Depth	1	612.51	612.51	242.91**
Site x season	9	75.83	8.43	3.34*
Site x depth	3	21.14	7.05	2.79
Season x depth	3	79.16	26.39	10.46**
Residual	9	22.69	2.52	...
Total	**32**	**14456.23**	**451.76**	**...**

6.3.2. Seasonal and spatial distribution pattern of inorganic nitrogen

The concentration of ammonium-N was higher during the rainy season than winter both in the undisturbed core zone and jhum fallows. However, seasonal difference in coal and limestone mine spoils was not prominent (Fig. 6.3a). Nitrate-N concentration was higher during winter than the rainy season at all the sites (Fig. 6.3b). Seasonal variation in total inorganic-N (NH_4^+-N + NO_3^--N) at different sites was not pronounced (Fig. 6.3c), but ammonium, nitrate and total inorganic nitrogen concentrations varied significantly ($p<0.01$) among the sites (Table 6.6 a, b & c).

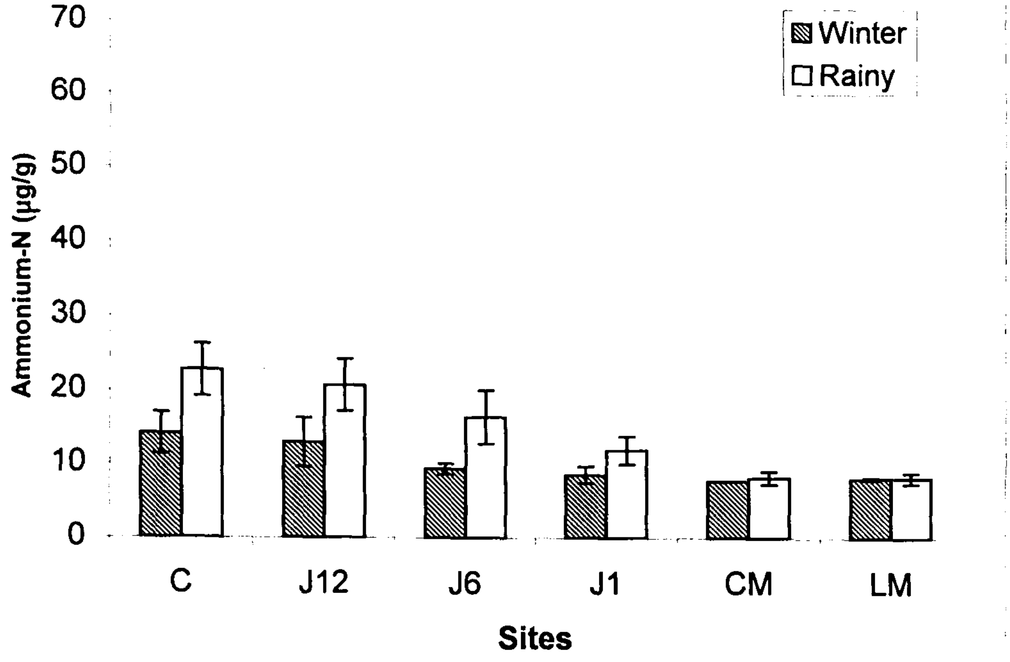

Fig. 6.3a. Concentration of ammonium nitrogen in surface (0-10 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

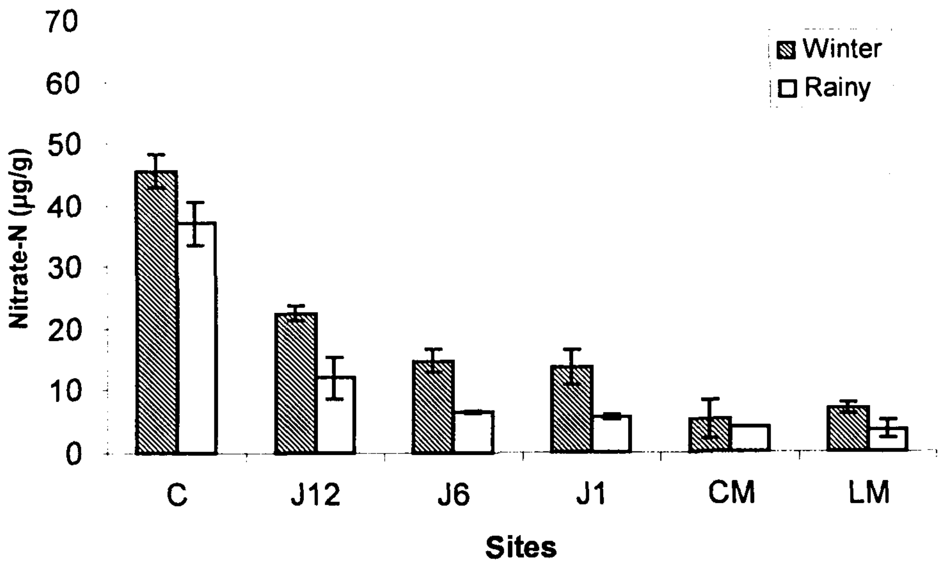

Fig. 6.3b. Nitrate nitrogen of surface (0-10 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

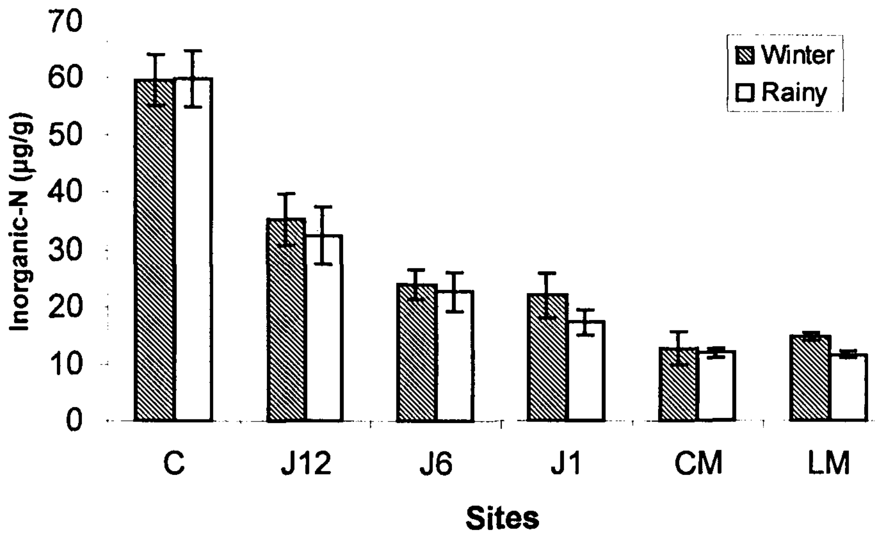

Fig. 6.3c. Inorganic nitrogen of surface (0-10 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal data and 3-9 replicate sites.

The core zone had the highest concentration of ammonium-N, nitrate-N and inorganic-N followed by jhum fallows and mine spoils. Inorganic-N concentrations ranged from 44.21 µg g^{-1} to 75.16 µg g^{-1} in the undisturbed core zone; from 15.14 to 43.62 µg g^{-1} in the jhum fallows and from 9.89 to 15.77 µg g^{-1} in the mine spoils. In the jhum fallows, concentrations of ammonium-N, nitrate-N and inorganic-N increased with the increase in the age of the fallow and their concentration was higher during the second year of the study both in the undisturbed core zone as well as jhum fallows (Table 6.5 a, b &c).

Table 6.5a. Ammonium nitrogen (NH_4^+-N, µg g^{-1}, ±SE) in soils of the study sites

Sites	2001		2002		Mean
	Winter	Rainy	Winter	Rainy	
Core zone*	**11.31**	**15.66**	**16.95**	**29.73**	**18.41**
	± 0.78	± 0.82	± 0.87	± 0.00	± 3.96
Jhum fallows:					
10-12- yr. old*	9.58	12.91	16.27	28.38	**16.79**
	± 0.20	± 0.00	± 0.00	± 1.13	± 4.10
6-8- yr. old*	8.60	12.70	10.05	20.00	**12.84**
	± 0.22	± 0.41	± 0.96	± 0.36	± 2.53
1- yr. old*	7.42	9.95	9.63	13.74	**10.19**
	± 0.19	± 0.21	± 0.64	± 0.25	± 1.31
Mean†	**8.53**	**11.85**	**11.95**	**20.71**	**13.27**
	± 0.62	± 0.95	± 2.15	± 4.24	± 1.92
Mine spoils:					
Coal*	7.62	7.27	7.73	9.01	**7.91**
	± 0.47	± 0.51	± 1.26	± 0.00	± 0.38
Limestone	7.93	7.37	8.20	8.82	**8.09**
	± 0.53	± 0.00	± 0.34	± 0.00	± 0.31
Mean‡	**7.78**	**7.32**	**7.97**	**8.92**	**8.00**
	± 0.15	± 0.05	± 0.24	± 0.10	± 0.09

*Mean of the replicate sites; †Mean of the jhum fallows; ‡ Mean of the mine spoils

Table 6.5b. Nitrate nitrogen (NO_3^--N, μg g^{-1}, ±SE) in soils of the study sites

Sites	2001		2002		Mean
	Winter	Rainy	Winter	Rainy	
Core zone*	**32.90**	**29.17**	**58.21**	**44.98**	**41.32**
	± 2.10	± 0.47	± 0.42	± 1.73	± 6.56
Jhum fallows:					
10-12- yr. old*	21.19	8.61	23.53	15.24	**17.14**
	± 1.47	± 0.45	± 0.86	± 0.88	± 3.34
6-8- yr. old*	12.83	6.59	16.47	6.24	**10.53**
	± 1.36	± 0.00	± 0.40	± 0.45	± 2.49
1- yr. old*	10.75	5.19	16.35	5.90	**9.55**
	± 0.75	± 0.00	± 0.40	± 0.00	± 2.58
Mean†	**14.92**	**6.80**	**18.78**	**9.13**	**12.41**
	± 3.19	± 0.99	± 2.37	± 3.06	± 2.38
Mine spoils:					
Coal*	8.15	3.82	2.16	3.75	**4.47**
	± 0.71	± 0.38	± 0.00	± 0.37	± 1.29
Limestone	7.63	4.91	5.95	2.11	**5.15**
	± 0.35	± 0.00	± 0.74	± 0.42	± 1.16
Mean‡	**7.89**	**4.37**	**4.06**	**2.93**	**4.81**
	± 0.26	± 0.54	± 1.90	± 0.82	± 0.34

*Mean of the replicate sites; †Mean of the jhum fallows; ‡ Mean of the mine spoils

Table 6.5c. Inorganic nitrogen (NH_4^+-N + NO_3^--N μg g^{-1}, ±SE) in soils of the study sites

Sites	2001		2002		Mean
	Winter	Rainy	Winter	Rainy	
Core zone*	**44.21**	**44.83**	**75.16**	**74.71**	**59.73**
	± 2.88	± 1.29	± 1.29	± 1.73	± 8.78
Jhum fallows:					
10-12- yr. old*	30.77	21.52	39.80	43.62	**33.93**
	± 1.67	± 0.45	± 0.86	± 2.01	± 4.94
6-8- yr. old*	21.43	19.29	26.52	26.24	**23.37**
	± 1.58	± 0.41	± 1.36	± 0.81	± 1.79
1- yr. old*	18.17	15.14	25.98	19.64	**19.73**
	± 0.94	± 0.21	± 1.04	± 0.25	± 2.28
Mean†	**23.46**	**18.65**	**30.77**	**29.83**	**25.68**
	± 3.78	± 1.87	± 4.52	± 7.15	± 4.26
Mine spoils:					
Coal*	15.77	11.09	9.89	12.76	**12.38**
	± 1.18	± 0.89	± 1.26	± 0.37	± 1.27
Limestone	15.56	12.28	14.15	10.96	**13.24**
	± 0.88	± 0.00	± 1.08	± 0.42	± 1.01
Mean‡	**15.67**	**11.69**	**12.02**	**11.86**	**12.81**
	± 0.11	± 0.60	± 2.13	± 0.90	± 0.43

*Mean of the replicate sites; †Mean of the jhum fallows; ‡ Mean of the mine spoils

Table 6.6a. Two-way ANOVA showing effects of site and season on ammonium-nitrogen of soils of the BR ($p<0.01$)**

Variation due to	d.f.	SS	MS	F
General mean	1	3671.91	3671.91	...
Site	5	397.00	79.40	6.43**
Season	3	305.33	101.78	8.25**
Residual	15	185.12	12.34	...
Total	**24**	**4559.36**	**189.97**	**...**

Table 6.6b. Two-way ANOVA showing effects of site and season on nitrate-nitrogen of soils of the BR (*$p<0.05$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	5181.16	5181.16	...
Site	5	3816.38	763.28	24.21**
Season	3	368.32	122.77	3.89*
Residual	15	472.89	31.53	...
Total	**24**	**9838.76**	**409.95**	**...**

Table 6.6c. Two-way ANOVA showing effects of site, season and depth on inorganic-nitrogen of soils of the BR (*$p<0.05$, **$p<0.01$)

Variation due to	d.f.	SS	MS	F
General mean	1	17576.56	17576.56	...
Site	5	6353.09	1270.62	23.48**
Season	3	538.92	179.64	3.32*
Residual	15	811.76	54.12	...
Total	**24**	**25280.33**	**1053.35**	**...**

Percentage contribution of inorganic nitrogen (NH_4^+-N + NO_3^--N) to TKN was found to be higher during winter, and it was highest in the mine spoils and lowest in 1-yr. old jhum fallow (Fig. 6.4).

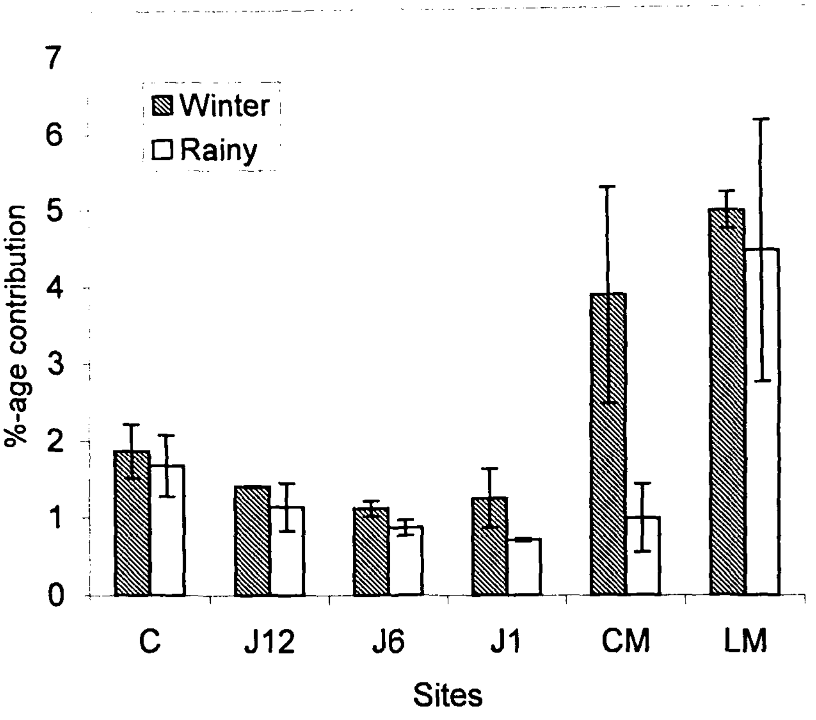

Fig. 6.4. Percentage contribution of inorganic nitrogen to TKN in surface (0-10 cm) soil layers of the BR {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) and limestone mine (LM) spoils}. The values are means (±SE) of seasonal values and 3-9 replicate sites.

6.3.3. Mineralization potential

The changes in the concentration of NH_4^+-N and NO_3^--N in surface soils incubated for 15 weeks are shown in Fig. 6.5 a & b.

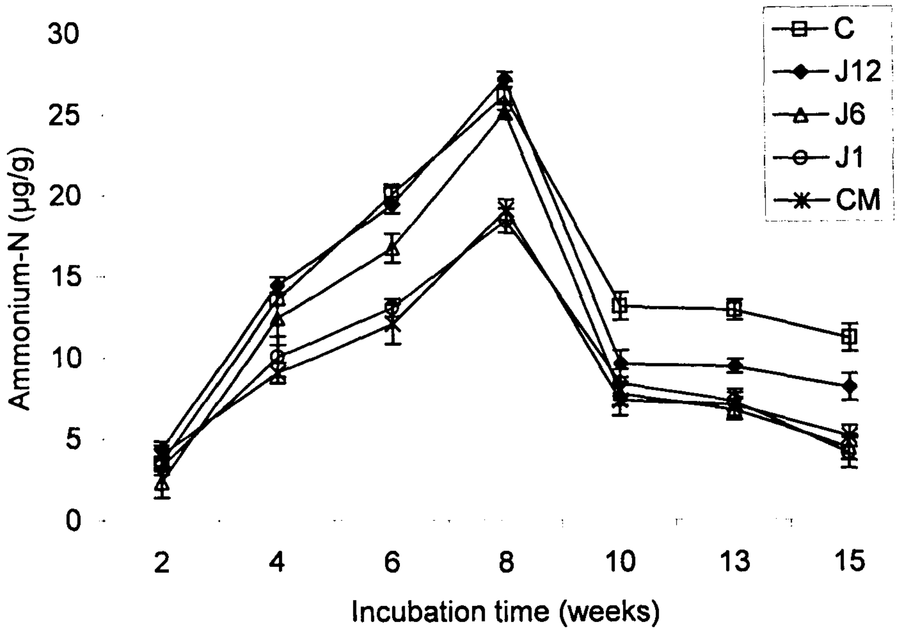

Fig. 6.5 a. Ammonium-N concentration in surface (0-10 cm) soils during 15 weeks incubation {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) spoils}.

