NUTRIENT CYCLING IN DEGRADED ECOSYSTEMS (GRASSLANDS) OF MEGHALAYA

(ABSTRACT)

BY

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THESIS SUBMITTED IN FULFILMENT OF THE DEGREE OF
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ABSTRACT

This study deals with the community composition, storage of N, P and K in different vegetation compartments and soil and their cycling between plant-soil system of the degraded plant communities represented by grasslands in Meghalaya. The study emphasizes the effects of altitude, climate, soil and protection against mild cattle grazing and annual burning on the various aspects mentioned above.

The experimental sites are located at Burnihat, Cherrapunji and Upper Shillong having an altitude of 100, 1300 and 1900 m, respectively in the East Khasi Hills district of Meghalaya. The data were collected during August 1988 to August 1989. The mean values of climatic variables were: maximum and minimum temperatures 26.0 and 22.4^{o}C, respectively and annual rainfall 2871 mm at Burnihat; maximum and minimum temperatures 19.7 and 16.6^{o}C, respectively and annual rainfall 16247 mm at Cherrapunji; and maximum and minimum temperatures 18.5 and 17.0^{o}C, respectively and annual rainfall 3268 mm at Upper Shillong.

The soil at Burnihat and Upper Shillong is sandy loam whereas at Cherrapunji it is highly stony; three-fourth of the total substratum being gravel or stone. Water holding capacity, pH, cation exchange capacity and total exchangeable bases are considerably low at Cherrapunji compared to the other sites. Organic carbon content increased significantly with altitude and ranges between 1.72 % at Burnihat and 3.5 % at Upper Shillong (protected stand). The mean values of total nitrogen content are

7488. 8847, 16679 and 11661 Kg ha-1 at Burnihat. Cherrapunji, and in the protected and unprotected stands at Upper Shillong, respectively. The extractable phosphorus is very low at all the sites and does not exceed 7.5 Kg ha-1. Exchangeable potassium ranges between 170 Kg ha-1 at Cherrapunji and 483 Kg ha-1 in the protected stand Upper Shillong.

Species content varied from 15 at Cherrapunji to 32 in the protected stand at Upper Shillong. The community at Burnihat was dominated by *Setaria glauca* whereas *Arundinella khaseana* and *Arundinella nepalensis* were dominants at Cherrapunji and Upper Shillong, respectively. Proportion of perennial species and chamaephytes in the community increased significantly with elevation. Legumes were poorly represented in all the grassland communities. forbs were most prominent at Upper Shillong, whereas the Cherrapunji grassland community was composed almost entirely of grasses. At Cherrapunji, species diversity was low and dominance was high compared to those at Burnihat and Upper Shillong. The grassland communities at various elevations were quite dissimilar. However, at Upper Shillong, there was about 80% similarity between the protected and unprotected stands.

Protection of community at Upper Shillong against annual winter burning and mild cattle grazing increased species content, density, cover and diversity. Dominance of *Osbeckia crinita* and *Arundinella nepalensis* declined following protection while that of *Imperata cylindrica* increased.

Nitrogen reserve in soil at Upper Shillong was approximately twice that of Burnihat and Cherrapunji. Of the total nitrogen in the soil-plant system, more than 98 % was present in soil and only 1 to 1.5 % participated in biological circulation. Difference in the standing state of nitrogen in vegetation was insignificant among the four communities and the mean value ranged between 10.2 g m-2 at Burnihat and 12.2 g m-2 at Upper Shillong (protected stand). In all the communities, belowground parts accumulated more N than aerial parts. Annual uptake was maximum (232 Kg ha-1) in the Cherrapunji community. At Burnihat and in the unprotected stand at Upper Shillong, annual uptake was about 40 % less than the uptake at Cherrapunji. In the protected stand at Upper Shillong, uptake (206 Kg ha-1) was less than Cherrapunji but more than other sites. About two-third of the total uptake was diverted to belowground parts at Burnihat and Upper Shillong, whereas at Cherrapunji, it was much higher (*ca.* 88 %). The annual release through litter and belowground detritus was more than the uptake at Burnihat and in the unprotected stand at Upper Shillong. At Cherrapunji and in the protected stand at Upper Shillong, release was less than the uptake. The annual budget showed a net loss of about 13 % of the total uptake at Burnihat and 6 % in the unprotected stand at Upper Shillong. On the other hand, there was a net retention of about 5 % at Cherrapunji and 21 % in the protected stand at Upper Shillong. In all the communities, turnover rate was near unity indicating almost complete recycling within a year.

The amount of extractable phosphorus in soil ranged between 4.2 Kg ha-1 at Upper Shillong and 7.5 kg ha-1 at Cherrapunji. Its mean accumulation in vegetation was maximum in the protected stand at Upper Shillong (2.48 g m-2) and minimum at Cherrapunji (0.96 g m-2). The grassland communities at *Burnihat* and Cherrapunji exhibited more or less equal value but the unprotected stand had lower value than the protected stand. In all the communities, accumulation was 2-3 times more in the belowground parts than in the aboveground parts. Of the total available phosphorus content in soil and that stored in plant system, about 56 % was in vegetation at Cherrapunji, 86 % in the protected stand, *ca.* 25 % at Burnihat and in the unprotected stand at Upper Shillong. The accumulation in belowground parts was relatively less (36 %) at Cherrapunji than the other sites (51-56 %). In all the communities, the annual uptake was more than the amount of extractable phosphorus in soil. The annual uptake was maximum (34 Kg ha-1) in the protected stand at Upper Shillong, and it is nearly two times that of Burnihat and Cherrapunji. In the unprotected stand, it was 26 Kg ha-1. About two-third of the total uptake was transferred to the belowground parts at Burnihat and in the unprotected stand. In the protected stand, it was more than the unprotected stand. At Cherrapunji, the proportion of belowground uptake was 75 %. The release was more than the uptake at Burnihat, Cherrapunji and in the protected stand. In the unprotected stand, however, it was slightly less than the uptake. The annual budget showed a net loss of about 26 and 6 % of the total phosphorus uptake at Burnihat and Cherrapunji. Interestingly, the unprotected stand retained 6 % in belowground vegetation. In all the communities, turnover rate was quite fast and the value ranged between 0.8 and 1.2; the minimum being at Burnihat and maximum in the unprotected stand.

The exchangeable potassium in the soil was related to the percentage of fine particles (clay + silt) and its amount was maximum in the protected stand (483 Kg ha-1) and minimum at Cherrapunji (170 Kg ha-1). At Burnihat, the reserve of exchangeable potassium in soil was about 50 % of that present in the protected stand at Upper Shillong, whereas in the unprotected community this was about twice that at Cherrapunji. Potassium content in the vegetation was maximum in the protected stand (8.37 g m-2) and minimum at cherrapunji (4.13 g m-2). It was 7.15 g m-2 in the unprotected stand and 5.56 g m-2 at Burnihat. Except at Burnihat, accumulation was more in the belowground than in the aboveground parts. The reverse was true at Burnihat. About 15-19% of the total labile potassium in soil and that stored in plant system participated in biological circulation. The annual uptake was maximum in the protected stand (139 Kg ha-1). A higher proportion of uptake was channelized to the belowground parts in all the communities except Burnihat where aboveground compartment was more prominent. The annual release through dead plant parts was less than uptake at all the sites except in the unprotected stand at Upper Shillong where the output and input were more or less equal. The annual budget showed a net gain of 20 % at Burnihat, 8 % at Cherrapunji and 13 % in the protected stand. Potassium turnover rate ranged between 0.95 and 1.16.

Protection of the community at Upper Shillong for about 7 months increased the accumulation of N, P and K in soil and vegetation compartments of the community. The uptake and release and daily flux rates between the compartments also increased. There was a build up of nitrogen and potassium mainly in the belowground phytomass of the community after protection.

A comparison of nutrient cycling in these grassland communities with those from other ecoclimatic zones of the country shows that in humid grasslands of Meghalaya, belowground parts play more important role in accumulation and cycling of nutrients than the aerial parts which have been reported to be of greater significance in other ecoclimatic regions of the country. The turnover of N, P and K is much faster in these grasslands compared to the subhumid, semiarid and Himalayan grasslands. The high turnover rate also depict the recycling of almost all the uptake of these elements annually in the grasslands of Meghalaya.

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We certify that the thesis entitled '**Nutrient Cycling in Degraded Ecosystems (Grasslands) of Meghalaya** submitted by ***Mr. Uma Shankar*** for the **Degree of Doctor of Philosophy** of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by him under our supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the **Ph.D. degree**. The work has not been submitted for any degree of any other University.

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CONTENTS

Chapter 1

General Introduction

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GENERAL INTRODUCTION

The Meghalaya state of India is gifted with the wealth of forest resources. Much of the area of the state receives an annual average precipitation of 2,000 mm or more and in certain parts, mostly the southern aspect facing Bangladesh, rainfall exceeds 10,000 mm per annum. Cherrapunji, the place known for the heaviest precipitation in the world is situated in this part of the state. The natural vegetation ranges from moist deciduous forest at lower elevation to subtropical broadleaved wet hill forest at higher altitude (Champion & Seth 1968). Of the total area of the state (22,490 Sq.km.), only 8,514 Sq.km. or 37.86 per cent is under forest cover. The State Forest Department owns only 8.48 per cent or 722.36 Sq.km. whereas 91.52 per cent or 7,791.64 Sq.km. is Community/Private forest. In addition to this, approximately 1,000 Sq.km. area is protected by the local tribesmen as **'Law-Lyngdoh'** or **sacred groves**.

During a short span of time from 1975 to 1982, the forest cover in the state has depleted by about 9 per cent (National Remote Sensing Agency Report 1983). According to a recent estimate, approximately 4,746.72 Sq.km. or 21.11 per cent of the total geographical area of the state is in the form of wastelands (Centre for Science and Environment 1986). Abandoned Jhum-lands and barren hill ridges or rock outcrops form the major part of the wastelands in the state.

Exploitation and degradation of land in Meghalaya have increased to alarming proportions. Awareness that the land resources are not infinite is not to the extent which could cause concern for protection and management of the life support systems. To meet the growing demands, the forest resources are being purportedly destroyed especially by Jhummias (shifting cultivators), timber merchants and consumers of fuelwood. Human interference in various other ways such as mining and developmental activities have further accelerated the pace of forest destruction. The grasslands which occur in this region could be best described as representing degraded stages of forest ecosystems. Clearance of forest cover has exposed the soil to extensive wash-out losses and depletion of nutrients under the influence of high rainfall. Development of plant communities on such sites is arrested at varying seral stages depending on soil conditions and prevailing biotic interferences. Land which was once highly productive has been degraded and in certain areas totally destroyed or rather desertified. Ecological restoration of degraded lands or wastelands to their innate productive potential is not an easy task. It requires an overall understanding of the critical factors and their interactions with the structure and functioning of the ecosystem.

Plant communities growing on degraded sites such as abandoned Jhum fallows and eroded hill slopes in Meghalaya are composed largely of annual species and perennial grasses. N.L. Bor (1940) and later on Bor(1942), Champion & Seth (1968), Bor (1960) and Dabadghao & Shankarnarayan (1973) have described the floristic composition of these and other grassland communities from Assam state (the Assam of English ruled India) and have grouped them under *Themeda-Arundinella* type cover. These grasslands owe their origin and existence to anthropogenic activities similar to their counterparts in other ecoclimatic zones of the country and represent a secondary seral stage (Whyte 1968; Yadava & Singh 1977; Misra 1983). On extremely degraded sites such as Cherrapunji and nearby areas, they are fairly stable. This is clearly evident from the fact that there is hardly any noticeable change in the floristic composition of southern aspect of Shillong plateau since the publication of the paper entitled *The relict vegetation of Shillong plateau* by N.L. Bor (1942). Rather, more forested area at higher elevation of Meghalaya has come under similar type of plant communities during past five decades or so.

Ecosystem is the unification of compartments and connecting fluxes that ensure transfers of energy and nutrients between the compartments (Bazilevich & Titlyanova 1980). The standing state of an ecosystem at a particular time is considered to be its **structure** whereas the **functioning** of the ecosystem is the change in its state with time. The functioning of an ecosystem may be of two kinds - <u>periodical</u> and <u>transitional</u> (Bazilevich & Titlyanova 1980). The former is characterised by periodic changes in flux intensities and matter reserves in compartments (e.g. from season to season) while the average values remain constant over a longer time scale. The climax ecosystems are closer to this kind of functioning. The latter type is characteristic of ecosystems that are passing from one regime to another, for example, from swamp to meadow or from meadow to steppe. The intensities of input and output fluxes and the reserves in compartments are changing over a time scale in this kind of functioning. An ecosystem would be in <u>recovering stage</u> while the reserves in components and flux rates are increasing with time, and in <u>degrading stage</u> if the losses occur in the reserves and the fluxes reduce in time.

Nutrient cycling which involves complex and continuous interactions between biotic and abiotic components of the ecosystem plays a key role in the growth and development of plant community on the degraded sites. Nutrients from the available pool in soil enter into vegetation through root system and are partitioned in above- and belowground part. At the same time a certain amount of nutrients flows out from the aboveground green plant parts to the live belowground plant parts. In the process of dying-off of aboveground and belowground plant parts, i.e., litter. Subsequent transformations lead to mineralization of most of the dead organic matter, carbon being released to the atmosphere as carbon dioxide and minerals returning to soil nutrient pool; a small fraction remains in the soil humus during the course of humification. Some nutrients are washed out from aboveground plant parts by leaching through precipitation and a small quantity is lost to the soil via root exudates.

Cycling of nitrogen in the ecosystem is rather complex. The basic or internal cycle as described above may be influenced by diverse peripheral processes (inputs and outputs) especially in case of nitrogen. Nitrogen inputs to grassland are primarily by symbiotic and nonsymbiotic nitrogen fixation, ambient precipitation, animal immigration and wind and surface water import. In managed grasslands fertilizers and sown legume-grass mixtures are responsible for the major inputs. Nitrogen losses from the grasslands may occur by denitrification, volatilization, leaching, wind and water erosion of particulate matter, and in harvest or animal export.

Clark (1977) studied internal cycling of nitrogen in blue grama grassland using tracer nitrogen (^{15}N) and recognized four nitrogen supplying mechanisms: i) internal translocation whereby nitrogen stored over winter in belowground plant parts move to new growth in the next growing season, ii) mineralization of easily decomposable organic nitrogen compounds, such as certain herbage compounds, root exudates and exfoliates, and short-lived unsuberized roots, iii) mineralization of organic nitrogen synthesized by micro-organisms subsisting on energy rich materials, and iv) polymerization of a part of microbially synthesized organic nitrogen to humic nitrogen which slowly releases it to the available nitrogen pool. Further improvement of the basic pathway of nutrient flow, particularly nitrogen, suggests that microbes subsisting on the decomposing organic matter (litter and root) and energy rich materials immobilize a part of inorganic nitrogen and synthesize it in the organic compounds (Clark 1977). After microbial death and decay nitrogen again becomes available for reuse by plants.

The phosphorus cycle in most grasslands is closed, with no significant gains or losses even in the areas of heavy precipitation (Clark *et al.* 1980). Thus it differs from nitrogen cycle which is open both to atmospheric fluxes and losses through leaching. Unlike nitrogen and phosphorus cycles, potassium cycle is characterised by its mode of return to the soil. Potassium from organic matter is released not primarily by decomposition but rather by physical weathering processes collectively called leaching. Leaching is the removal of substances from plants by the action of aqueous solutions associated with rain, dew, mist and fog (Tukey 1970).