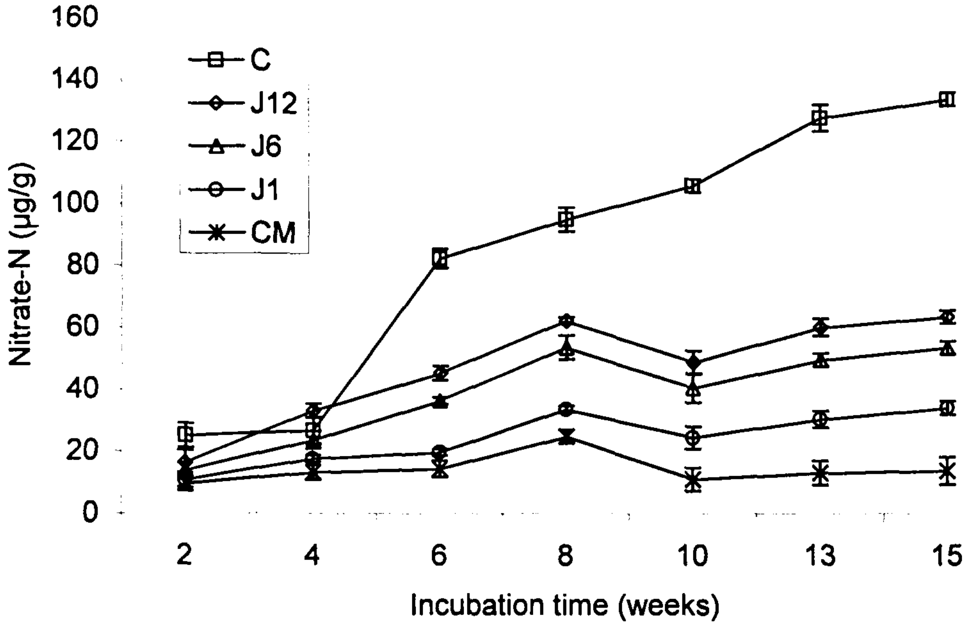

Fig. 6.5 b. Nitrate-N concentration in surface (0-10 cm) soils during 15 weeks incubation {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) spoils}.

The temporal variation in NH_4^+-N was similar in all the soil samples *i. e.*, it increased till 8 weeks and then declined until the end of the experiment. So far as the difference between sites is concerned, the soils of core zone, 10-12- and 6-8-yr. old jhum fields showed higher concentration than other sites. The concentration of nitrate nitrogen showed a steady increase till the end of the experiment. However, the increase with time was marked in case of core zone soil, which had the maximum concentration, followed in decreasing order by 10-12-yr. old jhum fallow, 6-8-yr. old jhum fallow, 1-yr. old jhum fallow and coal mine spoil.

Nitrogen mineralization potential of soils exhibited by change in the concentration of inorganic nitrogen (NH_4^+-N + NO_3^--N) during incubation has been shown in Fig. 6.5 c.

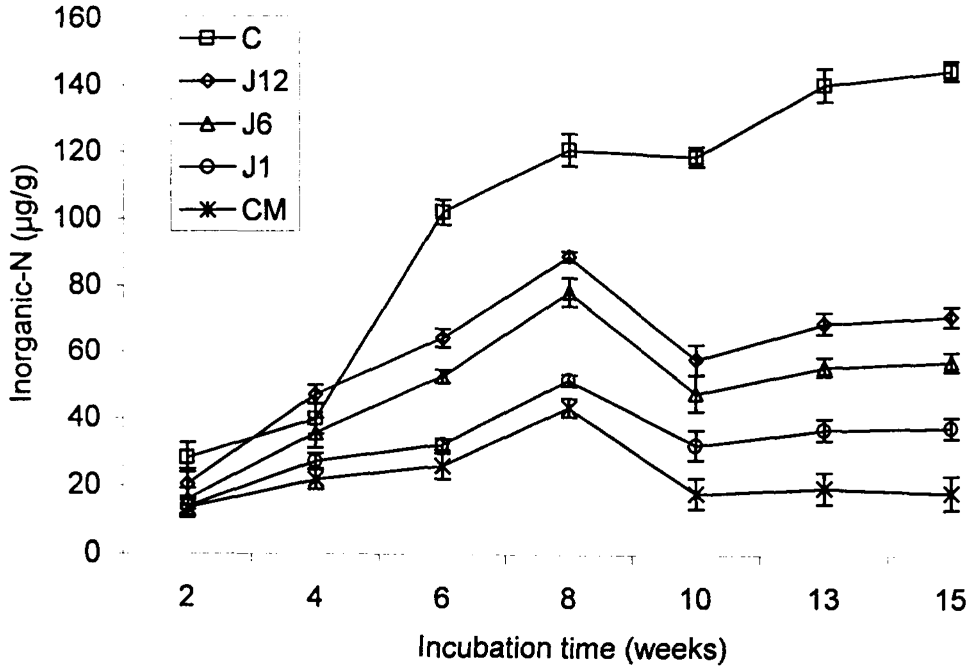

Fig. 6.5c. Nitrogen mineralization potential (inorganic N concentration) of surface (0-10 cm) soil during 15 weeks incubation {core zone (C), 10-12-yr. (J12), 6-8-yr. (J6) & 1-yr. (J1) old jhum fallows; coalmine (CM) spoils}.

With time the concentration increased until the 8th week except in the core zone soil where it continued to increase till 15th week. The mineralization potential followed the following order of sequence:

core zone>10-12-yr. old jhum fallow>6-8-yr. old jhum fallow>1-yr. old jhum fallow> coal mine spoil

Table 6.7. Ammonification (A_f), nitrification (N_f) and nitrogen mineralization (N_m) (µg g^{-1} day^{-1}) rates during 15 weeks of incubation under laboratory condition (values in parenthesis indicate the peak rate)

Sites	A_f	N_f	N_m
Core zone*	**0.54 (0.71)**	**1.67 (3.98)**	**2.20 (4.69)**
Jhum fallows:			
10-12-yr. old*	0.54 (0.71)	1.09 (1.21)	1.63 (1.92)
6-8-yr. old*	0.54 (0.71)	0.94 (1.20)	1.48 (1.91)
1- yr. old*	0.36 (0.48)	0.54 (1.00)	0.90 (1.48)
Mean†	**0.48 (0.63)**	**0.86 (1.14)**	**1.34 (1.77)**
Mine spoils:			
Coal*	**0.36 (0.36)**	**0.36 (0.75)**	**0.72 (1.11)**

*Mean of the replicate sites; †Mean of the jhum fallows

6.3.4. Nitrogen mineralization rate

Rate of ammonification (0.33 µg g^{-1} day^{-1}) as well as nitrification (0.74 µg g^{-1} day^{-1}) rate was maximum in the undisturbed core zone, followed in descending order by 10-12-yr., 6-8-yr., 1-yr. old fallows, and the minimum values (0.08 µg g^{-1} day^{-1} respectively) were recorded in the coal mine spoil. N-mineralization followed the same pattern. Ammonification rate was higher during the rainy season than the winter, while nitrification and mineralization rates were higher during winter season than the rainy season (Table 6.8).

Table 6.8. Ammonification, nitrification and nitrogen mineralization rates (µg g^{-1} day^{-1}, ±SE) under laboratory condition in soils of the study sites collected during winter and rainy seasons.

	Ammonification			Nitrification			Mineralization		
	Winter	**Rainy**	**Mean**	**Winter**	**Rainy**	**Mean**	**Winter**	**Rainy**	**Mean**
Core zone*	**0.25**	**0.41**	**0.33**	**0.81**	**0.66**	**0.74**	**1.07**	**1.07**	**1.07**
			± 0.08			± 0.07			± 0.00
Jhum fallows:									
10-12- yr. old*	0.23	0.37	0.30	0.40	0.21	0.31	0.63	0.58	**0.61**
			± 0.07			± 0.10			± 0.03
6-8- yr. old*	0.17	0.29	0.23	0.26	0.11	0.19	0.43	0.41	**0.42**
			± 0.06			± 0.08			± 0.01
1- yr. old*	0.15	0.21	0.18	0.24	0.10	0.17	0.39	0.31	**0.35**
			± 0.03			± 0.07			± 0.04
Mean†	**0.18**	**0.29**	**0.24**	**0.30**	**0.14**	**0.22**	0.48	0.43	**0.46**
Coal*	0.14	0.15	0.15	0.09	0.07	0.08	0.23	0.21	**0.22**
			± 0.00			± 0.01			± 0.01

*Mean of the replicate sites

†Mean of the jhum fallows

6.4. DISCUSSION

6.4.1. Seasonal and spatial dynamics of DHA and UA

A significant decline in dehydrogenase and urease activities from the surface (0-10 cm) to the subsurface (10-20 cm) soil layer is ascribed to greater population of some microbes, better aeration and greater nutrient availability. Gregorich *et al.*(1994) reported that enzyme activity increases with increase in organic matter content. On their studies on depth-wise distribution of enzyme activities, Tiwari (1996) and Rao *et al.* (1997) also reported a decreasing trend of DHA and UA with increasing depth in a sandy loam soil profile. The decline in activity at the lower soil depth was attributed to the reduction in organic matter, and inorganic nutrients and smaller microbial population (Maithani 1996).

Since microbes are chiefly responsible for production of soil enzymes (Burket and Dick 1998), physical, chemical and biological properties of soil system, which tend to influence soil microbes, should have a bearing on enzyme activities in the soil. The strong positive correlations between MBC and enzyme activities (dehydrogenase $r = 0.84$, $p<0.05$; urease $r = 0.86$, $p<0.05$), and MBN and enzyme activities (dehydrogenase $r = 0.84$, $p<0.05$; urease $r = 0.85$, $p<0.05$) (Fig. 6.6) clearly suggest a close relation between microbial biomass and activities of the two enzymes. Klose and Tabatabai (2000) have also reported a strong correlation between microbial biomass and urease activity in soil, thereby suggesting the microbial origin of urease in soils.

Tiwari *et al.* (2002) have reported higher DHA in undisturbed forest site in comparison to degraded and slightly degraded sites in humid tropical regions of north-eastern India. They estimated 40 % and 25 % reduction in DHA in degraded and moderately degraded sites respectively compared to the undisturbed site. In the present case, there was 19-45 % reduction in DHA and 16-61 % reduction in UA in the jhum fallows, compared to the core zone.

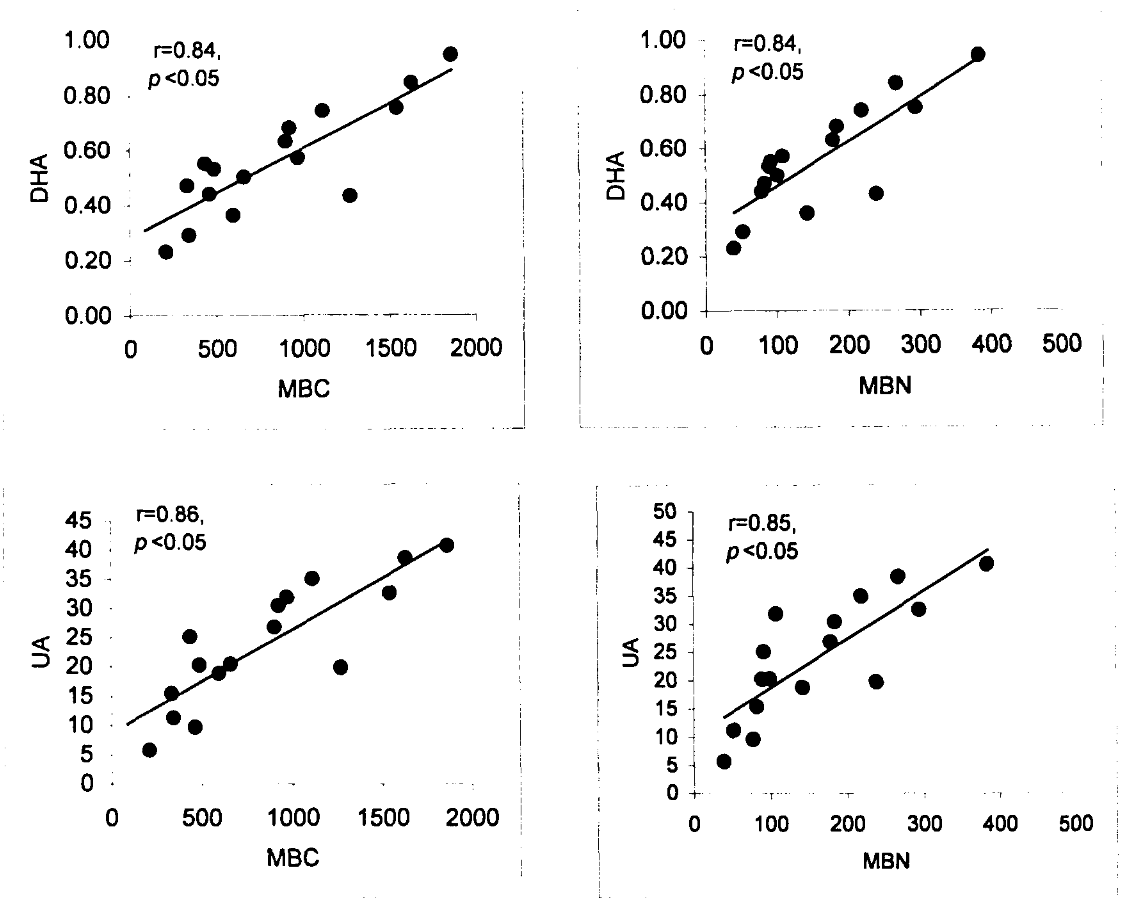

Fig. 6.6. Relationships between enzyme activities (DHA and UA) and microbial biomass in soils of the BR

Seasonal fluctuations in the urease activity in the soil are influenced by climate and soil type as well as quality, quantity and distribution of litter (Burns 1982). Miller and Dick (1995) and Liu *et al.* (2000) reported lowest urease activity during winter and highest during spring and summer. Results of these workers partially conform our findings where peak activity was recorded during autumn when temperature was around 34°C and trough was observed during winter when temperature was 10°C.