In brief, cycling of nutrients in the grassland ecosystems may be considered as a combination of biological cycle and abiotic processes. The biological cycle consists mainly of processes of matter transformation, i.e., the synthesis of organic and organomineral compounds, their transformation, re-synthesis and degradation to simpler compounds. All the transformation processes together contain the movement of chemical elements within a single ecosystem. Abiotic processes (inputs and outputs) are basically transport processes and play a major role in the movement of materials between ecosystems. Since water is the transporting medium in abiotic processes, the extent of abiotic processes depends on the hydrologic cycle. The relative importance of biological cycle and abiotic processes varies with ecosystems.

Nutrient cycling in temperate grassland ecosystems has been studied extensively and most of the work done on this aspect have been reviewed by Jones & Woodmansee (1979), Clark *et al.* (1980) and Bazilevich & Titlyanova (1980). Recently, Coleman *et al.* (1983), Macduff & White (1984), Ulehlova (1985), Ruess & McNaughton (1987), Jackson *et al.* (1988), Chapman *et al.* (1989) and Bobbink *et al.* (1989) have also contributed to the knowledge of nutrient cycling in grasslands. Similar works on tropical grassland ecosystems are relatively less (Dommergues 1963;

Bazilevich & Rodin 1966); Rosswall 1980; Robertson & Rosswall 1986). In India limited work has been done on nutrient cycling aspect of the ecosystem as compared to the phytosociological and productivity measurements (Pandey 1976; Billore & Mall 1976, 1985; Mishra 1979; Yadava 1980; Tiwari 1985; Agrawal & Tiwari 1987; Chaturvedi *et al.* 1988; Pandey & Singh 1990). Most of these studies are from the semiarid and subhumid regions. However, similar studies on the humid grasslands are few and far between.

Not much attention has been paid towards the study of nutrient cycling in humid grassland ecosystems of Meghalaya, although distribution of various grass species has been recorded by Bor (1940, 1960), and taxonomic studies were conducted by Neogi (1980), Myrthong (1980), Haridasan (1982) and Kumar (1984). Some work has also been done on grass-legume interaction in relation to soil nitrogen (Pradhan & Tripathi 1980, 1984, 1985), trampling (Pradhan & Tripathi 1983) and nitrification potential (Ramakrishnan & Saxena 1984). Ram (1986) studied the ecosystem structure and function of seral communities of degraded environment at Cherrapunji and data are now available on hydrology, soil fertility (Ram & Ramakrishnan 1988c, 1989) and productivity (Ramakrishnan & Ram 1988). However, no attempt has been made to understand the nutrient cycling in these grasslands of Meghalaya occurring at varying topography and exposed to markedly different climatic conditions and biotic stresses.

Considering the aforesaid facts, cycling of three major nutrients, viz., N, P and K which have strong influence on plant growth and productivity, was studied at three different sites which are distributed along an altitudinal gradient between 100 and 1,900 m altitude running across north-south direction in the state. At one of these sites, effects of prevailing biotic disturbances such as annual burning and mild cattle grazing were also studied. Data collected on storage of N, P and K in soil and vegetation components, their uptake by vegetation, transfers between different above- and belowground producer compartments and input to soil through decomposing litter and belowground parts during 1988-1989 are presented in this dissertation.

Chapter 2

Review of Literature

Chapter 2

REVIEW OF LITERATURE

Grasslands occur in a wide range of types, varying from floristically rich vegetation of the natural pasture to the single species sward characteristics of some agricultural situations. The world's grasslands have been classified in many different ways (Moore 1964). Generally speaking, grasslands may be of two main types - natural and artificial. Both natural and artificial grasslands cover at least 23 per cent of the land surface of the globe (Cragg 1980) and provide man and his livestock with the major part of their food supply. The area under grasslands is continuously expanding as a result of increasing human activities and desertification due to overuse of land.

Ecology of grassland communities has been intensively studied in different parts of the world such as tall grass prairie in America (Weaver 1917; Weaver & Fitzpatric 1932, 1934; Nicholson & Hulett 1969), savannas of northern tropical America (Beard 1953), desert grasslands (Humphrey 1958), grassland mosaic of Texas (Lynch 1962), central African grasslands (Vesey-Fitzgerald 1963), savannas of Llanos and Colombia (Bladystein 1967). International Biological Programme launched in 1964, included grassland biome studies in 1966 with the objective of learning more about the organic production and overall energy flow in the grassland ecosystems of the world. Massive amount of data collected from all over the world during 1967-74 have been compiled by Coupland (1979) and Breymeyer & Van Dyne (1980).

Whyte (1968) believes that there are hardly any artificial grasslands in India, but the existing grasslands are not wholly natural either; they owe their existence to human activities. According to him, climax grasslands equivalent to steppe, range, pampa or savanna appear to be absent in India. Champion (1936) also doubts the existence of climax grasslands in the country, although they are commonly found as an interim stage in the succession and sometimes may be relatively very stable (pre-climax) under the influence of repeated fire and grazing. According to Misra (1983), exclusive grasslands are not found in India and the data on grasslands are mostly based on the analysis of savannas which are maintained by shifting cultivation, grazing, burning and desertification and represent a disclimax (Misra 1946), preclimax (Champion & Seth 1968) or subclimax (Singh *et al.* 1985).

The earlier studies on grasslands initiated in this country were mostly descriptive and directed towards the classification of grasslands (Bor 1938). Ecological studies on the Indian grasslands were initiated by Bharucha & Dave (1944). Pandeya (1952) worked on grasslands at Sagar in Madhya Pradesh and gave detailed community structure and successional trends as related to topography, soil type and grazing pattern. Indian Council of Agricultural Research conducted a reconnaissance survey of grasslands in India during 1954-1962 for the proper management and improvement of grassland resources of the country. The report of the survey has been published in the form of a book entitled **The grass cover of India** (Dabadghao & Shankarnarayan 1973). After this numerous studies were undertaken in different parts of the country under IBP and MAB programmes to analyse the structure and function of grassland ecosystem. These studies which mostly deal with phytosociology, biomass and productivity have been summarised by Yadava & Singh (1977), Misra (1983), Singh *et al.* (1985) and Pandeya (1988).

Nutrient cycling through various components of an ecosystem is an important functional attribute and serves as a powerful basis to the understanding of its stability (Pomeroy 1970). A perusal of literature reveals that the grassland ecosystems have received relatively less attention than the forest ecosystems for the study of mineral cycling. Furthermore, studies on temperate grasslands are more numerous than the tropical grasslands. Most of the studies on nutrient cycling in tropical grasslands are available from MAB and IBP sites in India and there is extreme insufficiency of data on humid grasslands. Virtually, the understanding of nutrient cycling in tropical savannas is yet tentative, since the quantitative data on this aspect are deplorably few (Lamotte & Bourlière 1983).

Nutrient cycling in an ecosystem is primarily controlled by its static and dynamic properties (Burke 1989). Community composition, total nutrient pool of soil and texture etc. are static properties at time scales of decades, whereas dynamic properties include soil available nutrient pools, soil moisture and temperature and population of microbes in the soil which vary widely over shorter time scales, i.e., diurnally, monthly, seasonally and/or annually and across the altitudinal gradient. Other factors which influence cycling of nutrients in grassland ecosystems include fertilizer application, burning and climatic conditions of the area.

The patterns of nutrient cycling in annual and perennial grasslands are generally the same. The most important difference between the two is the death of most vegetation (except seeds) at the end of each growing season in case of the former. Therefore, annual grasslands do not internally recycle and store nutrients from one season to the other (Jones & Woodmansee 1979). Consequently, large amounts of nutrients enter and leave vegetation compartment in annual grasslands than those dominated by perennial species (Cole *et al.* 1968; Clark 1977; West & Skujins 1977; Woodmansee *et al.* 1978).

Among the essential macronutrients, nitrogen assumes special significance because of its importance to plants and animals alike. Cyclic flow of nitrogen is a key function of grassland ecosystem, since forage production in many grasslands is limited by the current supply of nitrogen (Green & Cowling 1960; Power & Alessi 1971; Gutschick 1981). In many cases plants have to suffer inadequacy of nitrogen for uptake in spite of the fact that soil contains a large amount of nitrogen in the system. McGarity (1959) and Bruce (1965) have reported that grass swards growing in cleared rainforest soils of north-eastern tropical and subtropical Australia suffer from nitrogen deficiency even though the soils contain upto 8,000-10,000 Kg N ha-1 in the rooting zone. The short-grass, mixed-grass and tall-grass prairies in USA retain more than 90 per cent of nitrogen in the soil (Bokhari & Singh 1975). Trumble & Woodroffe (1954) reported a total of 1,400 Kg ha-1 of nitrogen in a shrub-steppe pasture with a ratio of 11:2:1 in the rooting medium, living plant tissue and litter. In a dry subhumid grassland at Varanasi, top 30 cm soil retained 88-91 per cent of nitrogen (Pandey 1976). Protected, semi-protected and open grassland communities at Kanpur contained 91 to 96 per cent of total system's nitrogen in the soil (Mishra 1979). In a tropical grassland ecosystem at Kurukshetra, 92 to 95 per cent of nitrogen was present in soil and only 5-8 per cent was involved in biological circulation (Yadava 1980). In a study from Pauri hills, Tiwari (1982) cited that of the total amount of nitrogen present in the system, more than 99 per cent was in the soil. In a Himalayan grassland at Garhwal, 97.6 to 99.5 per cent nitrogen was retained in soil (Agrawal & Tiwari 1987).

Findings of Dahlman *et al.* (1969) in a prairie ecosystem of native grassland reveal that more than 96 per cent of the system's nitrogen in the soil is found in the form of organic matter. Soil nitrogen which is mostly in the organic form, resides in the steady state (Clark *et al.* 1980), and is unavailable to plants (Date 1973). Norman (1966) found that only 8 per cent of 3,400 Kg ha-1 nitrogen was available for pasture growth. Such a low availability of nitrogen was mainly attributed to the slow rate of mineralization of organic nitrogen which was hardly sufficient to meet the requirements of vigorously growing pasture swards. Further, the annual inputs of nitrogen through various other agencies are offset by losses of approximately equal magnitude (Clark *et al.* 1980). Therefore, the annual requirement of nitrogen for plant growth in the grassland ecosystem is met largely by the cycling of nitrogen already present in the system. The amount of such nutrient which actively participates in the cycling process is generally very less compared to large reservoir in soil which turns over very slowly, perhaps less than once every century (Coleman *et al.* 1983).

Legumes play an important role in cycling of nitrogen in the grassland ecosystem by enhancing its input into the system. The amount of nitrogen that is made available through fixation by pasture legumes depends on the proportion and efficiency of leguminous species present in the system. Findings of several workers suggest that nitrogen input by fixation ranges between 100 and 200 Kg ha-1 Yr-1 (Henzell & Norris 1962; Allison 1965; Whitehead 1970). However, Melville & Sears (1953) reported values as high as 600-700 Kg ha-1 Yr-1 for red and white clover-rye grass pasture in New Zealand under very good growth conditions. Contrary to these findings, Simpson (1965) reported that white clover actually competed with associated grass for soil nitrogen and thus there was virtually no contribution by the clover to the grass.

Nitrogen input through rainfall varies with location and ranges between 2-10 Kg ha-1 Yr-1 (Junge 1958; Jones & Woodmansee 1979).

All those processes which enhance the loss of nitrogen from soil system, restrict the availability of nitrogen to plants. The loss may be temporary or permanent. Temporary loss of nitrogen from the system may be either due to fixation of soluble nitrogenous compounds (NH_4) in the crystal lattices of clay minerals and organic matter in the soil (Bremner 1965) or immobilization of nitrogen in microbial biomass (Coleman *et al.* 1983; Singh *et al.* 1989). The permanent loss of nitrogen from the system occurs through runoff, leaching, denitrification, volatilization and removal of plants and animal products. Leaching loss of nitrogen in form of nitrate is often quite prominent. Wetselaar (1962) reported that 25 to 250 Kg ha-1 Yr-1 nitrogen could be lost by leaching in fallow soil. According to Ram & Ramakrishnan (1988c), nitrogen loss through percolation may range between 3.6 and 7.0 Kg ha-1 Yr-1 in the grasslands at Cherrapunji. Due to high intensity of rain and water movement, losses through leaching are greater in the tropics than in the temperate region. Further, higher nitrification due to favourable temperature all-year-around also accounts for greater losses of nitrogen by leaching in tropical areas .

Nutrient uptake by vegetation depends on a number of factors such as availability of nutrients in the soil pool, soil texture, soil moisture regime, root mass and root surface area, mycorrhizal association, species composition, the stage and rate of growth (Williams 1964), length of growth season, and environmental factors (Trumble & Woodroffe 1954; Willard & Schuster 1973) including nature and intensity of disturbances in the community. The availability of allied nutrients may influence the uptake of a particular nutrient, for example, nitrogen limitation to ecosystem productivity due to phosphorus deficiency is an extensive topic of study (Gutschick 1981).

Total annual nitrogen uptake ranges from 53.6 to 83.0 Kg ha-1 in short-grass prairie, 56.0-102.3 Kg ha-1 in mixed-grass prairie and 53.5 to 67.8 Kg ha-1 in tall-grass prairie. In all these grasslands, belowground uptake was more than the aboveground uptake (Bokhari & Singh 1975). In an annual grassland at SJER, California, nitrogen uptake varied between 68 and 1 ha-1 Yr-1 during the three successive years of the study (Woodmansee & Duncan 1980). On an average, annual plant uptake of nitrogen from soil ranges from 30 Kg ha-1 Yr-1 to 260 Kg ha-1 Yr-1 at the IBP and MAB sites in India (Lamotte & Bourlière 1983). Misra (1983) reported that uptake of nitrogen in tropical savannas is greater in subhumid climate than the semiarid zone. Available data further indicate that nitrogen uptake is less in the central Himalayan grasslands (Tiwari 1985; Agrawal & Tiwari 1987; Chaturvedi *et al.* 1988) compared to the semiarid (Billore & Mall 1976, 1985; Yadava 1980) and dry subhumid grasslands of India (Pandey 1976; Mishra 1979; Pandey & Singh 1990).

Evidences furnished by these and other workers from other parts of the world suggest that rapid nitrogen uptake occurs when both atmospheric temperature and soil water are adequate to support plant growth. The uptake starts after winter and the rate increases through spring, reaching at its summit during rainy season. The uptake rate declines during winter. Results from SJER ungrazed pasture, California, provided by Jones & Woodmansee (1979) indicate that the period of rapid uptake is associated with rapid growth of vegetation and high decomposition and mineralization rates which are in turn related to the increase in temperature during spring. In the tropical grasslands of India, the rate of uptake is maximum during rainy season (Misra 1983) when majority of plants in the community are in their peak period of vegetative growth.

The amount of nutrients returned to the soil through litter and belowground detritus plays a key role in the nutrient cycling within an ecosystem, since it supports new plant growth.

The amount of nitrogen returned annually to the soil in the prairies ranged between 43.6 and 79.2 Kg ha-1 (Bokhari & Singh 1975). In tropical grasslands it ranged from 20 Kg ha-1 in semiarid to between 100 and 150 Kg ha-1 in subhumid and humid grasslands (Lamotte & Bourlière 1983).