Positive correlation between enzyme activities and soil nutrients such as nitrate, potassium and organic matter was reported by Kumari and Charya (1997). Rao *et al.* (1997) mentioned that soil organic matter and soil moisture are the prime factors responsible for variation in enzyme activities. Stott and Hagedorn (1980) have also reported high positive correlation between UA and SOC (r = 0.59) in Argentine agricultural soils. This seems to be true in the present case also where activity of DHA and UA was positively correlated with SMC, TKN and SOC (Fig. 6.7 & 6.8). Brezezenska

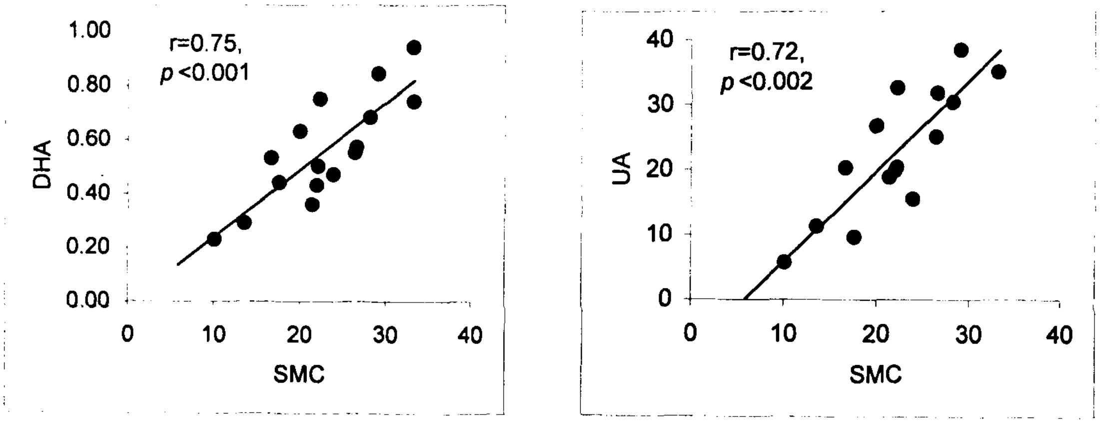

Fig. 6.7. Relationships between activities of DHA and UA and SMC in soils of the BR

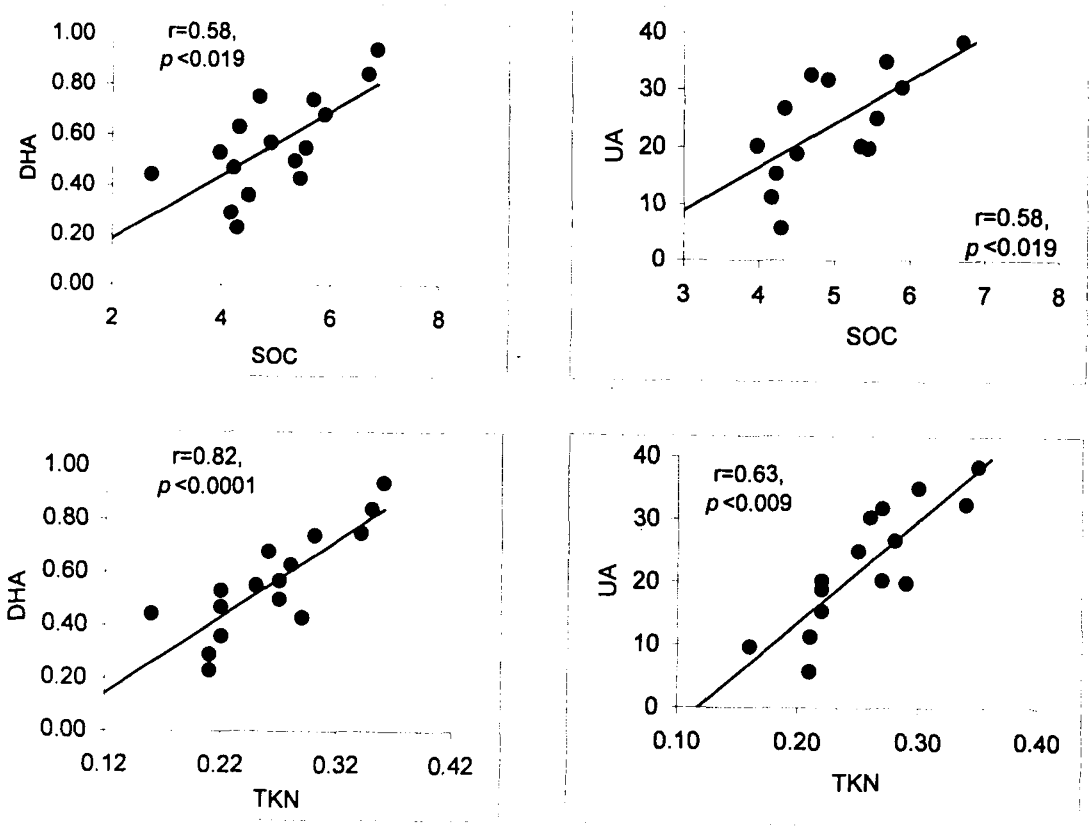

Fig. 6.8. Relationships between enzyme activities (DHA and UA) and SMC in soils of the BR

et al. (1998) found that soil moisture content and temperature influence the DHA indirectly by affecting the soil oxidation-reduction status.

The significant correlations between DHA and UA & WHC and CEC revealed that apart from SMC, TKN and SOC, WHC and CEC also play a role in influencing the enzyme activity in soil (Fig. 6.9).

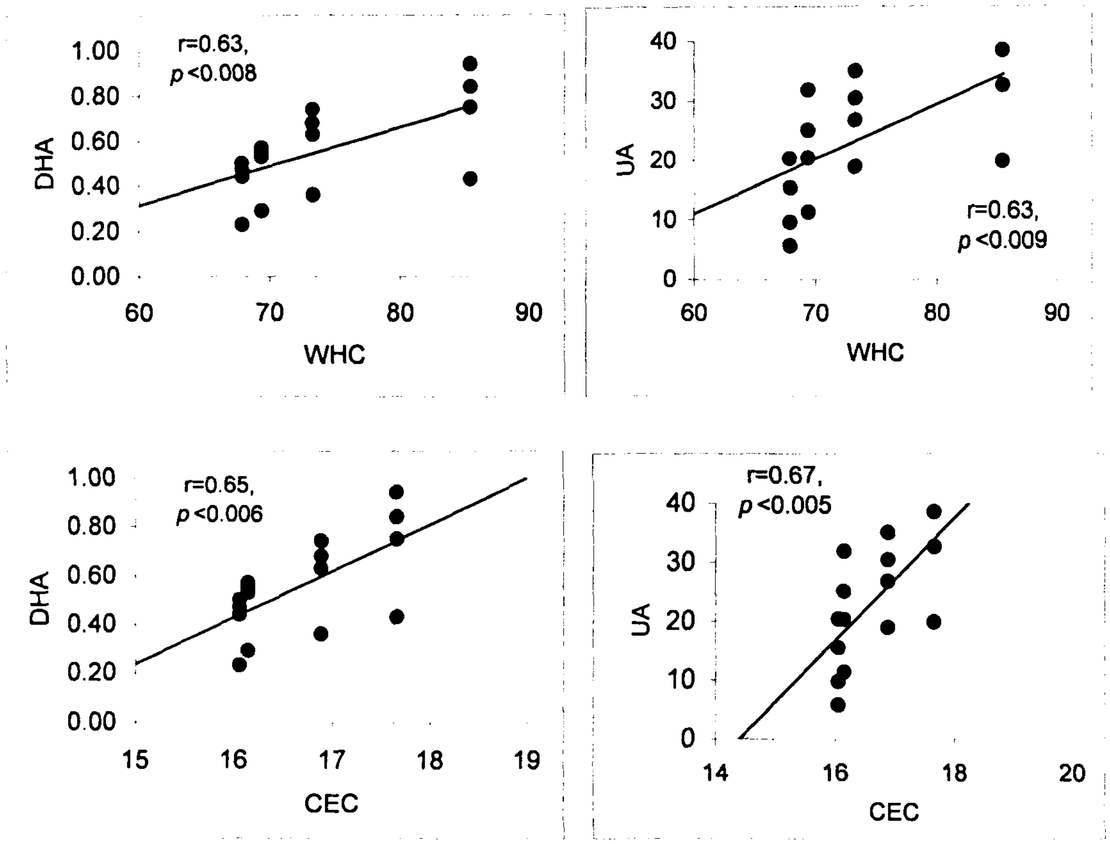

Fig. 6.9. Relationships between activities of DHA and UA and WHC and CEC in soils of the BR

6.4.2. Effect of shifting cultivation

The sudden drop in DHA and UA in 1-yr. old jhum fallow is the effect of removal of vegetal cover, which accelerates the loss of organic matter and nutrients from the soil. Garcia *et al.* (1997) found that devegetation of soils in semi-arid areas lead to reduction of their biochemical quality in contrast to natural or undisturbed area. As the regrowth of vegetation started, the dehydrogenase and urease activities steadily increased from young to old communities on jhum fallows, which may be attributed to the build up of organic matter and nutrients in the soil. Pancholy and Rice (1973) reported that dehydrogenase and N-releasing enzymes such as urease increased during plant succession in an abandoned field. Earlier reports on urease soil enzyme reveal that activity is generally higher in older pineapple orchard soils than the younger ones (Tiwari 1988), in forest soils than the grasslands (Tiwari and Mishra 1995), in pasture than the tillage soils (O'Toole *et al.* 1985) and in no tillage soils than the plow-grain soils (Klein and Kloths 1980). Palma and Conti (1990) reported that variation in distribution of UA in grassland and forest soils is related to the type of vegetation and organic matter.

6.4.3. *Seasonal and spatial distribution of inorganic nitrogen*

Variation of inorganic-N pool in soil is mainly attributed to three main processes, namely variation in mineralization rates, uptake by plants and microbes, and losses through soil erosion, leaching, run-off and denitrification. The decrease in nitrate-N in undisturbed core zone and jhum fallows during the rainy season may be due to the greater demand by plants which grow vigorously during this period. However, importance of leaching and denitrification, which are paramount factors responsible for nitrogen loss during the rainy season, cannot be ruled out. Schmitt and Randall (1994) also opined that lower nitrate-N during rainy season could be because of NO_3^- losses via leaching and denitrification. In fact, water favours biological activity and substrate diffusion but also simulates heterotrophic mineralization (Xie and Steinberger 2001), thus increasing NH_4^+ availability in soil during the rainy season (Castaldi and Aragosa 2002). Nitrifiers are known to be affected by low pH and temperature and moisture stress (Grant 1994). Nitrogen increase during winter may be partly associated with decreased demand by plants owing to their slow growth (Maithani *et al.* 1998). The availability of NH_3 decreases exponentially with decreasing pH (De Boer and Kowalchuk 2001).

Inorganic soil N, predominantly NO_3^-, has been a useful tool for predicting crop nitrogen needs in low rainfall areas, but has generally been less successful in more humid regions because of NO_3 losses via leaching and denitrification. Higher ammonium-N and lower values of nitrate-N and inorganic-N during the rainy season might have resulted from greater leaching loss and higher uptake by plants. Singh *et al.* (1991) reported that plant uptake is high during wet period and immobilization in microbial biomass is low compared to dry period.

The contribution of inorganic-N to total soil nitrogen was very small and it varied among different ages of jhum fallows. However, in the mine spoils, its contribution to total N pool was found to be higher than the undisturbed core zone and the jhum fallows, thereby suggesting that organic N content of the mine spoils was very low. The higher contribution of inorganic-N in the oldest fallow could be the result of increased mineralization of nutrients from SOM.

6.4.4. Nitrogen mineralization potential

Potential mineralization serves as an indicator of the accumulation of readily mineralizable residues, which contribute to the release of inorganic N over the succeeding growing season(s). Its measurement under incubation appear to predict N mineralization in the field correctly (Delphin 2000). Glaser *et al.* (2001) reported that N mineralization peaked on 20th day after incubation in laboratory and decreased thereafter. In the present study N mineralization continued until the last sampling time (15th week). The total mineralized N after 15 weeks accounted for 2-6 % of total soil N and it was lower than the values (6 %) reported from laboratory incubations by Bernhart-Reversat (1982) and 11 % reported from natural savanna ecosystem by Glaser *et al.* (2001).

Greater N mineralization rate up to the 8th week of incubation may be ascribed to the mineralization of the more labile soil organic matter. The subsequent decrease in the rate might have resulted from exhaustion of the fraction of mineralizable SOM. This in turn causes N-immobilization or decrease in size of the microbial population during incubation (Sanchez *et al.* 1997).

6.4.5. Ammonification, nitrification and mineralization pattern

In acid soils, like ours, that produce nitrate often show a high degree of spatial variability, which is not explained by local differences in ammonium availability (Sitaula and Bakken 1993; De Boer and Kester 1996; Laverman *et al.* 2000), rather it may be due to presence of natural inhibitors of autotrophic nitrifiers (Gallardo and Merino 1992). Therefore, in a low pH environment N-mineralization is dependent on nitrification rather than on ammonium availability (Strong *et al.* 1997). This is evident from a strong positive correlation between N-mineralization and nitrification ($r=0.99$, $p<0.001$) (Table 6.9). The positive correlation between nitrification and NH_4^+ concentrations ($r=0.73$, $p<0.05$) is also in agreement with the current theory that the regulation of net nitrification ultimately depends on availability of NH_4^+ (Aber and Melillo 1991; Menyailo *et al.* 2003). Castaldi and Aragosa (2002) also reported that both ammonification and nitrification are directly limited by substrate availability (NH_4^+, NO_3^-, organic C) and low temperature and indirectly by water content and capacity of soil to retain water (Granli and Bøckman 1994).

The peak net N mineralization during the rainy season occurred when the soil moisture conditions were optimum for microbial activity at all the sites. The high rate in the undisturbed core zone and 10-12-yr. old jhum fallows could be because of high SMC and SOM which serve as readily available C sources to the soil microbes (Maithani *et al.* 1998) and the decrease in nitrification rate in 1-yr. old fallow may be due to several reasons, such as allelopathic inhibition by organic compounds and reduction in ammonium-N availability (Montangnini *et al.* 1986). *Eupatorium adenophorum*, which dominated 1-yr. old field has been reported to produce allelopathic effects on the forest crops growing in the jhum fallows (Tripathi *et al.* 1981). The low nitrification rate in the coal mine spoil could be due to the low pH.

Soil physical properties also influenced nitrogen mineralization as is evident from the positive correlation between N-mineralization and proportion of microaggregate in soil (Table 6.9). This is in agreement with the findings of Rovira and Vallejo (2002) who observed a decrease in mineralization with decreasing particle size. Puri and Ashman (1998) studied the relationship between gross N mineralization and microbial biomass in field condition using ^{14}N pool dilution technique. They found no significant relationship between gross N mineralization and soil MBN pool. They concluded that only a fraction of the microbial biomass was involved in N mineralization. Contrary to their findings, significant positive correlation ($p<0.05$) between N mineralization and MBC as well as MBN were observed in the present study indicating involvement of microbial biomass in the process (Table 6.9).

Glaser *et al.* (2001) found close correlation between total N content and cumulative N mineralization ($r = 0.87$) but no relation with carbon. Positive correlations between N mineralization with SOC and TKN obtained in the present study are in agreement with those found by Abbadie and Lensi (1990) and Mordelet *et al.* (1993) in Cote d'Ivoire savanna ecosystems. The enzyme activities such as DHA and UA also influenced N mineralization as is evident by a significant positive correlation ($p<0.05$) between the two (Table 6.9).

Table 6.9. Correlation coefficients (r) between ammonification (A_f), nitrification (N_f) and N mineralization (N_m) and other soil parameters (n=24, *p*<0.05, ns = not significant)

Variables	BD	MiA	WHC	CEC	SOC	TKN	P	MBC	MBN	DHA	UA	NH_4^+-N	NO_3^--N	NH_4^+-N + NO_3^--N	N_f
A_f	0.72	0.51	0.76	0.75	0.57	0.51	0.61	0.52	0.57	ns	ns	ns	0.54	ns	ns
N_f	0.59	ns	0.64	0.61	ns	0.72	0.58	0.78	0.77	0.82	0.85	0.73	0.77	0.88	-
N_m	0.65	0.51	0.71	0.67	ns	0.76	0.64	0.82	0.81	0.82	0.85	0.72	0.82	0.92	0.99

6.4.6. Effect of shifting cultivation and mining on nitrogen mineralization

Glaser *et al.* (2001) reported that selective removal of acacias from the woodland and short-term cultivation for 3 years significantly ($p<0.05$) decreased total carbon and nitrogen contents and mineralization. The low concentration of soil carbon and nitrogen as well as the low total nitrogen mineralization in the recently cleared fields (1-yr. old fallows) was probably caused by a lack of organic matter input due to devegetation. The beneficial effects of trees on N mineralization and decrease in soil N after land clearing and cultivation have been shown for tropical soils (Mazzarino *et al.* 1993; Saikh *et al.* 1998). This fact has been well documented in studies of Lamto savannas by Abbadie and Lensi (1990), who found higher soil respiration and N mineralization rates under woody savanna than under the herbaceous layer, and by Mordelet *et al.* (1993), who found similar results under tree clumps and open savanna. The latter workers attributed the enhanced biological activity to the conditions prevailing under the tree canopies, such as high carbon inputs due to a large root biomass, and microfaunal activities, which improve soil aeration, all of which favoured higher N mineralization rates under savanna tree canopies. The above findings explain the observed higher N mineralization rate in the undisturbed core zone and in the older jhum fallows and lower rates in 1-yr. old fallow and the mine spoils, which were without the tree cover. A steady increase in the inorganic N pool during recovery in the older fallow could be due to higher net N mineralization and low leaching losses of inorganic-N (Maithani *et al.* 1998).

Chapter 7

Litter decomposition

7.1. Introduction

Decomposition of forest litter is the primary means of transferring nutrients into forms available for plant uptake, and is one of the most crucial processes in the biogeochemical cycle of the forest ecosystems (DeCatanzaro and Kimmins 1985). Litter originating from both above- and below - ground parts, is the major pathway of supply of energy and N to soil in most terrestrial ecosystems (Swift *et al.* 1981). During decomposition, some of the C and N are assimilated into microbial tissue and a part is microbially converted into resistant humic substances. The process of detrital decay is complex and is facilitated by the activities of wide range of macro- and micro- organisms (Haynes 1986). These activities are influenced by numerous factors such as the chemical composition and physical structure of the detritus and environmental factors such as temperature, moisture, aeration and pH (Couteaux *et al.* 1995). Much emphasis has been placed on the mass balance between leaf litter inputs and litter decomposition (Xiong and Nilsson 1997) and on the chemical composition of leaf litters affecting rates of decomposition (Cadisch and Giller 1997). Three essential factors control the decomposition of plant residues and the build-up of organic matter - namely resource quality and quantity, soil environmental conditions and the decomposer community (Bottner *et al.* 1998)

Within an ecosystem, plant litter quality is the most important factor in determining the rate of decomposition (Aerts 1997; Cadisch and Giller 1997). Therefore, the litter characteristics of the dominant plant species in an ecosystem strongly influence decomposition process (Hoorens *et al.* 2003). The decomposition process starts both through leaching and through maintenance of optimal residue moisture content for microbial catabolism (Vanlauwe *et al.* 1995). Fungi, bacteria and invertebrates (Dighton 1997), soil temperature and soil moisture content (Kochy and Wilson 1997) and the quality of litter in terms of its susceptibility to be attacked by decomposers influence decomposition rate. Decomposition has been related to initial concentration of N (Wardle *et al.* 1997; Quested *et al.* 2002), lignin (Sariyildiz and Anderson 2003), polyphenols (Seneviratne *et al.* 1999) and carbon to lignin ratio (Aber and Melillo 1982). Melillo *et al.* (1982) observed a strong negative linear relationship between initial lignin / N ratio and disappearance rate of leaf litter. Swift *et al.* (1979) concluded that leaching was the main factor influencing the initial weight loss of leaf litter.