Not all the nutrients held in live herbage are transferred to the dead compartment. A substantial amount is withdrawn prior to leaf abscission and redistributed to the perennial organs where it is stored until the initiation of new flush of growth in the ensuing season. This phenomenon of nutrient translocation in plant body is well understood in case of trees (Wallace *et al.* 1974; Cole *et al.* 1977). Conclusive evidence for this kind of internal cycle of nitrogen in the grassland ecosystems was provided by using tracer nitrogen (^{15}N) by Clark (1977). He suggested four major pathways of nutrient return to the soil. They include: 1) internal translocation whereby nitrogen of one season is stored over winter in belowground parts and then it moves to new growth in the next growing season, 2) mineralization of easily decomposable organic nitrogenous compounds such as certain herbage compounds, root exudates, exfoliates and shortlived unsuberized roots, 3) mineralization of organic nitrogen synthesized by microorganisms subsisting on energy rich materials and humic nitrogen. Possibility of internal translocation of food reserves, upward during the prime growth period and downward in the post monsoon period, in a semiarid grassland at Kurukshetra has been indicated by Singh & Yadava (1974) and Yadava (1980).

Soil microbes play a very critical role in nutrient return to the soil by intercepting freshly mineralized nitrogen from organic material. The quick release of microbially immobilized nitrogen expedites quick return of nitrogen to the plant. Singh *et al.* (1989) hypothesized that in tropical savanna in India, nitrogen is immobilized in microbial biomass during unfavourable summer period and mineralized with the onset of favourable conditions during rainy season, thereby playing an important role in nitrogen cycling within the ecosystem. McGill *et al.* (1974) noted that the amount of nitrogen contained in microbial biomass is comparatively very less than that present in soil organic matter in Saskatchewan grassland. They further reported that under favourable conditions the turnover rates of nitrogen in soil microorganisms was much faster than the nitrogen locked-up in detrital substances.

Phosphorus is second only to nitrogen in limiting primary productivity in grasslands. Phosphorus has no gaseous phases and tends to exist in nearly constant amounts in any given ecosystem over a period of years. Due to insignificant inflows and outflows, phosphorus cycle is closed (Odum 1969). Phosphorus cycling studies in grassland ecosystems are based mainly on two assumptions: i) normal inputs and outputs are very small, and 2) the pool of labile phosphorus is relatively large, which exists in rapid equilibrium with soil solution (Jones & Woodmansee 1979). The loss of phosphorous from the ecosystem can be replenished to a certain extent by weathering of primary minerals, such as apatite, in parent rock material (Lajtha & Schlesinger 1988), atmospheric deposition, fertilizers and supplemental feeds for domestic animals (Jones & Woodmansee

1979). However, the main supply of available phosphorus comes from the mineralization of soil organic matter, microbial and animal materials.

Losses of phosphorus by leaching and erosion are believed to be negligible. Ram & Ramakrishnan (1988c) estimated a loss of 1.7 to 2.2 Kg ha-1 Yr-1 through runoff and sediment losses and about 0.3 Kg ha-1 Yr-1 through percolation from Cherrapunji grasslands, which receive more than 10,000 mm rainfall within a year.

Cole *et al.* (1977) developed a simulation model of phosphorus cycle in semiarid grasslands. This model predicted plant and decomposer uptakes and turnover rates of the principal phosphorus compartments. In these grasslands, rates of decomposer uptake were 4-5 times greater than plant uptake.

Annual uptake of phosphorus by plants in an annual grassland at SJER, California, was estimated to be 14.5 Kg ha-1 (Jones & Woodmansee 1979). At MAB research sites in India, it ranged from 4.9 Kg ha-1 Yr-1 in semiarid grasslands to 49.6 Kg ha-1 Yr-1 in dry subhumid grasslands (Lamotte & Bourlière 1983). Major portion of phosphorus uptake was associated with the aboveground net production in subhumid and humid sites. Conversely, in semiarid grasslands, 65 % of the phosphorus uptake was directed to the belowground net production. In all the ecoclimatic zones of the country, the rate of uptake is highest during rainy season. Recent studies by Billore & Mall (1985) gave still higher values (42 to 77 Kg ha-1 Yr-1) of phosphorus uptake in the grassland at Ujjain. In a Himalayan grassland at Champhi (Chaturvedi *et al.* 1988), phosphorus uptake was 2.9 Kg ha-1 Yr-1 only.

The amount of phosphorus that returns from plants to soil varies from 3.2 Kg ha-1 Yr-1 to 30.3 Kg ha-1 Yr-1; the minimum value corresponds to the humid grassland and maximum value to the dry subhumid site in India (Lamotte & Bourlière 1983). The rate of release is greater during winter than monsoon. In humid tropics, free iron and aluminium hydroxides and sesquioxides tend to fix phosphorus in soil, rendering it immobile and often unavailable for plant uptake (Laverdiere 1982; Wood *et al.* 1984). Leaching of plant parts is another route by which phosphorus is returned to the soil. Broomfield & Jones (1972) found that 60 % to 83 % phosphorus in ground-up material was water soluble and mostly inorganic. They showed that continuous leaching equivalent to 24.4 cm of rain removed 90 % of phosphorus.

Information on potassium cycling through different vegetation components of grassland ecosystem is very much limited. Potassium differs from nitrogen and phosphorus principally in its mode of return. Decomposition of organic matter is not the major pathway of potassium release. It is rather freed by physical weathering processes collectively called leaching. Long *et al.* (1956) by using radioactive isotope demonstrated the presence of labelled compounds of potassium in leachates. As defined by Tukey (1970), leaching is the removal of substances from plants by the action of aqueous solutions associated with rain, dew, mist and fog.

Potassium exists is soil in available solution pool which is in equilibrium with exchangeable potassium adsorbed on colloidal particles. Plants absorb potassium from this pool predominantly through diffusion and mass flow of the potassium ion to the roots. The potassium is then absorbed actively and translocated to new growth. The potassium content of grasses may be close to the nitrogen content. Also, it is highly dependent on growth stage, for example, at pre-bloom stage, herbage potassium content varied from 1 to 4 % which declined sharply at full bloom stage (Clark *et al.* 1980). de Wit *et al.* (1963) suggested that 1% was the critical lower level for potassium at the vegetative stage of growth. Stewart & McConagher (1963) observed that the potassium content of ryegrass increased with increasing soil activity. Potassium uptake by forages ranges from 10 to 50 Kg ha-1 Yr-1 (Wagner & Jones 1968). On the MAB research sites in India, the potassium uptake ranged from 86 to 180 Kg ha-1 Yr-1 (Lamotte & Bourliere 1983). In the grassland community at Ratlam, potassium uptake (18 Kg ha-1 Yr-1) was much lower than the values reported earlier by Billore & Mall (1976). At other places like Ujjain, it ranged from 48 to 100 Kg ha-1 Yr-1 (Billore & Mall 1985). In a Himalayan grassland at Champhi, it was found to be about 24 Kg ha-1 Yr-1 (Chaturvedi *et al.* 1988). The return of potassium through litter and decay of belowground detritus was only one-third of the total uptake in semiarid grassland communities at Ratlam (Billore & Mall 1976) and Ujjain (Billore & Mall 1985) whereas it was about 40 % of the total uptake in a Himalayan grassland at Champhi (Chaturvedi *et al.* 1988). The turnover rate of potassium in semiarid grassland ranged between 44 and 52 % under varying grazing intensities (Billore & Mall 1985).

Every plant species has conceivable combination of adaptations to expedite its suitability for livelihood in a matrix of certain environmental and edaphic conditions. Allocation of reserves to root growth at the expense of shoot growth at low nutrient availabilities is well documented phenomenon (Chapin 1980). If nutrient supply from soil is insufficient for growth, nutrients that support continued growth of meristems and young leaves come from older leaves (Williams 1955). Upto 90 % of maximum leaf nitrogen and phosphorus, and 70% of potassium, are translocated out of senescing leaves before abscission (Williams 1948; Brady 1973). Root absorption capacity is usually higher in rapidly growing species from fertile habitats than in plants from infertile habitats under all growth conditions (Christie & Moorby 1975; Grundon 1972; Harrison & Helliwell 1979) or only at moderate and high nutrient availabilities (Blair & Cordero 1978). Plants from infertile habitat maximize nutrient intake through a high root:shoot ratio and mycorrhizal associations rather than through a high root absorption capacity (Nye 1977; Nye & Tinker 1977). A high efficiency of nutrient use could be an important adaptation to nutrient stress (Grundon 1972; White 1972, 1973).

Tissue nutrient concentrations of wild plants depend upon inherent growth rate, growth response to nutrient availability and environmental heterogeneity (Chapin 1980). Infertile habitats, which can support only a slow growth rate, are dominated by perennial rather than by annual species (Grime & Hunt 1975). On the basis of physiological characteristics that recur repeatedly in phylogenetically unrelated species, Grime

(1977, 1979) provided evidence for the existence of three primary plant strategies in plants: a) stress tolerant species that grow in unfavourable environments, b) competitive species, and c) ruderal species that occupy habitats which are favourable but exposed to disturbances. He further emphasized that knowledge of the combinations of characteristics that allow effective exploitation of environments of differing fertility is essential to the understanding of the ecological and evolutionary patterns in natural communities. Such information is, however, very much limited in case of grassland species, particularly in Indian grasslands which occupy degraded land in different ecoclimatic regions of the country.

From the account presented above, it is clearly evident that the study of nutrient cycling in the grassland ecosystem of the tropics is very much limited compared to their temperate counterparts. The studies which have been conducted under IBP and MAB programmes in India are particularly confined to the arid, semiarid and subhumid regions of the country and most of these deal mainly with the accumulation and internal cycling of two major elements, i.e., nitrogen and phosphorus. The humid grasslands growing under varying ecoclimatic conditions in north-east India where moist deciduous and dense evergreen forest constitute the natural vegetation are markedly different in many respects from their counterparts in other parts of the country. In fact complex interactions between human activities, climate and topography which influence the structure and functioning & development of humid grasslands in Meghalaya are not clearly understood.

Chapter 3

Study Sites

Chapter 3

STUDY SITES

GEOGRAPHICAL LOCATION

The study was conducted at Burnihat, Cherrapunji and Upper Shillong in East Khasi Hills district of the Meghalaya state of India (Fig. 3.1, Table 3.1). Burnihat is situated 90 Km north of Shillong, the capital of Meghalaya, whereas Cherrapunji and Upper Shillong are 55 and 14 Km south-west of Shillong, respectively. At all the three stations an area of 2-3 hectares was fenced in November 1987 and monthly sampling was started in August 1988. At Upper Shillong, study was also carried out in an unprotected plot adjacent to the fenced one, which was exposed to cattle grazing and annual burning of the vegetation during winter (February). Thus there were four study sites at three stations: Burnihat (BUR), Cherrapunji (CHR), and protected (USP) and unprotected (USU) stands at Upper Shillong. The sampling was done during 1988-89.

Table 3.1. Geographical location of the study sites.

Site	Latitude	Longitude	Altitude
Burnihat	26°03′ N	91°50′ E	100 m
Cherrapunji	25°04′ N	91°42′ E	1300 m
Upper Shillong	25°34′ N	91°50′ E	1900 m

CLIMATE

The climate of Meghalaya ranges from tropical at

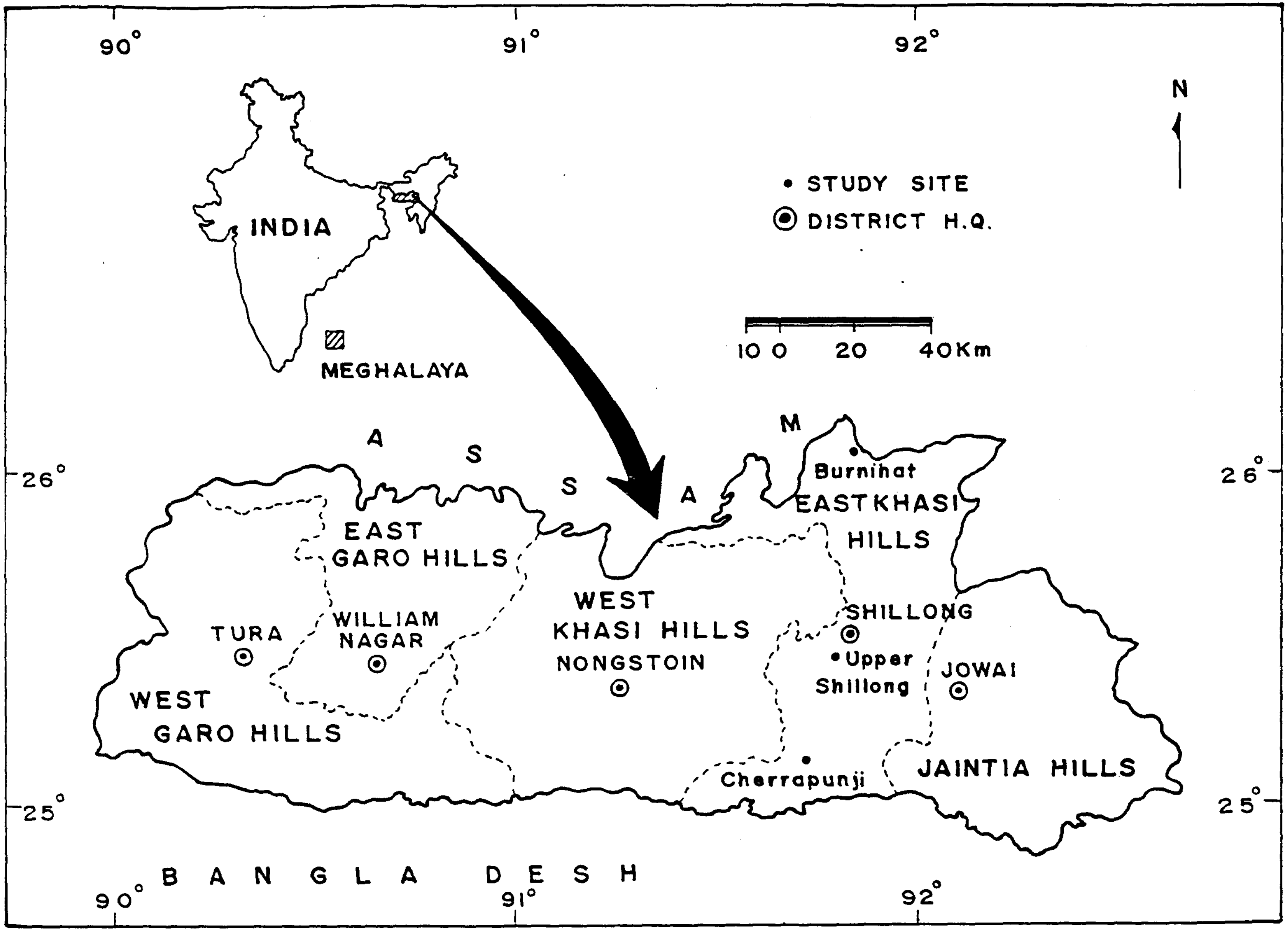


Fig. 3.1 Map showing geographical location of the study sites.

A close view of the grassland community at Burnihat

Growth of *Axonopus compressus* in the grassland community at Burnihat

An overview of the grassland community at Cherrapunji

Growth of *Arundinella khaseana* in the grassland community at Cherrapunji

Highly stony coarse-textured soil supporting grass growth at Cherrapunji

Arundinella khaseana seedlings growing on rock surface at Cherrapunji

Protected grassland community at Upper Shillong

Unprotected grassland community at Upper Shillong lower altitude to subtropical at higher altitude. The climate of Burnihat is tropical, whereas Cherrapunji and Upper Shillong are characterised by subtropical climate. The rainy season (mid-May to mid-October) is quite prolonged, winter (November to February) is severe and relatively dry and spring (March to mid-May) is bright and warmer than winter season. Climatic diagrams of the study sites are shown in Fig. 3.2 and climatic analogues are given in Table 3.2.