Wardle *et al.* (1997) and Quested *et al.* (2002) found that litter mixture decompose faster than expected when the component species differ in their litter nutrient concentration. This could be explained by a single litter chemistry parameter i.e., litter N concentration. However, Hoorens *et al.* (2003) in their study found that litter decomposition rate was related to P concentration and not with the N concentration.

The present chapter analyzes *in situ* decomposition of leaf litter of dominant tree species in the core zone and the jhum fallows, as well as decomposition of mixed leaf litters of the core zone, jhum fallows and mine spoils under laboratory condition.

7.2. METHODS

7.2.1. *In situ* leaf litter decomposition

Leaf litter decomposition and patterns of nutrient dynamics during decomposition were studied using nylon mesh (2 mm) litterbag (15 x 15 cm) (Gilbert and Bocock 1960). Newly senesced leaves of dominant species were collected from the undisturbed core zone and 10-12 year old jhum fallow of the BR in March, 2000. *Eurya acuminata* and *Saurauia roxburghii* were dominant in the communities on jhum fallow, while *Calophyllum polyanthum, Elaeocarpus floribundus* and *Helicia nilagirica* dominated the undisturbed core zone. The phytosociological attributes of the selected species are given in Table 7.1.

Table 7.1. Dominant tree species of the core zone and jhum fallows in BR

Species	Density (trees ha^{-1})	Basal area (cm^2 tree^{-1})
Core zone:		
Calophyllum polyanthum	4	875.72
Elaeocarpus floribundus	4	273.51
Helicia nilagirica	63	173.01
10-12-yr. old jhum fallows:		
Eurya acuminata	76	20.02
Saurauia roxburghii	55	410.38

The collected leaf litters were air-dried in the laboratory and sub-samples were oven-dried at 70°C for 48 hours for determining the dry mass. Three grams of the air-dried leaves were placed in each bag and stitched with nylon threads. For each species, 20 bags were prepared and placed on the forest floor at 5 places in the core zone. Five litterbags were retrieved at 120, 295 and 400 days intervals. The litters were washed gently to remove the adhering soil particles and dried at 70°C for 48 hours. The samples were powdered and analysed for C, N, P and K contents.

7.2.2. Mixed litter decomposition under laboratory condition

For the study of the litter decomposition under the laboratory condition, mixed leaf litters and the samples of surface soil were collected from each of the selected sites and brought to laboratory. The soil was spread in a tray and the litterbags were kept on top of it and covered with the soil. The litterbags were taken out at 2, 4, 8, 16, 24, 32, 40 and 48th weeks following the method outlined by Okeke and Omaliko (1992). For the coalmine area, leaf litter samples were collected from the adjacent forested area and the decomposition pattern was studied by keeping the litter in the mine spoils in the similar fashion.

7.2.3. Analysis

The oven-dried leaf litter samples, both initial and those collected at different time intervals were powdered in a cyclotec (TECATOR) for the determination of the chemical composition. The ash content was determined by igniting the sample at 550°C for 6 hours in a muffle furnace. Carbon content was calculated as 50 % of the ash free weight. Nitrogen, phosphorus and potassium contents were determined according to Allen *et al.* (1974) and Anderson and Ingram (1993). Lignin and cellulose were determined following the method outlined by Peach and Tracey (1956).

7.2.4. Statistical analysis

Annual decomposition rate constant (k) was calculated from the data on the percent mass remaining using the negative exponential decay model (Olson 1963)

$$k = \ln (x/x_o)t$$

Where, x_o=initial dry weight; x=weight remaining at the end of the investigation and t is the time in years. Similarly, N, P and K mineralization constants (k_N, k_P and k_K) were calculated by substituting dry weight with N, P and K contents in the foregoing formula (Singh and Shekhar 1989). The time required for 50 % (t_{50}) and 99 % (t_{99}) decay and mineralization were calculated as $t_{50} = 0.693/k$ and $t_{99} = 5/k$.

The data were analyzed using 2-way and 3-way analysis of variance (ANOVA) (fixed effect model) to test the effects of initial leaf litter chemistry, time and / or site on the rate of decomposition and nutrient release. These were correlated with other properties of the soil/ spoil by computing coefficients of correlation (r) according to Zar (1974).

7.3. RESULTS

7.3.1. Initial chemistry of the leaf litter

Carbon content in the leaf litter did not vary much between the species. However, N concentration varied from a maximum of 1.09 % in *Eurya acuminata* to the minimum of 0.72 % in *Saurauia roxburghii*. Phosphorus concentration was low in all the species. It varied from 0.03 % in *Calophyllum polyanthum* to 0.05 % in *Eurya acuminata*. Potassium concentration was maximum (0.30 %) in *Elaeocarpus floribundus* and minimum (0.10 %) in *Helicia nilagirica*. The C/ N ratio varied widely from 32.98 in *Saurauia roxburghii* to 22.02 in *Eurya acuminata* (Table 7.2).

Cellulose and lignin concentrations varied widely among the species. Leaves of *Eurya acuminata* had low cellulose and lignin content whereas those of *Calophyllum polyanthum* were rich in lignin (42 %). Cellulose concentration was maximum (27.5 %) in *Elaeocarpus floribundus* (Table 7.2).

Table 7.2. Initial chemical composition (%, ±SE) of the leaf litter used for *in situ* decomposition study (n=3).

Species	C	N	P	K	Cellulose	Lignin	C/N
Calophyllum	24.00	0.99	0.027	0.14	27.50	42.00	24.24
polyanthum	±0.38	±0.01	±0.003	±0.03	±0.35	±1.00	
Elaeocarpus	23.25	0.89	0.051	0.30	14.00	37.50	26.12
floribundus	±0.60	±0.01	±0.003	±0.002	±2.00	±0.50	
Helicia	23.70	1.02	0.031	0.10	26.50	38.00	23.24
nilagirica	±0.31	±0.01	±0.002	±0.01	±1.50	±1.00	
Eurya	24.00	1.09	0.051	0.22	10.00	34.00	22.02
acuminata	±0.98	±0.01	±0.005	0.05	±2.00	±2.00	
Saurauia	23.75	0.72	0.049	0.16	23.00	39.50	32.98
roxburghii	±0.46	±0.01	±0.003	±0.07	±2.00	±0.50	

Carbon content in the leaf litters of different sites did not show significant variation. Nitrogen concentration was maximum (1.76 %) in 10-12-yr. old jhum fallow and minimum (1.22 %) in 1-yr. old fallow. Phosphorus concentration was relatively low ranging from 0.07 % in the litter samples collected near coalmine spoil to 0.10 % in 6-8-yr. old jhum fallow. Potassium concentration was also low, varying from 0.08 % in the jhum fallows to 0.04 % in the core zone. The C/ N ratio was maximum (37.30) in the samples from 1-yr. old jhum fallow and minimum (26.67) in 10-12-yr. old jhum fallow (Table 7.3).

Wide variation in concentrations of cellulose (18-31 %) and lignin (20-42 %) were observed between the leaf litters of different sites. Litter of the 1-yr. old jhum fallow was poor in cellulose as well as lignin whereas those of the undisturbed core zone and 10-12-yr. old fallow were rich both in lignin and cellulose. Litter samples collected near coalmine spoil was similar in chemical composition to that of 10-12-yr. old fallow, except in cellulose content which was low at this site (Table 7.3).

Table 7.3. Initial chemical composition (%, ±SE) of the mixed leaf litter samples collected from different sites in the BR (n=3).

Sites	C	N	P	K	Cellulose	Lignin	C / N
Core zone*	47.50	1.49	0.076	0.043	29.00	40.50	31.88
	± 0.75	± 0.003	± 0.01	± 0.002	± 1.15	± 4.50	
Jhum fallows:							
10-12-yr. old *	47.00	1.76	0.090	0.068	31.00	40.00	26.67
	± 0.56	± 0.001	± 0.07	± 0.001	± 1.18	± 5.00	
6-8-yr. old *	46.50	1.44	0.097	0.080	19.00	37.00	32.29
	± 0.72	± 0.001	± 0.01	± 0.002	± 1.03	± 4.50	
1-yr. old *	45.50	1.22	0.09	0.080	19.00	20.00	37.30
	± 0.57	± 0.009	± 0.04	± 0.002	± 1.04	± 2.50	
Mean†	46.33	1.49	0.09	0.08	23.00	32.33	32.09
Mine spoil:							
Coal*	47.80	1.70	0.067	0.049	18.00	42.00	28.12
	± 0.35	± 0.003	± 0.08	± 0.001	± 1.12	± 2.00	

* Mean of the replicate sites; † Mean of the jhum fallows

7.3.2. Weight loss pattern

During the initial 120 days, the average rate of weight loss was maximum (5.9 mg day^{-1}) in *Eurya acuminata* and minimum (2.09 mg day^{-1}) in *Helicia nilagirica*. This was followed by a significant (p<0.01) increased rate of weight loss during 120-295 days. During this period, the rate was minimum (4.89 mg day^{-1}) in *Calophyllum polyanthum* and maximum (8.89 mg day^{-1}) in *Eurya acuminata.* The rate slowed down considerably during 295 and 400 days. During this period also the average weight loss was maximum in *Eurya acuminata* and minimum in *Calophyllum polyanthum* (Fig. 7.1).

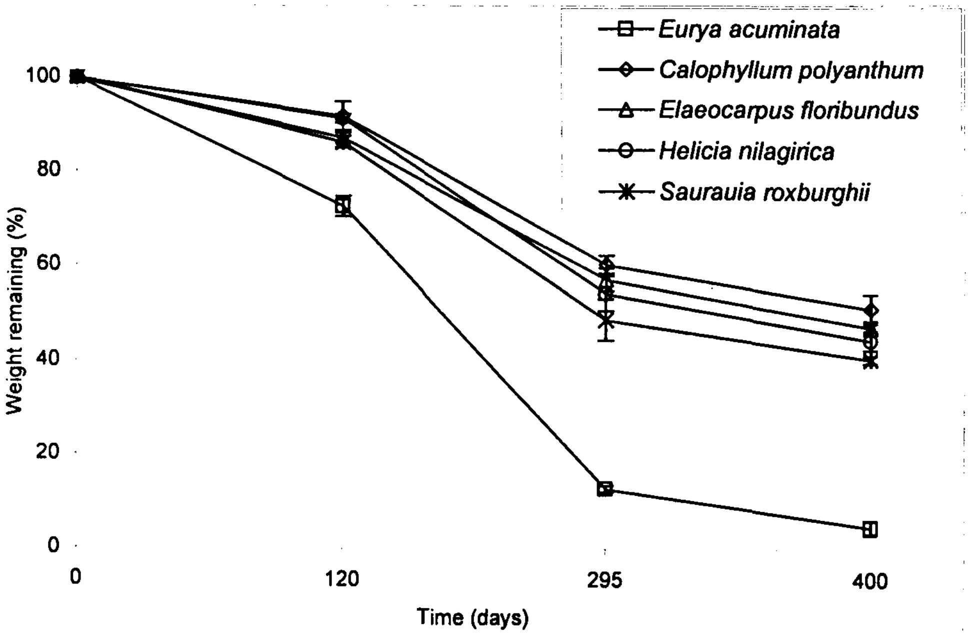

Fig. 7.1. Weight remaining (%) during *in situ* leaf litter decomposition. Values are mean (± SE) of 3 replicates.

In *Eurya acuminata* 96 % of the initial dry mass decomposed at the end of 400 days while *Calophyllum polyanthum* leaf litter decomposed only 51 % during the same period.

The annual decay constant (k) was lowest (0.79) in *Calophyllum polyanthum* and highest (3.56) in *Eurya acuminata*. The time required for 50 % decay (t_{50}) varied between the species and it increased from 0.19 in *Eurya acuminata* to 0.88 in

Calophyllum polyanthum. Similarly, t_{99} also increased from 1.40 in *Eurya acuminata* to 6.33 in *Calophyllum polyanthum* (Table 7.4).

The weight loss pattern was similar for the leaf litters of different sites, but the rate varied significantly ($p<0.01$) between the sites (Fig. 7.2).

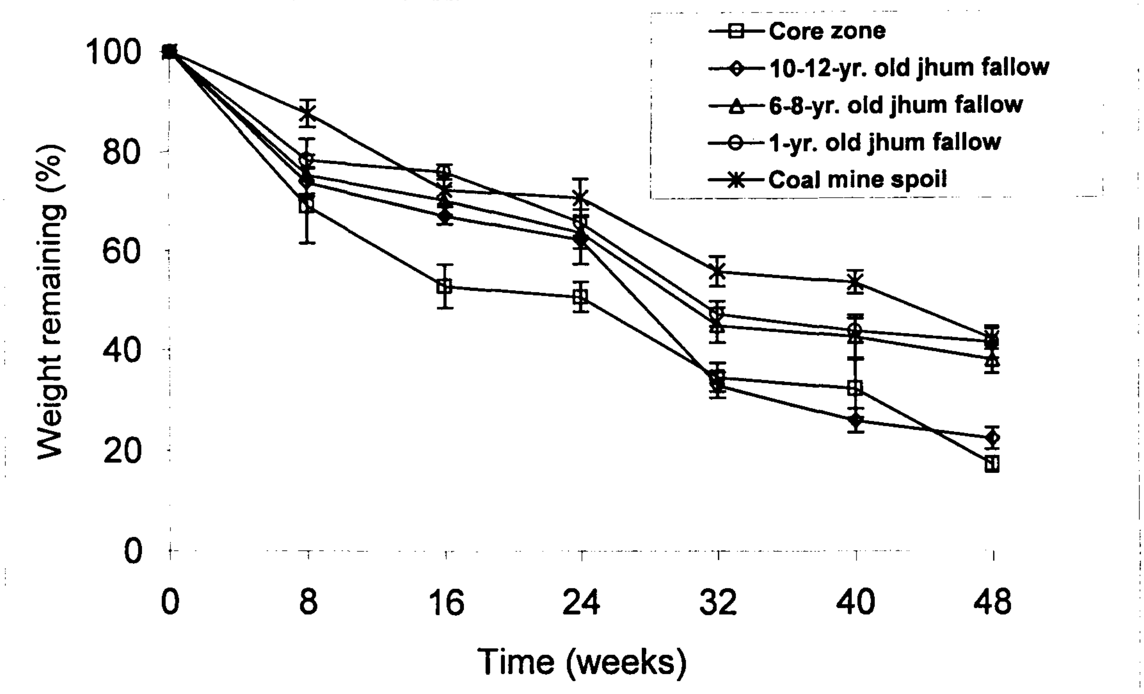

Fig. 7.2. Mixed litter decomposition pattern under laboratory condition. The values are means (±SE) of 3-9 replicate sites.

At the end of the investigation (48th week), the average rate of weight loss was maximum (8.18 mg day^{-1}) in the undisturbed core zone and minimum (5.21 mg day^{-1}) in the coal mine spoil. The litter from core zone decomposed at a faster rate with 17 % of the original dry mass remaining at the end of the 48 weeks while that of coalmine spoil decomposed at a slower rate with 42 % of the original dry mass remaining during the same period. The annual decay constant (k) was lowest (0.87) in coalmine spoil and highest (1.76) in undisturbed core zone. The time required for 50 % decay (t_{50}) varied from 0.39 in undisturbed core zone to 0.80 in coal mine spoil. Similarly, t_{99} also increased from 2.84 to 5.75 (Table 7.5).

7.3.3. Nutrient mineralization

Nitrogen release from decaying leaf continued till 400 days, though with differential rate in different species. However, in case of P and K it slowed down in all litters after 295 days (Fig. 7.3 a, b & c). *Eurya acuminata* exhibited the highest rate of mineralization constant for N (3.56), P (3.56) and K (4.46). *Calophyllum polyanthum* showed lowest (0.67) N mineralization rate while *Elaeocarpus floribundus* showed the lowest rate for P (0.39) and K (1.20) (Table 7.4).