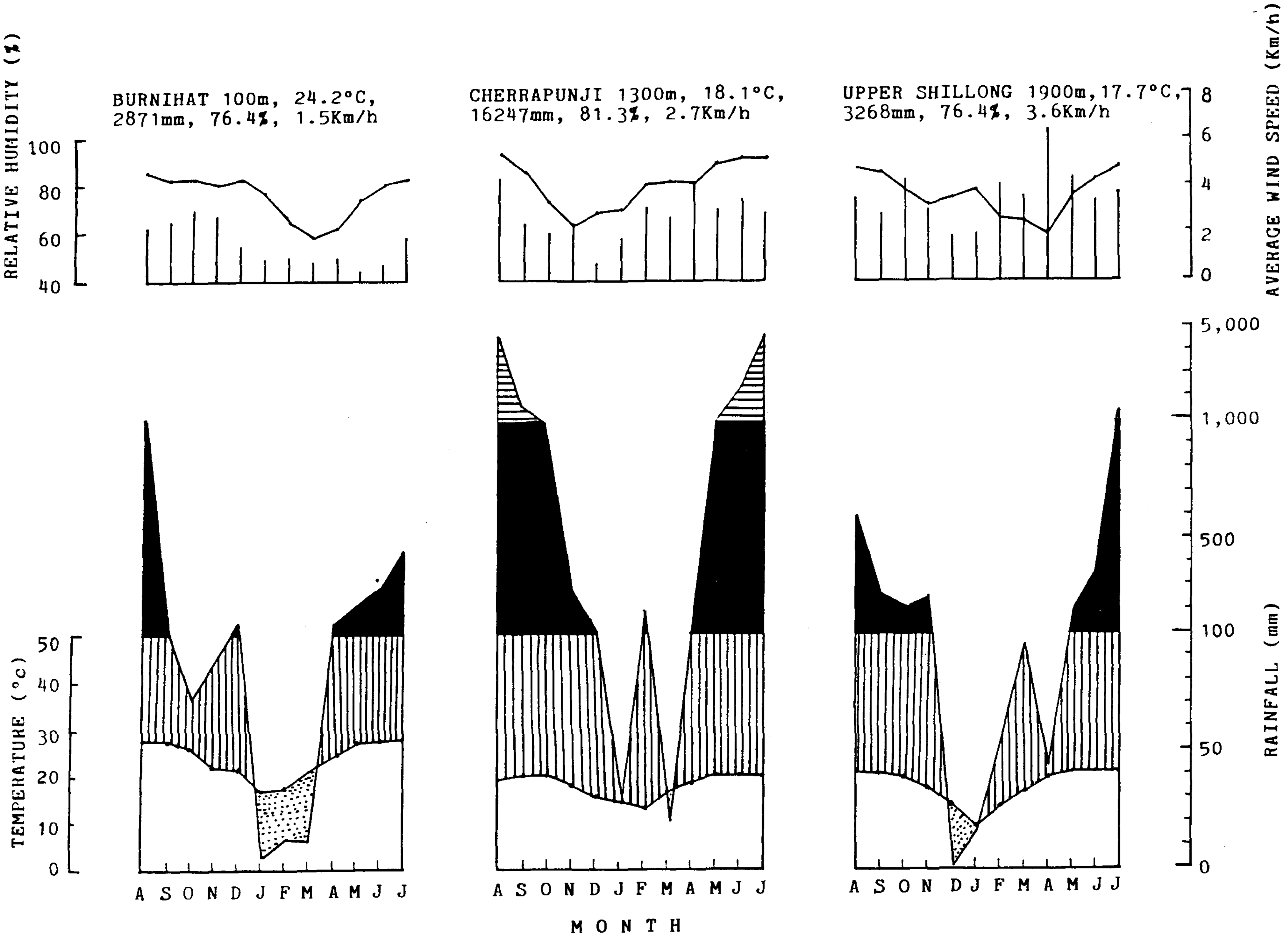
Table 3.2. Climatic analogues for the study sites.

Climatic analogue	Burnihat	Cherrapunji	Upper Shillong	Reference
Climate	Tropical	Subtropical	Subtropical	Hargreaves (1971)
Thermal regime	Megathermal	Mesothermal	Mesothermal	Subrahmanyam & Kumar (1977)
Moisture regime	Humid	Perhumid	Perhumid	------ do ------
Vegetation related to climate	Deciduous forest	(Broadleaf, evergreen forests)		Champion & Seth (1968)

Rainfall

The total annual rainfall and its seasonal distribution are the two measures of great ecological significance which influence the vegetation of the tropics. The study sites receive more than 200 cm rainfall in a year. Cherrapunji, the world's wettest spot receives an average total annual rainfall of 12,500 mm. The annual rainfall received here during the study period (August 1988-July 1989) was, however, 16,247 mm. It was 2,871 mm at Burnihat and 3,268 mm at Upper Shillong. Of the total annual precipitation, about 80 per cent or even more occurred during

Fig. 3.2 *Climatic diagrams of the study sites. The monthly mean temperature (thin line) and precipitation (thick line) are shown as curves. Precipitation up to 100 m has been scaled such that 10 degrees centigrade of temperature correspond to a precipitation of 20 mm. The dotted area reveals the period when precipitation goes below the temperature curve and the vertically hatched area shows the period when precipitation exceeds temperature. Precipitation above 100 mm is printed in the scale of 1:10 (black area) and above 1000 mm is printed in the scale of 1:100 (horizontally hatched area). In figures at top, bars stand for average wind speed and curve for relative humidity. The values displayed are altitude (m), mean annual temperature (°C), total annual rainfall (mm), mean relative humidity (%) and average wind speed (km h^{-1}).*


BURNIHAT 100m, 24.2°C,
2871mm, 76.4%, 1.5Km/h
CHERRAPUNJI 1300m, 18.1°C,
16247mm, 81.3%, 2.7Km/h
UPPER SHILLONG 1900m, 17.7°C,
3268mm, 76.4%, 3.6Km/h
RELATIVE HUMIDITY (%)
100
80
60
40
AVERAGE WIND SPEED (Km/h)
8
6
4
2
0
TEMPERATURE (°c)
50
40
30
20
10
0
RAINFALL (mm)
5,000
1,000
500
100
50
0
A S O N D J F M A M J J
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A S O N D J F M A M J J
MONTH

rainy season at all the sites and rest was received mostly during the summer season. Winter season experienced occasional showers and was relatively dry.

According to Wringley (1981), for each 100 m increase in altitude, rainfall generally increases approximately 333 mm which may even be greater in places like Assam where as much as 833 mm increase per 100 m is recorded. Even though the sites under present investigation are situated in Assam (*sensu* Wringley), the site at mid altitude receives highest rainfall (Fig. 3.3). This variation is due to the fact that the sites are situated in the tropics where the increase in precipitation with elevation stops at *ca.* 1000-1500 m and above this elevation rainfall generally decreases with height due to large difference in water vapour content between the lower and upper layers of the troposphere and the predominance of vertical air movements (Nieuwolt 1977).

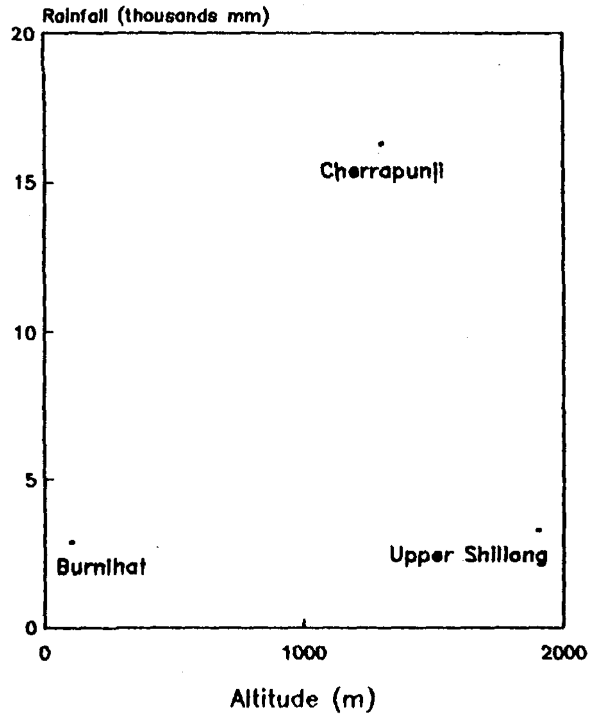


Fig. 3.3. Relationship between altitude and rainfall over the study sites.