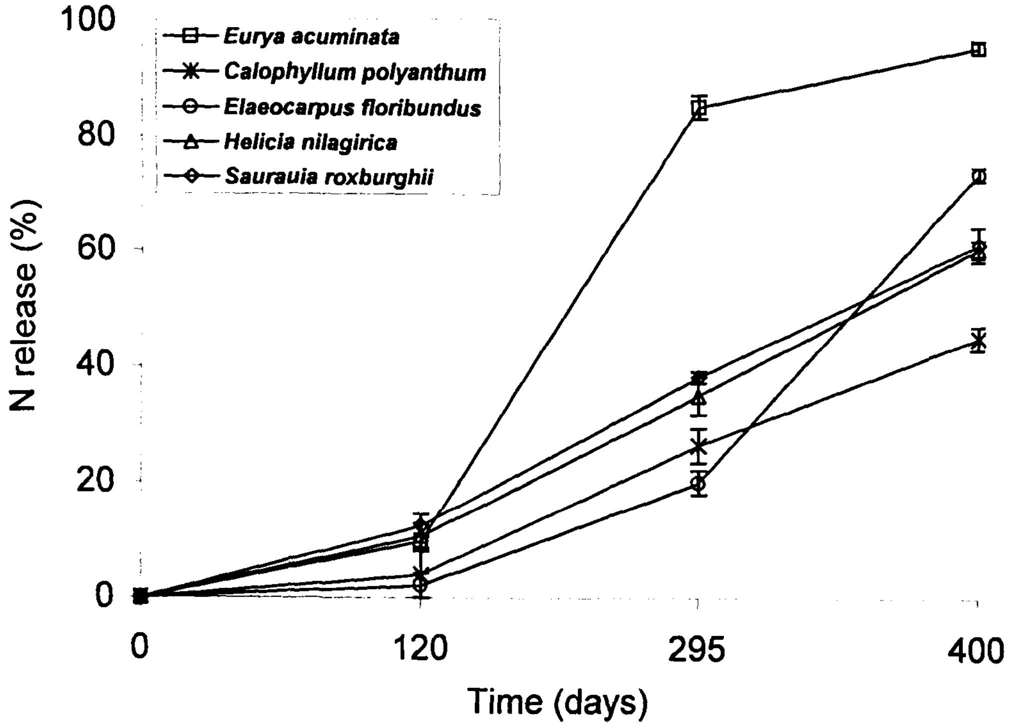

Fig. 7.3 a. Nitrogen (N) release pattern during *in situ* leaf litter decomposition. Values are mean (± SE) of 3 replicates.

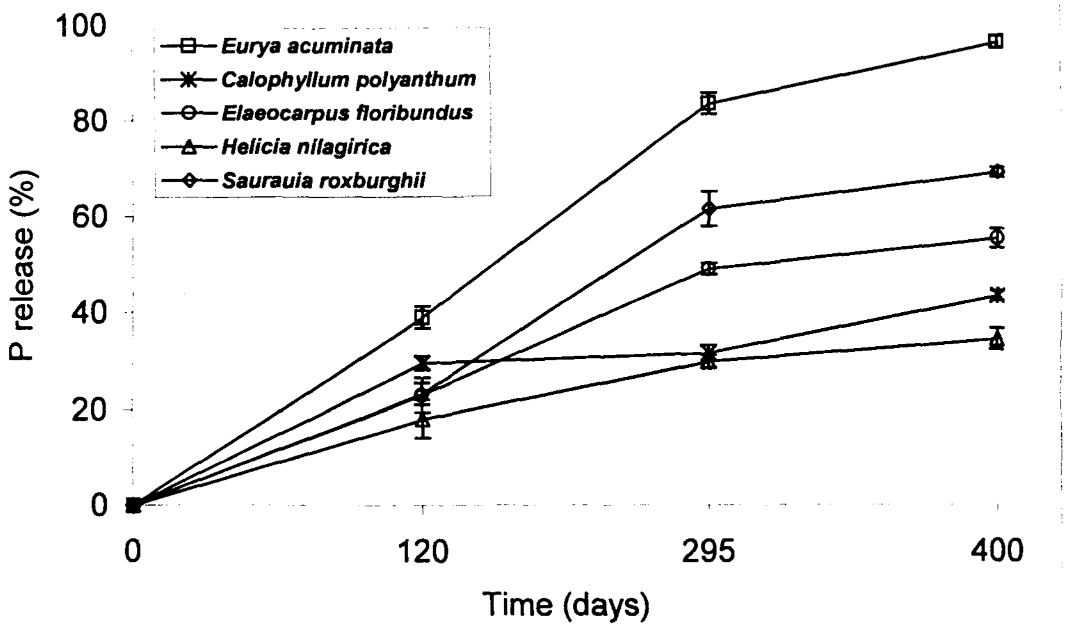

Fig. 7.3 b. Phosphorus (P) release pattern during *in situ* leaf litter decomposition. Values are mean (± SE) of 3 replicates.

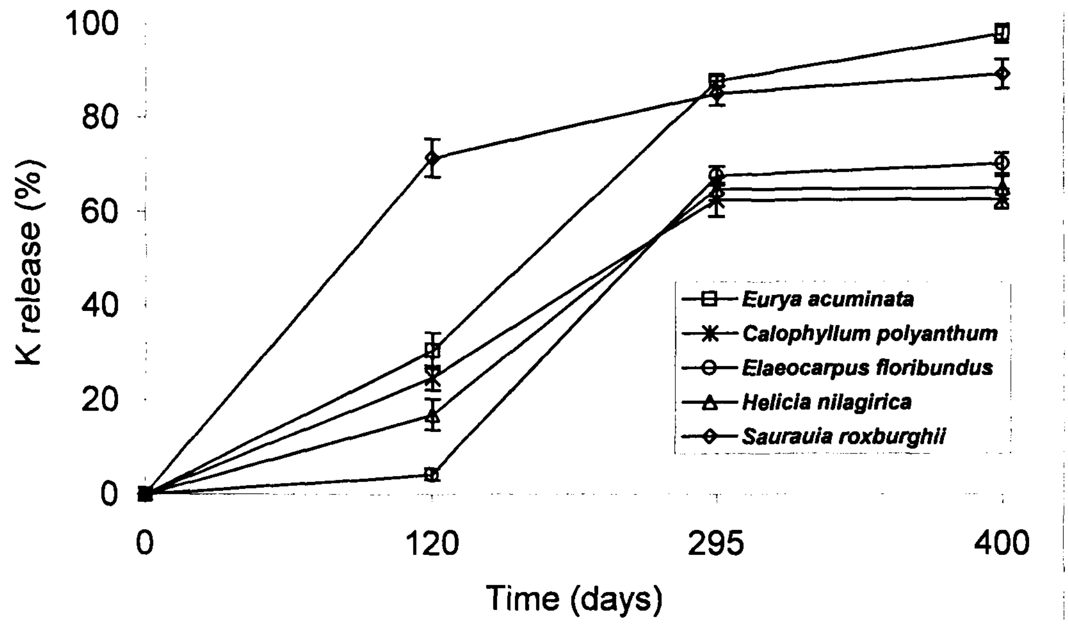

Fig. 7.3 c. Potassium (K) release pattern during *in situ* leaf litter decomposition. Values are mean (± SE) of 3 replicates.

Table 7.4. Annual decay constant (k) and N, P & K mineralization constants (k_N, k_P and k_K) of the leaf litter under field condition

	Calophyllum polyanthum	*Elaeocarpus floribundus*	*Helicia nilagirica*	*Eurya acuminata*	*Saurauia roxburghii*
Decay constant					
k	0.79	0.90	0.86	3.56	1.05
t_{50}	0.88	0.77	0.81	0.19	0.66
t_{99}	6.33	5.56	5.81	1.40	4.76
N mineralization					
k	0.67	1.04	1.43	3.56	1.06
t_{50}	1.03	0.67	0.48	0.19	0.65
t_{99}	7.46	4.81	3.50	1.40	4.72
P mineralization					
k	0.62	0.39	0.90	3.56	1.31
t_{50}	1.12	1.78	0.77	0.19	0.53
t_{99}	8.06	12.82	5.56	1.40	3.82
K mineralization					
k	1.41	1.20	1.27	4.43	2.59
t_{50}	0.49	0.58	0.55	0.16	0.27
t_{99}	3.55	4.17	3.94	1.13	1.93

In case of the mixed leaf litter decomposition under laboratory condition, nitrogen, phosphorus and potassium mineralization continued till the end of the investigation. However, it slowed down after 16 weeks in case of P and K (Fig. 7.4 a, b & c). Nitrogen mineralization constant varied from 0.28 in coal mine spoil to 0.71 in the core zone, for phosphorus it ranged from 0.21 in coal mine spoil to 0.58 in the core zone, and for potassium the constant value ranged from 1.46 in the coal mine spoil to 2.85 in the core zone. The values increased with the increase in the age of the jhum fallow for all the nutrients (Table 7.5).

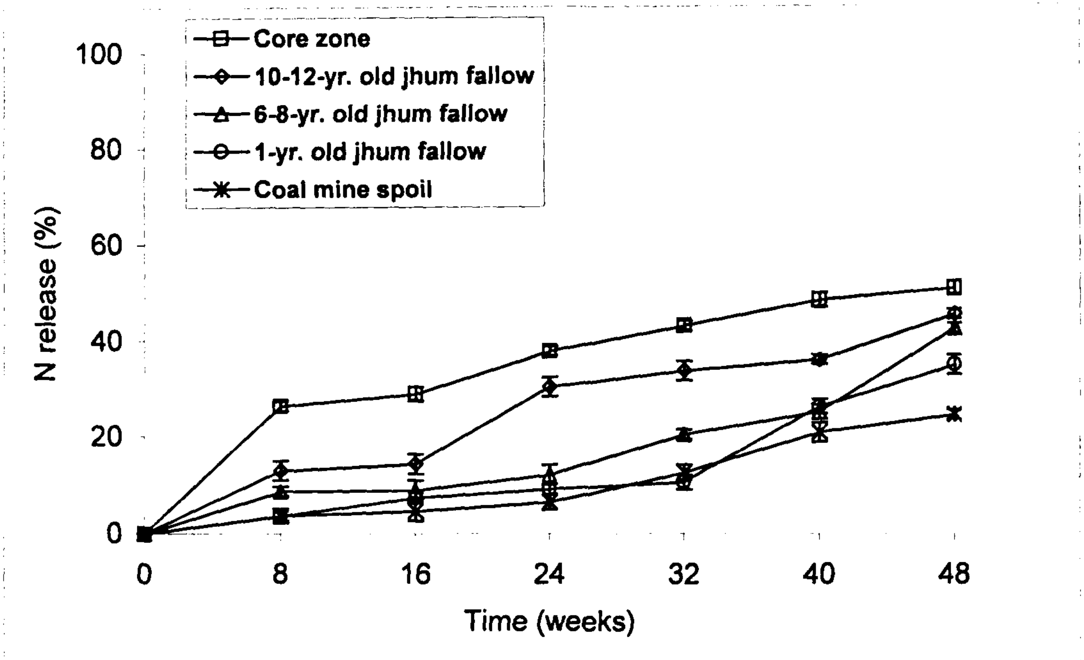

Fig. 7.4 a. Nitrogen (N) release pattern during decomposition of mixed leaf litter under laboratory condition. The values are means (±SE) of 3-9 replicate sites.

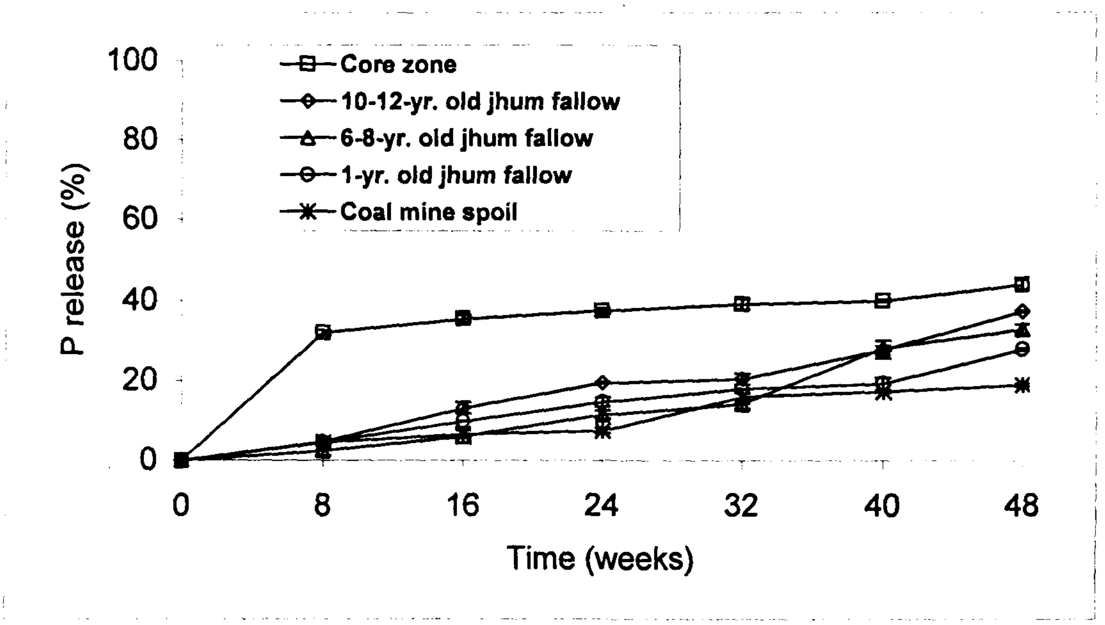

Fig. 7.4 b. Phosphorus (P) release pattern during decomposition of mixed leaf litter under laboratory condition. The values are means (±SE) of 3-9 replicate sites.

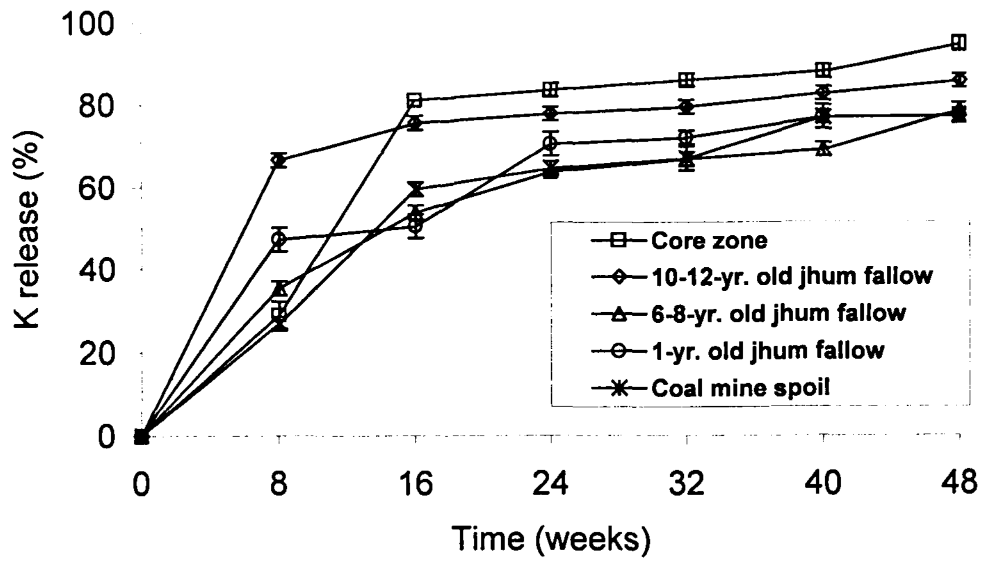

Fig. 7.4 c. Potassium (K) release pattern during decomposition of mixed leaf litter under laboratory condition. The values are means (±SE) of 3-9 replicate sites.

Table 7.5. Annual decay constant (k) and N, P and K mineralization constants (k_N, k_P and k_K) of the mixed leaf litters under laboratory condition

	Core zone	10-12-yr. old jhum fallow	6-8-yr. old jhum fallow	1-yr. old jhum fallow	Coal mine spoil
Leaf decay					
k	1.76	1.50	0.97	0.88	0.87
t_{50}	0.39	0.46	0.71	0.79	0.80
t_{99}	2.84	3.33	5.15	5.68	5.75
N mineralization					
k	0.71	0.60	0.55	0.43	0.28
t_{50}	0.98	1.16	1.26	1.61	2.48
t_{99}	7.04	8.33	9.09	11.63	17.86
P mineralization					
k	0.58	0.47	0.40	0.33	0.21
t_{50}	1.19	1.47	1.73	2.10	3.30
t_{99}	8.62	10.64	12.50	15.15	23.81
K mineralization					
k	2.85	1.91	1.52	1.47	1.46
t_{50}	0.24	0.36	0.46	0.47	0.47
t_{99}	1.75	2.62	3.29	3.40	3.42

7.4. DISCUSSION

Rate of leaf litter decomposition is regulated by a hierarchy of interacting physical, chemical and biotic factors (Couteaux *et al.* 1995; Heal *et al.* 1997). Factors which contribute to the complex nature of decomposition are: seasonal heterotroph activity, heterotroph's nutrient demand, environmental conditions regulating heterotroph activity, species tissue palatability, species composition of litter, tissue composition of litter, nutrient content of litter, nutrient mobility, and nutrient input i.e., leafwash and litter fall (Gosz *et al.* 1973). Laiho *et al.* (2004) argued that litter quality, relative moisture deficiency, higher acidity, lower substrate temperature, and oxygen deficiency may interact to constrain organic matter decomposition. At a global scale, litter chemistry is only of secondary importance in explaining variation in litter decomposition rates.

The climatic control of litter decomposition is partly mediated through indirect effects on litter chemistry. In some climatic regions, particularly in the tropics, litter quality parameters seem to be the best predictors of decomposition rates, while environmental conditions such as soil characteristics and micro-climate appear to be less important (Lavelle *et al.* 1993; Kochy and Wilson 1997; Aerts 1997).

7.4.1. Initial leaf litter chemistry

Initial N (0.59-1.03 %) and lignin (23.7-43.2 %) concentrations of leaf litter of dominant tree species are well within the range (N - 0.36-3.90 % and lignin - 4.5-46.4 %) reported by Vogt *et al.* (1991) and Myers *et al.* (1994) for various tropical and temperate tree species. However, the N concentration (1.2-1.8 %) in the mixed leaf litter was higher than individual species litter. Species like *Calophyllum polyanthum* having more sclerophyllous cells had greater lignin concentration and low nutrient level than other species. Cellulose is used as an energy source by several decomposers and is a major component of the foliage. Its concentration (10 - 27 %) was lower than the values (21.3 -

31.7 %) reported by Bloomfield *et al.* (1993) for a few tropical species. The cellulose in the mixed leaf litter (18-31 %) was, however, similar to those obtained by these workers.

7.4.2. Weight loss pattern and rate of litter turnover

In the initial phase of decomposition after leaching of most soluble components, soil faunal activity becomes more important. Animals break up plant litter and mix it with mineral materials. During this stage, soil fauna probably neglect leaves with higher phenol and lignin contents (Palm and Rowland 1997), and therefore their decomposition is slow. The rapid rate of decay after an initial lag-phase was the net effect of a large number of processes such as utilization of readily available energy sources by microbes, loss of water-soluble components and non-structural carbohydrates of the leaf litter (Bloomfield *et al.* 1993), and removal of leaf litter particles by animals, especially termites, operating on the freshly fallen litter on the forest floor (Swift *et al.* 1979). A decline in the rate of weight loss after rapid phase of decay is attributed to higher percentage of recalcitrant fractions like cellulose, lignin and tannin present in the residue during the advanced stage of leaf decay. These substances are known to control decay rate by showing resistance to enzymatic attack and by physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield *et al.* 1993).

A relatively higher rate (24-48 % of initial weight) of weight loss during the rainy season till 295 days could be the result of the aforesaid processes and the effects of physical determinants such as temperature and soil moisture content (Sujatha *et al.* 2003), while a relatively slow rate (12-21 % of initial weight) during post-rainy season could be attributed to decline in soil moisture content and processes associated with it including reduced microbial activity and presence of organic residue rich in recalcitrant materials.

The annual decay constant (k) was negatively related to initial lignin and N concentration. Thus higher rate of *Eurya acuminata* was due to the high N and low lignin concentration, while the lower rate of *Calophyllum polyanthum* was due to low N and high lignin concentration. Similar results have also been reported by Swift *et al.* (1979) and Laishram and Yadava (1988).

In small-scale experiments of short duration, using defined cohorts of plant litters and more precise analytical methods, the effects of litter colonization by key fungal species during microbial succession become apparent (Cox *et al.* 2001). Similarly under laboratory condition, where much of the environmental variability encountered in the field can be factored out, forest floor materials from different sites and associated microbial communities, emerge as important variables in rates of litter decomposition (Prescott 1996; Chadwick *et al.* 1998). This is evident from the significant positive relationship between litter mass loss and initial litter chemistry and the soil properties (Table 7.7).

Under the laboratory condition, weight loss was positively ($p<0.05$) related to C, N, cellulose and lignin concentrations and negatively related to phosphorus and potassium concentrations (Table 7.6). Similar relationship has been observed by Kainulainen and Holopainen (2002) in Scots pine needle in Finland. Linear relationship between the decay constant and initial lignin concentration was also reported by Lin *et al.* (2002) in the Fushan broadleaved forest of northeastern Taiwan. The chemical nature of the detrital materials differed at different sites as is evident from higher concentration of N in 10-12-year old fallow, as compared to the 6-8- and 1-year old fallow, and higher concentration of cellulose and lignin in the core zone than the jhum fallows and mining site. These could be the important determinants of the observed variability in the decomposition rates. Loranger *et al.* (2002) studied the influence of soil properties and litter quality on decomposition rate in two semi-evergreen tropical forests. Their studies support the contention that litter quality is one of the most important determinants of decomposition in tropical forests (Lavelle *et al.* 1993).

The concentration of cellulose in plant material greatly affects the decomposition rate of plant-derived litter (Pavel *et al.* 2004). Several studies have shown that species with high cellulose content decompose at a faster rate. In the present study also, litter of the core zone and 10-12-yr. old jhum fallows having high cellulose content decomposed at a faster rate than those of younger fallows and the mine area, which had low concentration of cellulose. McClaugherty and Berg (1987) and Melillo *et al.* (1989) also reported that long-term decomposition rate was increased by a high cellulose content. Though Sariyildiz and Anderson (2003) reported that initial concentration of Klason lignin was the best predictor for mass losses from litter species and litter types.

The fastest decomposition was observed in the undisturbed core zone where C/N ratio was 32 followed by the jhum fallows (C/N ratio 32) and the mine spoils (C/N ratio 28). Slow rate of decomposition of high quality material (low C/N ratio) indicate the greater role of soil organisms than the quality of litter itself, in the decomposition process. The litter turnover rate (k) was faster in the jhum fallow than the rate (k=0.002 - 0.045) observed by Simmons and Hawkins (2004) in the western streams, British Columbia and by Lin *et al.* (2002) for four dominant tree species (0.60 - 0.97) of the Fushan broadleaved forest of northeastern Taiwan. However, value of the present study (0.88 - 1.76) is within the range (0.41 - 2.39) observed by Loranger *et al.* (2002) in the semi-evergreen forests of Grande-Terre (Guadeloupe).

7.4.3. Nutrient release pattern

Slower rate of nutrient release up to 120 days when season was dry followed by a rapid rate of release during the rainy season (up to 295 days) could be the influence of leaching. Highest K mineralization rate in *Eurya acuminata* compared to the other species could be due to its susceptibility to leaching and high initial K concentration. Yavit *et al.* (2004) have reported similar mineralization pattern though K concentration did not vary seasonally in their case. Warm-humid rainy season favoured mineralization, while immobilization was the dominant process during dry-winter season. The present study suggests rainfall and temperature to be the most important climatic factors, which affected the decomposition of leaf litter and nutrient dynamics under the *in situ* condition.

The low quality materials having high C/N ratio immobilizes N at a faster rate, while the high-quality litter with low C/N ratio releases nutrients at a faster rate during decomposition (Myers *et al.* 1994). As a result, release of N from *Eurya acuminata* litter, which had a C/N ratio of 22, was much faster compared to other species where C/N ratio ranged between 33 to 42. Net high mineralization of N in decomposing leaf litter of *Eurya acuminata* may be due to the high initial N concentration in leaf litter (1.09 %) as suggested by Berg and Staaf (1981) who argued that the immobilization phase could be missing, particularly in litter having high N-content. The reverse trend was obtained for *Calophyllum poyanthum* where the initial concentration of N was low (0.99 %). Teklay & Malmer (2004) in their study on the decomposition pattern of *Cordia africana* and *Albizia gummifera* found that *A. gummifera* with higher concentration of N had significantly greater mass loss and N loss than *C. africana*. The continuous decrease in K concentration of the litter of all the species throughout the decomposition period is related to its highly mobile nature and loss due to leaching (Bargali *et al.* 1993, Sujatha *et al.* 2003).

Release of nutrients from the mixed litter continued till the end of the investigation (48th week) though some workers (e.g. Edmonds and Thomas 1997) have reported immobilization in the first 12 months. Contrary to this, Lin *et al.* (2002) observed mineralization of foliar N over 3.5 years in the four dominant tree species of the Fushan broadleaved forest of northeastern Taiwan. Regina (2001) observed a progressive loss of P and K in the decomposing oak leaves but a tendency to retain N.

Table 7.6. Correlation coefficients (r) between mass loss of mixed leaf litter and nutrient release with initial litter quality (n=16, $p<0.05$; ns=not significant)

Variables	C	N	P	K	Cellulose	Lignin	C/N
Mass loss	0.93	0.71	-0.75	-0.90	0.95	0.77	-0.69
N release	0.99	0.65	-0.63	-0.86	0.77	0.91	-0.66
P release	0.97	0.59	-0.76	-0.94	0.81	0.83	-0.58
K release	0.89	ns	-0.89	-0.99	0.82	0.68	ns

A positive correlation between weight loss and initial P concentration has been demonstrated by Meentemeyer and Berg (1986). Contrary to their result, a negative relationship between the two was obtained in the present study (Table 7.6). The present study also revealed positive effect of initial C, N, cellulose and lignin contents and a negative effect of P and K contents and C/N on the nutrient release from mixed leaf litter (Table 7.6).

Soil nutrients also affect litter nutrient dynamics (Hobbie and Vitousek 2000). Among the soil properties, bulk density (r=0.94), WHC (r=0.88), CEC (r=0.97), TKN (r=0.76), P (r=0.80), MBC (r=0.84) and MBN (r=0.89) were more important. The positive relationship obtained between nutrient release from decaying mixed litter and soil TKN and P shows a close relation between the two, albeit indirectly (Table 7.7).

Table 7.7. Correlation coefficients (r) between mass loss of mixed leaf litter and nutrient release with soil characteristics (n=16, $p<0.05$, ns=not significant)

Variables	Soil parameters									
	SMC	CEC	SOC	TKN	P	MBC	MBN	DHA	UA	Nm
Total mass loss	0.53	0.97	0.60	0.76	0.80	0.84	0.89	0.64	0.69	0.61
N release	0.50	0.91	0.62	0.78	0.75	0.83	0.84	0.64	0.73	0.68
P release	0.51	0.97	0.63	0.81	0.81	0.88	0.90	0.66	0.72	0.70
K release	ns	0.99	0.62	0.82	0.84	0.90	0.93	0.65	0.67	0.69

The mixed leaf litter kept in soils of the undisturbed core zone with high SOM content decomposed very fast and the nutrient releases (NPK) was fastest at this site. In the core zone though the litter samples had high lignin concentration, decomposition was faster than other sites. This explains the importance of physical, chemical and biological properties of soil and a combination of both quality of litter and nature of substrates in litter decomposition on the forest floor. The litter quality i.e., N, P, cellulose, Klason lignin, hexose and pentose sugar (mainly from hemicelluloses) concentration, itself vary within species according to soil type (Sariyildiz and Anderson 2003).

7.4.4. Effect of shifting cultivation and mining on leaf litter decomposition and nutrient mineralization

Decay constant (k) of mixed leaf litter under laboratory condition showed 50 % reduction in both the jhum fallow and the mine spoil as compared to the core zone. The nitrogen mineralization was 39 % less in jhum fallow and 61 % less in the mine spoil. The reduction in phosphorus mineralization was 43 % in jhum fallow and 64 % in mine spoil. Reduction in potassium mineralization was about 48 % at both places. Thus, the impact of soil conditions on litter decomposition and nutrient release was more pronounced in mine spoils than jhum fallows.

Chapter 8

GENERAL DISCUSSION

Biosphere reserves, having humans as a major integral component, are excellent sites for exploring the impact of anthropogenic activities on the vegetation, biodiversity and soil. Nokrek Biosphere Reserve is one of the fourteen biosphere reserves of India. The core zone of the reserve comprises of evergreen forest, semi-evergreen forest and a deciduous forest, whereas bamboo patches, seral communities on jhum fallows, grasslands and riverine forest occur in the buffer zone.

Shifting cultivation and mining of coal and limestone are the two major anthropogenic activities in the buffer zone of the BR. While slash and burn agriculture is practiced in the entire buffer zone by about 85 % of the population, coal mining is restricted to West Darrenggre, Siju, Pyndengru-Balphakram and Selsela Blocks of the biosphere reserve. The limestone quarrying is done around Dana-Adugiri village. The limestone quarries are located near the boundary of the BR, but the coalmines are close to the core zone.

Due to increase in human population, the impact of these activities is noticed on soil and land in the buffer zone of the BR. The adverse effects of these activities start with the vegetation destruction for shifting cultivation and mining, which in turn initiates a series of physical, chemical and biological changes in the soil ultimately leading to degradation of land.

Changes in physical properties of soil

Bulk density of the surface soils particularly at mining sites (coalmine spoil) registered a marked increase where the proportion of silt particles as well as organic matter content was significantly lower than other sites. The bulk density marginally decreased from core zone to jhum fallows. The soil moisture content, though varied seasonally, its mean value was lower at all human impacted sites in the buffer zone. In the upper soil layer (0-10 cm), there was 31 % reduction on the jhum fallows compared to the core zone. The most adversely affected site was mine spoil where the soil moisture was 56 % lower than the core zone (Table 8.1) because of its coarse textured nature with low SOM content.

Table 8.1. Physical properties of soils of the buffer zone of the BR. Values in parentheses are percentages of the undisturbed core zone of the BR

Sites	SMC (%)	WHC (%)	Microaggregates (%)
Upper soil layer (0-10 cm):			
Core zone*	**26.67 (100)**	**85.48 (100)**	**37.77 (100)**
Jhum fallows:			
10-12-yr. old*	24.83 (93)	73.30 (86)	29.28 (78)
6-8-yr. old*	22.53 (84)	69.40 (81)	23.62 (63)
1-yr. old*	19.53 (73)	67.91 (80)	22.51(60)
Mine spoils:			
Limestone	14.01 (55)	43.89 (51)	19.41(51)
Coal*	9.29 (35)	19.18 (22)	48.54 (129)
Lower soil layer (10-20 cm):			
Core zone*	**26.08 (100)**	**76.22 (100)**	-
Jhum fallows:			
10-12-yr. old*	24.77 (95)	67.82 (90)	-
6-8-yr. old*	22.20 (85)	63.47 (83)	-
1-yr. old*	19.26 (74)	61.81 (81)	-
Mine spoils:			
Limestone	14.76 (57)	50.18 (66)	-
Coal*	7.37 (28)	17.42 (23)	-

*Mean of the replicate sites

A gradual decline in water holding capacity (WHC) from the core zone to jhum fallows is attributed to decrease in the proportion of fine particles. It is evident from a significant positive relation between WHC and percentage of silt particle ($r=0.68$, $p<0.001$). Another important factor that contributed to decrease in WHC was soil organic matter (SOM), which was also positively related to WHC ($r=0.83$, $p<0.001$). Greater amount of SOM resulted from large amount of litter on the forest floor in the core zone. A marked decline in WHC at coal mining sites is attributed to increase in the proportion of sand particles and low SOM. However, relatively greater WHC of the limestone mine spoil appears to be due to high proportion of clay compared to the coalmine spoils.

The proportion of micro-aggregates (<0.3 mm) was more in the core zone (37.77 %) than in the jhum fallows (22.51 - 29.28 %). Compared to the core zone and jhum fallows, the coalmine spoil had a high proportion of micro-aggregate and low proportion of macro-aggregate, but the trend was reversed in case of limestone mine spoil. Greater amount of microaggregates was responsible for higher concentration of organic carbon as well as higher C/N ratio in the core zone soil (Table 4.18). They are more stable than macroaggregates because of binding by humus, iron and aluminium oxides and clay particles (Wild 1996) and contain about 12 % more SOC than macroaggregates and have higher C / N ratios (Ashman *et al.* 2003).

Changes in chemical properties of soil

Though the soils of the entire BR were acidic (pH=4.28-6.03) in nature, coalmine spoil was most acidic and limestone mine spoil was least acidic. The acidity was high in the lower soil depth at all sites.

The cation exchange capacity (CEC) of soils in the buffer zone was lower than the core zone, except at limestone mine spoil where CEC was higher than the core zone. It was negatively correlated ($r=0.86$, $p<0.05$) to the percentage of sand particles and positively correlated ($r=0.53$, $p<0.05$) with the clay content of the soil.

The mine spoils had significantly lower soil organic carbon (SOC) content compared to the core zone. Percentage reduction in SOC in jhum fields in relation to the undisturbed core zone was relatively less than the mine spoils. In the former, it ranged between 75-91 %, while in the latter case it varied between 14-30 % (Table 8.2). Higher organic carbon and nutrients (N, P and K) status of the undisturbed core zone soil as compared to the jhum fallows is in conformity with the findings of several workers. Agbenin and Goladi (1997) recorded 38 % reduction in organic carbon, 41 % in TKN and 39 % in organic nitrogen, following continuous cultivation without fertilization. Garcia-Oliva *et al.* (1999) reported that slash and burn could cause significant disruption of soil carbon cycling in the forest ecosystem, and noticed 32 % decrease in SOC associated with macro-aggregates due to conversion of tropical deciduous forests into pastures by burning. Significant reduction in soil organic matter following conversion of tropical forests into pastures and agricultural fields due to logging, shifting cultivation and tillage practices have been reported by Brown *et al.* (1994) and Henrot and Robertson (1994)). Loss could reach up to 50 % in organic matter and total nitrogen contents in comparison to the undisturbed natural forests sites (Hajabbasi *et al.* 1997; Saikh *et al.* 1998). Brand and Pfund (1998) noted a net loss of 20-22 % soil fixed carbon and nitrogen after burning in shifting cultivation systems.

Predictably, low percentage of organic carbon in mine spoil has also been reported by Das Gupta (1999). In contrast, Toy and Shay (1987) could not find significant difference in organic matter content between the mine spoils and natural soils in Northern Great Plains.

Shifting agriculture and mining activity caused greater loss in total Kjeldahl nitrogen (TKN) and inorganic (NH_4 + NO_3) nitrogen than available phosphorus and exchangeable potassium. Predictably, the maximum reduction was observed at mining sites (Table 8.2).

Table 8.2. Chemical properties of soils of the buffer zone of the BR. Values in parentheses are percentages of the undisturbed core zone of the BR

Sites	SOC (%)	pH	CEC (meq/100g)	TKN (%)	Inorganic-N (µg/g)	Available P (µg/g)	Exchangeable K (µg/g)
Upper soil layer (0-10 cm):							
Core zone*	**5.93 (100)**	**5.81 (100)**	**17.66 (100)**	**0.34 (100)**	**59.72 (100)**	**4.38 (100)**	**248 (100)**
Jhum fallows:							
10-12-yr. old*	5.10 (86)	5.77 (99)	16.89 (96)	0.27 (79)	33.93 (57)	3.21 (73)	233 (94)
6-8-yr. old*	4.65 (78)	5.74 (99)	16.15 (92)	0.24 (71)	23.38 (39)	2.20 (50)	208 (84)
1-yr. old*	4.15 (70)	5.66 (97)	16.06 (91)	0.22 (65)	19.74(33)	2.19 (50)	233 (94)
Mine spoils:							
Coal*	1.50 (25)	4.71 (81)	2.49 (14)	0.04 (12)	12.38 (21)	1.41 (32)	60 (24)
Limestone	0.52 (9)	7.99 (138)	20.70 (117)	0.02 (6)	13.24 (22)	1.68 (38)	153 (62)
Lower soil layer (10-20 cm):							
Core zone*	**4.53 (100)**	**5.50 (100)**	**16.29 (100)**	**0.27 (100)**	-	**3.34 (100)**	**185 (100)**
Jhum fallows:							
10-12-yr. old*	4.39 (97)	5.35 (97)	15.46 (95)	0.22 (81)	-	2.14 (64)	153 (83)
6-8-yr. old*	3.44 (76)	5.28 (96)	14.60 (90)	0.19 (70)	-	1.88 (56)	143 (77)
1-yr. old*	2.95 (65)	5.25 (95)	11.51 (71)	0.17 (63)	-	1.67 (50)	175 (95)
Mine spoils:							
Coal*	1.12 (25)	4.57 (83)	3.34 (21)	0.05 (19)	-	1.83 (55)	90 (49)
Limestone	0.64 (14)	8.00 (145)	17.76 (109)	0.04 (15)	-	1.64 (49)	153 (83)

*Mean of the replicate sites

Most mine wastes are poor in nitrogen and phosphorus (Singh *et al.* 2002) due to leaching and the lack of binding power of phosphorus. Low phosphorus acts as a limiting factor during early succession and colonization on surface-mined lands (Iverson and Wali 1992). The TKN and inorganic nitrogen in the soils of jhum fields were, however, quickly replenished during regrowth of vegetation. This trend was not observed in case of available phosphorus and exchangeable potassium (Table 8.2). The concentration of available phosphorus was related to the concentration of organic carbon as is evident from the positive relation between the two (r=0.93).

Changes in biological properties of soil

The concentration of microbial biomass carbon (MBC) varies widely (61-2000 µg g^{-1}) between different temperate and tropical forest soils (Vance *et al.* 1987; Henrot and Robertson 1994; Diaz-Ravina *et al.* 1995). The values obtained in the present study are close to the upper limit of the range suggesting that soils of the BR are rich in MBC.

Significant variation of microbial biomass in forest soils due to soil type and seasonal fluctuations has been reported by Diaz-Ravina *et al.* (1995). In their study, 71 % variation in the microbial biomass was due to the soil type; season accounted only 18 % variation and the interaction between the soil type and season explained only 8 % variation. MBC in the surface soil has been related to organic matter content by Lavahun *et al.* (1996) and Singh *et al.* (2002). Therefore significant variation in MBC between different sites in the BR is attributed to differences in SOM and SOC contents.

Reduction in MBC as a result of shifting cultivation and selective logging of forest trees in north-east India has been reported by Singh *et al.* (2002) and Tiwari *et al.* (2002). Henrot and Robertson (1994) reported marked decline in MBC in humid subtropical soils because of vegetation removal. In the present study, there was 74 % reduction in MBC in the surface soil of 1-yr. old fallow in comparison to primary forest in the core zone (Table 8.3). The recovery started with the growth of plants and the concentration of MBC in 10-12-yr. old-field was only 44 % less than the core zone. Higher MBC content was also reported in old-growth forests than 3- and 10-year-old forests, planted following harvest in British Columbia (Chang *et al.* 1995).

Table 8.3. Biological properties of soils of the buffer zone of the BR. Values in parentheses are percentages of the undisturbed core zone of the BR

Sites	MBC (µg/g)	MBN (µg/g)	DHA (TPF released µg/g/24h)	UA (NH_4 released µg/g/24h)
Upper soil layer (0-10 cm):				
Core zone*	**1579 (100)**	**296.26 (100)**	**0.74 (100)**	**32.89 (100)**
Jhum fallows:				
10-12-yr. old*	887 (56)	181.17 (61)	0.60 (81)	27.76 (84)
6-8-yr. old*	562 (36)	85.55 (29)	0.48 (65)	22.10 (67)
1-yr. old*	418 (26)	75.15 (25)	0.41 (55)	12.79 (39)
Mine spoils:				
Coal*	200 (13)	-	-	-
Limestone	159 (10)	-	-	-
Lower soil layer (10-20 cm):				
Core zone*	**840 (100)**	**87.40 (100)**	**0.36 (100)**	**19.42 (100)**
Jhum fallows:				
10-12-yr. old*	562 (67)	84.01 (96)	0.36 (100)	16.68 (86)
6-8-yr. old*	304 (36)	66.19 (76)	0.28 (78)	12.95 (67)
1-yr. old*	244 (29)	54.95 (63)	0.28 (78)	7.07 (36)
Mine spoils:				
Coal*	171 (13)	-	-	-
Limestone	215 (26)	-	-	-

*Mean of the replicate sites

Similar results were obtained by Mao *et al.* (1992) from the mixed secondary monsoon forest of tropical China. They demonstrated that removal of litter altered soil microbial biomass content and accelerated loss of carbon and nutrients. Srivastava and Singh (1991) noted remarkable decline in the amount of MBC following conversion of tropical forests into other land use systems. They found higher microbial biomass nutrients in forests, followed by savanna, cropland and lowest in mine spoils.

In the present study, coal and limestone mine spoils had lowest value of MBC. Das Gupta (1999) observed that mine spoils always had a lower bacterial and fungal population than the unmined control site due to the harsh environmental conditions like direct sunlight, low relative humidity, very low organic carbon content and low WHC of the spoil. Srivastava (1992) recorded minimum microbial biomass nutrients (C, N and P) in a 5-year-old mine spoil and maximum in the mixed forest. The present study revealed 26 % reduction in MBC in limestone mine spoil and 13 % reduction in coal mine spoil (Table 8.3) though Neale *et al.* (1997) found a clear trend of increase in MBC with the application of lime.

The organic matter that increases the availability of nutrients such as nitrogen was the chief contributory factor for high MBN in the core zone soil. Significantly higher MBN in the undisturbed core zone supporting primary subtropical semi-evergreen forest than the developing communities on jhum fallows and mine spoils in the buffer zone could be attributed to high SOM, since both were positively related ($r=0.89$, $p<0.05$) and other microenvironmental factors that favour growth of the microbes on the forest floor.

Inorganic-N pool in soil is influenced mainly by three main processes, viz., mineralization rate, uptake by plants and microbes, and losses through soil erosion, leaching, run-off and denitrification. The greater reduction of inorganic-N (78 %) in mine spoil could be due to high losses through leaching and run off in the absence of organic matter, plants and microorganisms that help in retention of ammonium-N and nitrate-N. The soil pH plays an important role in the availability of NH_3, which decreases exponentially with decreasing pH (De Boer and Kowalchuk 2001). Growth of nitrifiers is also known to be affected by low pH, temperature and moisture stress (Grant 1994).

Besides being highly acidic, the mine spoils were coarse textured. These might have helped in increasing the loss of nitrate nitrogen via leaching and denitrification.

The contribution of inorganic-N to total soil nitrogen varied from 0.98 % to 4.70 %. In the mine spoils, its proportion was higher than the undisturbed core zone and the jhum fallows suggesting presence of low amount of organically bound nitrogen in the substratum. A gradual build up of inorganic-N during secondary succession on jhum field was associated with increasing soil organic matter level in soil (Table 8.2).

Changes in biological processes of soil

The enzyme activities, that indicate the activities of microbial community in the soil, were adversely influenced by shifting agriculture and the mining activities (Table 8.3). The effect was more prominent in the upper layer than the lower layer. Tiwari *et al.* (2002) observed higher dehydrogenase activity (DHA) at undisturbed forest site in comparison to degraded and slightly degraded sites in humid tropical regions of north-eastern India. They noted 40 % and 25 % reduction in DHA in degraded and moderately degraded sites respectively compared to the undisturbed site. In the present case, there was 19-45 % reduction in DHA and 16-61 % reduction in UA.

The highest enzyme activity in the undisturbed core zone of the BR followed by 10-12-yr. old stand on the jhum fallow is attributed to greater microbial biomass due to higher organic matter and nutrient contents, improved soil structure, and favourable microclimate on the forest floor. A sharp decline in DHA and urease activity (UA) in 1-yr. old jhum fallow was related to removal of vegetal cover and burning of slash, which on one hand, stopped input of plant detritus, and on the other, accelerated the loss of organic matter through fast decomposition and nutrients through rainwater. As the regrowth of vegetation started, the enzyme activities steadily increased thereby indicating build up of organic matter and nutrients in the soil. Garcia *et al.* (1997) also found that devegetation of soils in semi-arid areas led to reduction in their biochemical quality in contrast to the natural or undisturbed area.

The decrease in nitrification rate after slash and burn operation in 1-yr. old fallow may be due to reduction in ammonium-N availability (Table 6.9). Presence of natural inhibitors of autotrophic nitrifiers in acid soils has been found to be responsible for the high spatial variability of nitrification rate (0.36 - 1.09 µg $g^{-1}day^{-1}$). *Eupatorium adenophorum*, which has been reported to have allelopathic effects, dominated 1-yr. old field (Tripathi *et al.* 1981). Thus there is possibility of inhibition of nitrification due to production of certain chemicals by weeds like *Eupatorium adenophorum* as well as natural inhibitors present in soil. The low nitrification rate in the coal mine spoil could be due to its low pH (3.50).

Mazzarino *et al.* (1993) and Saikh *et al.* (1998) showed the beneficial effects of trees on soil N mineralization in the tropics. Mordelet *et al.* (1993) attributed the enhanced biological activity in soil under savanna tree canopies to the high carbon inputs through large root biomass, and microfaunal activities.

Nitrogen mineralization potential as well as rate in the core zone was highest among all sites (Table 8.4). This is attributed to the presence of large amount of more labile soil organic matter. Exhaustion of the fraction of more mineralizable SOM and higher N-immobilization or decrease in size of the microbial population during incubation may be responsible for reduction in the N mineralization potential (Robertson *et al.* 1988; Sanchez *et al.* 1997). Similarly low potential of jhum fallow soils and mine spoils are related to the above factors.

The total mineralized N after 15 weeks accounted for 2-6 % of total soil nitrogen. These values are similar to that (6 %) reported from laboratory incubations of Cambisols from a West African savanna ecosystem (Bernhart-Reversat 1982) and lower than 11 % reported from natural savanna ecosystem by Glaser *et al.* (2001).

Table 8.4. Changes in the leaf litter decomposition (LD), soil N mineralization potential (Mpot), soil N mineralization rate (N_m) and litter nutrient release at the upper soil layer (0-10 cm) of the buffer zone of NBR due to shifting agriculture and mining activities. Values in parentheses are percentages of the undisturbed core zone of the BR

Sites	Mpot (µg/g/h)	N_m (µg/g/h)	LD (%)	N release (%)	P release (%)	K release (%)
Core zone*	**2.20 (100)**	**1.26 (100)**	**82.76 (100)**	**50.72 (100)**	**44.22 (100)**	**94.22 (100)**
Jhum fallows:						
10-12-yr. old*	1.63 (74)	0.72 (57)	77.65 (94)	45.20 (89)	37.51 (85)	85.24 (91)
6-8-yr. old*	1.48 (67)	0.70 (56)	62.07 (75)	42.29 (84)	33.09 (75)	78.21 (83)
1-yr. old*	0.90 (41)	0.46 (37)	58.62 (71)	34.75 (69)	28.07 (63)	76.90 (82)
Mine spoils:						
Coal*	0.72 (33)	0.28 (22)	57.96 (70)	24.37 (48)	18.97 (43)	76.67 (81)
Limestone	-	0.21 (17)	-	-	-	-

*Mean of the replicate sites

Decomposition was most rapid in the undisturbed core zone followed by the jhum fallows and the mine spoils (Table 8.4). Duchesne and Wetzel (1999) also found very fast decomposition of *Populus tremuloides* and *Quercus rubra* in undisturbed plots of the fertile site. The litter turnover rate (k) in the undisturbed site is within the range (0.41 – 2.39) reported by Loranger *et al.* (2002) in the semi-evergreen forests of Grande-Terre (Guadeloupe) but higher than the rate (0.60-0.97) recorded by Lin *et al.* (2002) for four dominant tree species of the Fushan broadleaved forest in northeastern Taiwan.

Depending on the stage of the decomposition process, different chemical parameters of litter are correlated well with mass loss. Though the mixed litter of the core zone had high initial lignin concentration, its decomposition occurred at a faster rate indicating the importance of the soil conditions, where the litters were kept. The positive relationships between nutrient release and soil moisture level, nutrient content (particularly N and P) and biological characteristics such as MBC, MBN and enzyme activities clearly reveal the importance of soil properties on the nutrient release from decaying litter. Thus, in the undisturbed core zone with high SMC, CEC, SOC, TKN, P, etc, release of NPK from the leaf litter was faster compared to the jhum fallows and mine spoils. Importance of soil nutrients in litter nutrient dynamics has been emphasized by Hobbie and Vitousek (2000). Sanchez (2001) reported that initial substrate quality affects the rate of release of nutrients, but it may not affect the decomposition rates. The results of this study support the view that initial substrate quality also affects the release of N, P and K from decomposing leaf litter, besides soil properties.

Thus, shifting cultivation and coal and limestone mining adversely affected the physico-chemical and biological properties as well as the biological processes of the soil in the buffer zone of the BR. Some soil fertility indicators such as TKN, P and K exhibited a recovery of 73 % to 94 % during 10-12 years of vegetation growth, but certain biological parameters such as MBC, MBN and N mineralization could reach only up to

55-60 % recovery during this period. Contrary to this, impact of coal and limestone mining was much more serious and process of recovery in nutrient status of mine spoils is also extremely slow on account of extreme acidity (in coal mine spoil), extreme alkalinity (in limestone mine spoil), low concentration of SOC, TKN, available P, exchangeable K and MBC, and slow rate of litter decomposition and nutrient release.

SUMMARY

The Nokrek biosphere reserve is located in the western part of Meghalaya in the Garo Hills between 90°13' E and 90°35' E longitudes and 25°20' N and 25°29' N latitudes. The biosphere reserve is spread over an area of 820 sq. km (core zone 47.48 sq. km, buffer zone 772.52 sq km) on a hilly terrain where altitude ranges from 200 to 1412 m a.s.l. The climate of the area is monsoonic with 3012 mm annual rainfall and 24°C mean temperature. The evergreen, semi-evergreen and deciduous forests occur in the core zone, while riverine forests, successional communities on jhum fallows, bamboo groves, tea gardens, orange orchard, paddy fields in the valleys and coal and limestone mining sites are found in the buffer zone.

Slash and burn agriculture (locally called 'jhum') is the major human activity with about 85 % population involved in it. The average area under jhum in each village is 243.70 ha. It is estimated that 31,473 ha or 38.47 % area on the hill slopes of the biosphere reserve is influenced by slash and burn agriculture. Besides this, substantial area in the southern side of the biosphere reserve is affected by coal and limestone mining. The extensive coal mining is going on in West Darrengiri, Siju, Pyndengru-Balphakram and Selsela Blocks, while limestone quarrying is being done around Dana-Adugiri village.

The forest in the core zone is dominated by tree species such as *Helicia nilagirica, Calophyllum polyanthum* and *Dysoxylum gobara. Rhynchotechum ellipticum, Piper griffithii* and *Dendrocnide sinuate* are dominant shrubs, and *Pteris quadriaurita, Elatostemma sikkimense* and *Impatiens* spp. are important herbs. *Macaranga indica, Eurya acuminata* and *Callicarpa vestita* (trees), *Solanum myriacanthum, Rhynchotechum ellipticum, Rubus khasianus, Clerodendrum viscosum* and *Leea edgeworthii* (shrubs); and *Eupatorium adenophorum, Eragrostis unioloides Abacopteris*

multilineata, Ageratum conyzoides, Pogostemon auricularis and *Borreria articularis* (herbs) were dominant in the jhum fallow communities.

Desmodium triquetrum, Cissampelos pareira, Indigofera atropurpurea and *Ziziphus oenoplea, Paspalum* sp., *Ageratum conyzoides* and *Bidens pilosa* were present on the coalmine spoils. *Smilax aspera, Trigonostemon semperflorens, Morinda angustifolia, Pteris* sp. *Axonopus compressus* and *Eragrostis artovirens* were recorded in the limestone mine spoil area.

In order to determine the effects of these two major activities on soil, several physico-chemical and biological properties were studied in the undisturbed core zone, jhum fallows of three different ages viz., 10-12-, 6-8- and 1-year old fallow, and mining (coal and limestone) sites over a period of three years (2000-2002) on seasonal basis. The important findings of the study are summarized as under:

1. The texture of the soil was sandy loam in the core zone and jhum fallows, sandy in the coalmine spoil and sand-clay-loam to clay-loam in the limestone mine spoil.
2. Bulk density of the top layer (0-10 cm) was 1.2 g/cm^3 in the core zone, 1.8 g/cm^3 in coalmine spoil and 1.1 g/cm^3 in jhum fallows. The limestone mine spoil had a bulk density of 0.8 g/cm^3.
3. Water holding capacity was maximum (85.48 %) in the core zone and minimum (19.18 %) in the coalmine spoil.
4. The soil moisture content (SMC) though varied significantly between different seasons and soil depths; the highest value was recorded in the core zone (26.67 %) followed by jhum fallows (19.53 - 24.83 %) and lowest in the mine spoils (9.29 %).
5. The proportion of micro-aggregates (<0.3 mm) was more in the core zone (37.77 %) than in the jhum fallows (22.51 - 29.28 %). Compared to the core zone and

jhum fallows, the coalmine spoil had a high proportion of micro-aggregate and low proportion of macro-aggregate, but the trend was reversed in case of limestone mine spoil.

6. The soil was acidic (pH=3.50 - 6.03) in nature at all sites except in limestone mine spoil which was alkaline (pH ≈ 8). The soil in the core zone was less acidic than the jhum fallows. Lowest pH (3.50) was recorded in the coalmine spoil.
7. Cation exchange capacity (2.92 meq/100g) of the coalmine spoil was lowest and that of limestone mine spoil was maximum (19.23 meq/100g). There was a drastic reduction (80 %) in the CEC in coalmine spoil compared to the core zone.
8. Organic carbon content declined from the maximum value (5.93 %) in the core zone to 5.10 % in 10-12-yr., 4.65 % in 6-8-yr. and 4.15 % in 1-yr. old fallows. The minimum value (1.01 %) was recorded in the mine spoils. There was 30 % reduction in the 1-yr. old jhum fallow and 83 % in mine spoils compared to the upper soil layer of the core zone.
9. The core zone had the highest concentration of TKN, available phosphorus and exchangeable potassium followed by jhum fallows; mine spoils recorded the lowest value.
10. Both microaggregates and macroaggregates had highest C and N concentrations in the core zone, followed in decreasing order by jhum fallows and mine spoils. The C/N ratio was, however, always higher in microaggregates.
11. The microbial biomass carbon (MBC) concentration in the upper soil layer ranged from 840 to 1579 μg g^{-1} in the core zone, 244 to 887 μg g^{-1} in jhum fallows and 171 to 215 μg g^{-1} in the mine spoils.
12. The soil of the core zone had maximum concentration of microbial biomass nitrogen (MBN) (296 μg g^{-1}) followed in descending order by 10-12-yr. (181 μg g^{-1}), 6-8-yr. (86 μg g^{-1}) and 1-yr. old (75 μg g^{-1}) fallow.

13. The upper soil layer recorded a sharp fall in MBC (73 %) and MBN (75 %) in 1-yr. old fallow compared to the core zone following vegetation destruction and burning of slash. There was 89 % loss in MBC in the mine spoils.
14. Highest dehydrogenase and urease activities were recorded in the core zone and lowest in 1-yr. old jhum field.
15. In 1-yr. old fallow, there was 45 % reduction in DHA and 61 % reduction in UA in the upper soil layer compared to the core zone. At the lower layer, the reduction was relatively less.
16. Highest mineralization potential (121.0 $\mu g\ g^{-1}$ inorganic N) was observed in the core zone and lowest (43.7 $\mu g\ g^{-1}$ inorganic N) in the mine spoil. The loss in N mineralization potential in the upper layer was 59 % in 1-yr. old jhum fallow and 67 % in the mine spoils.
17. Ammonification (0.31 $\mu g\ g^{-1}\ day^{-1}$), nitrification (0.95 $\mu g\ g^{-1}\ day^{-1}$) and mineralization (1.26 $\mu g\ g^{-1}\ day^{-1}$) rates were maximum in the core zone, decreasing successively in the younger jhum fallows, and their minimum values were recorded in the coalmine spoil.
18. In 1-yr. old jhum fallow, there was 74 %, 32 % and 63 % loss in ammonification, nitrification and mineralization respectively at the upper layer of the soil compared to the core zone. The corresponding losses in the mine spoils were 87 %, 58 % and 80 %.
19. The decomposition of leaf litter of dominant species in the core zone was strongly influenced by their chemical composition such as nitrogen and lignin concentration.
20. Mixed leaf litter decomposition under laboratory condition was highest in core zone soil (k=1.76), followed in descending order by 10-12-yr. old jhum fallow

(k=1.50), 6-8-yr. old jhum fallow (k=0.97), 1-yr. old fallow (k=0.88) and mine spoil (k=0.87).

21. N, P and K mineralization constants for the mixed leaf litter were highest in the core zone (0.71, 0.58 and 2.85 respectively) and lowest in the mine spoil (0.28, 0.21 and 1.46 respectively).

22. Destruction of vegetation, either for shifting cultivation or for mining, had a drastic effect on most of the physical, chemical and biological properties of the soil as is evident from the results presented above. However, when the field is abandoned after few years of cultivation, the fertility of the soil show a gradual recovery. This is clearly evident from the fact that all the above parameters, except bulk density and macroaggregates, increased during 10-12 years of secondary succession on jhum fallows (Figure 9a). During this period, soil moisture content, water holding capacity, cation exchange capacity, soil organic carbon, exchangeable potassium and enzyme activities showed more than 80 % recovery while the recovery in total Kjeldahl nitrogen, available phosphorus, microbial biomass carbon and microbial biomass nitrogen was about 60-70 %. The impact of mining was much stronger than shifting agriculture. Though all parameters showed a significant change, the chemical and biological properties were most adversely affected (Figure 9b).

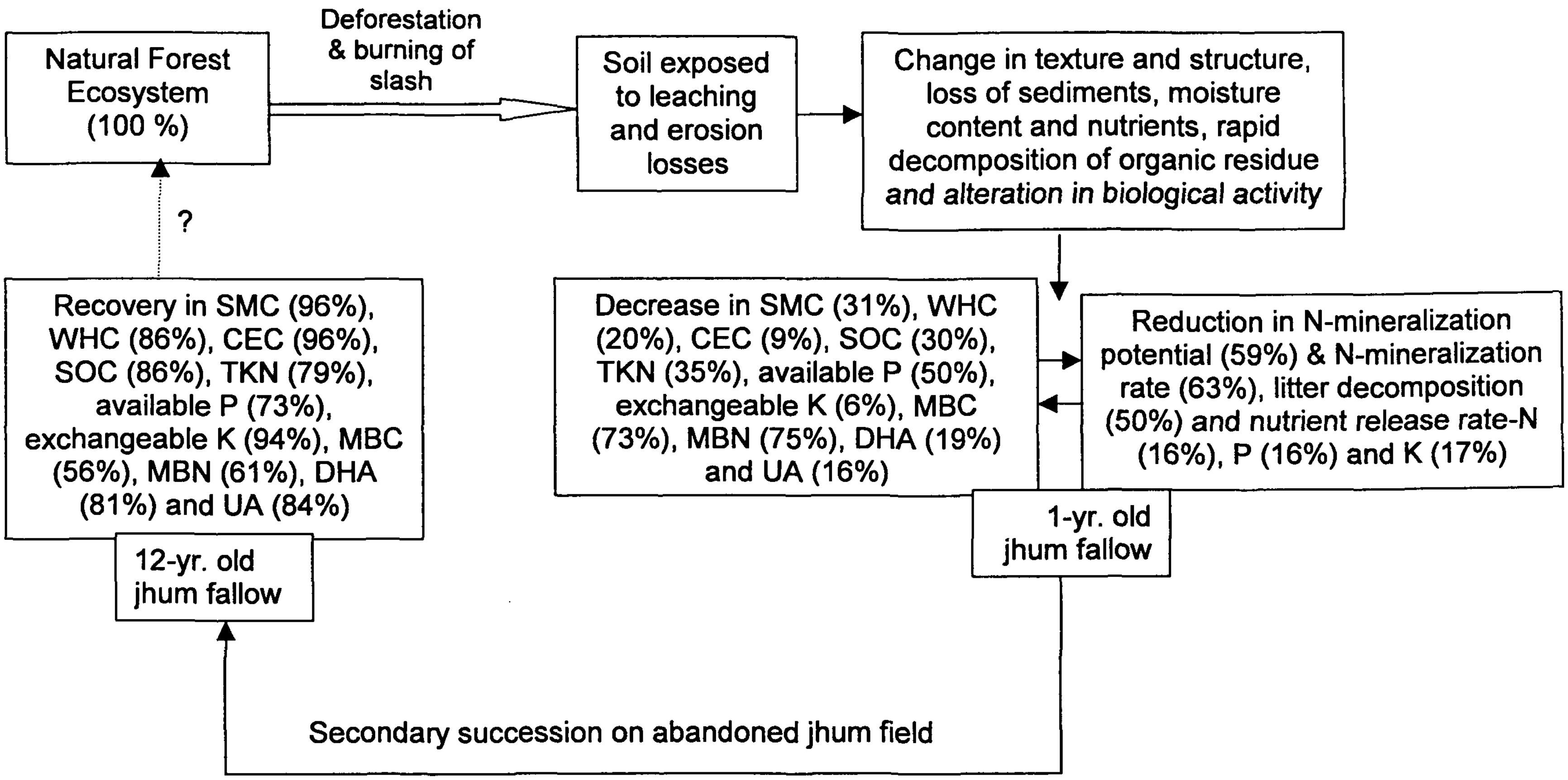

Fig. 9a. Impact of shifting cultivation on physico-chemical and biological properties of soils of the BR and its recovery during secondary succession on jhum fallow. Values in parentheses within the boxes are percent reduction/ recovery over the control site (core zone).

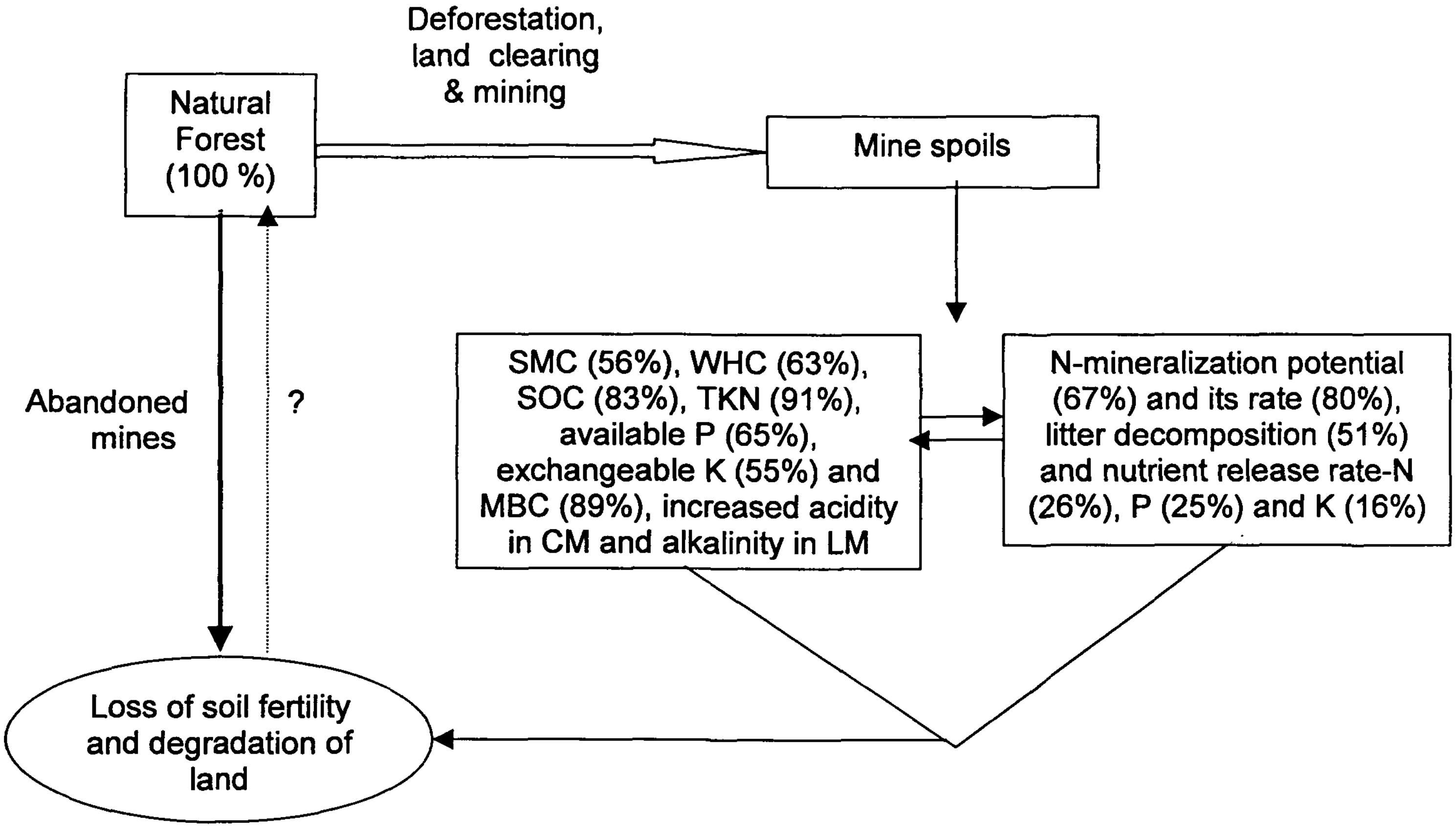

Fig. 9b. Impact of mining on physico-chemical and biological properties of soils of the BR. Values in parenthesis within the boxes are percent reduction over the control site (core zone).

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BIODATA

NAME : Miss Vanlalhruaii Ralte
FATHER'S NAME : Shri R. Siamkunga (L)
MOTHER'S NAME : Smt. Lalrinthangi
PRESENT ADDRESS : Department of Botany
North-Eastern Hill University
Shillong – 793 022
Meghalaya, India
PERMANENT ADDRESS : Vaivakawn
Aizawl – 796 009
Mizoram
DATE OF BIRTH : 7th October, 1976
NATIONALITY : Indian

EDUCATIONAL QUALIFICATIONS:

Examination/ Degree	Year of passing	Board/ University	Grade/ Class	Percentage of marks obtained
H.S.L.C.	1991	MBSE	I	67.22
P.U. (Sc.)	1994	NEHU	II	59.11
B.Sc. (Botany)	1997	NEHU	II	55.75
M.Sc. (Botany)	1999	NEHU	I (Gold Medalist)*	70.61

* Awarded **President Dr. Shankar Dayal Sharma Gold Medal 1999** for General Proficiency

RESEARCH EXPERIENCE:

- Worked as a Junior Research Fellow in the research project entitled, "Studies of the human impact on the buffer zone ecosystems of Nokrek Biosphere Reserve, Meghalaya" (January 2000-September 2003) under the Ministry of Environment and Forests, Govt. of India. Under this project, community structure, plant diversity and soil properties, rare, endemic and threatened plant species and medicinal plant diversity were studied.

WORKSHOPS/ SEMINARS/ SYMPOSIA ATTENDED:

- Orientation course in "Taxonomy of Angiosperms" conducted at University Department of Botany, T.M. Bhagalpur University, Bhagalpur, India (11-25th September, 2001).
- National Seminar on "Intellectual Property Rights" organized by North-Eastern Hill University, Shillong, India (24-25th May 2002).
- National Seminar on "Botanical researches in Wildlife Sanctuaries and National parks of Assam" held at Handique Girls' College, Guwahati, India (27-28th July, 2002) for poster presentation (Medicinal Plants of Nokrek Biosphere Reserve, Meghalaya).
- International Conference on "Mountain Environment and Natural Hazards Management" and XXIV Institute of Indian Geographers' Meet, held at Department of Geography, North-Eastern Hill University, Shillong, India (27-29th March 2003).
- International Seminar on "Recent Trends in Plant Ecology and Biodiversity Research" held at North-Eastern Hill University, Shillong, India (20-22nd May 2004) for poster presentation (Effect of shifting cultivation and mining on soil properties in Nokrek Biosphere Reserve of Meghalaya).

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