Temperature

Temperature always goes down with altitude but the rate of decrease and the lapse rate are far from uniform (Lautensach & Bögel 1956) and vary with cloudiness, seasons, between day and

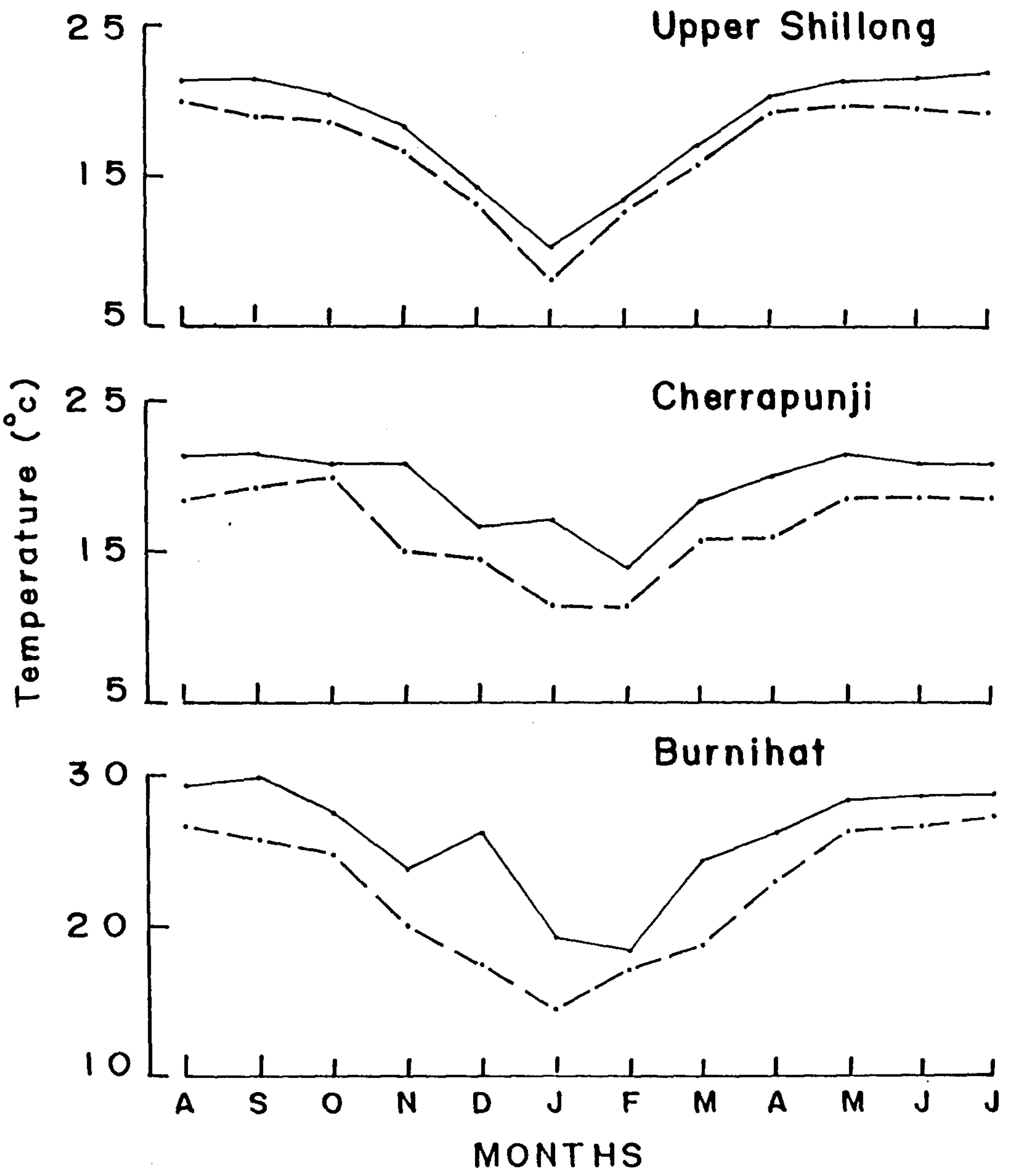


Fig. 3.4 Monthly variation in minimum (dashed line) and maximum (continuous line) temperatures at the three study sites.

night and also depend on prevailing topography. The difference in mean monthly maximum and minimum temperatures was comparatively greater during winter period at Burnihat than at Cherrapunji but it was not remarkable at Upper Shillong (Fig. 3.4). At Cherrapunji the seasonal uniformity of the temperature was high and, conversely, at Burnihat it was the least. During winter, the temperature sharply declines at Upper Shillong and reaches as low as 2.8°C or even below.

Relative humidity

At all the three sites, relative humidity was maximum during rainy season and minimum during April-May except at Cherrapunji where the values were greater during spring due to appreciable amount of rainfall together with low temperature and high cloudiness during the period (Fig. 3.2).

Cloudiness and wind speed

Meghalaya experiences a great variety of cloud types which are of varying stratiform and distribution pattern. Though there is no quantitative measure of cloudiness, it is certainly higher over Meghalaya compared to other parts of the country. During rainy season (July) cloudiness is more than 75 per cent and during winter (January) it is about 25 per cent (Landsberg 1945; Nieuwolt 1977).

The average wind speed is related to the altitude and it is generally higher during February to May months (Fig. 3.2).

GEOLOGY

The Shillong plateau which reaches upto 2,000 m above the alluvial plain of Brahmaputra valley is a detached remnant of the Indian shield and projects far toward the eastern Himalayan syntaxis (Gnasser 1964). The hard crystalline rocks represent the mass of archaean gneisses, schists and granites. The gneisses are finally banded, grey to pinkish in colour and contain microcline, biotite, subordinate quartz with or without sillimanite and plagioclase. The intrusive granites are mostly porphyritic with large flesh-coloured microclines and biotite. The granites also intrude the Shillong schists but are less frequent in the Shillong quartzites (Gnasser 1964). The clay minerals frequent on the study sites are being shown in Table 3.3.

Table 3.3. Distribution of clay minerals over the study sites.

Site	Mineral	Reference
Burnihat	Kaolinite, Mica, Chlorite	Munna Ram *et al.*(1979)
Cherrapunji	Illite (D), Kaolinite	Mukherjee *et al.*(1971)
Upper Shillong	Mica, Kaolinite, Chlorite	Munna Ram *et al.*(1979)

SOIL

In general, soils of Meghalaya are derived *in situ* from the underlying gneisses, schists and granite rocks of archaean age (Gnasser 1964) and may be grouped under laterite (oxisol) type (Pascoe 1950).

Soil colour

The colour varies widely from reddish at higher elevations to blackish at low lying areas where incoming colloidal materials from the high altitude areas are deposited and become black under impeded drainage conditions due to hydration of iron compounds in the soil. The Munsell soil colour notation for the soils of study sites given in Table 3.4 indicates that colour ranges from yellowish red to brown.

Table 3.4. Munsell colour notation for three soil layers of the study sites.

Depth (cm)	Munsell notation	Colour
	Burnihat	
0-10	10YR 5/3	Brown
10-20	10YR 4/3	Dark brown
20-30	10YR 5/3	Brown
	Cherrapunji	
0-10	10YR 4/2	Dark greyish brown
10-20	10YR 4/4	Dark yellowish brown
20-30	7.5YR 5/6	Stony brown
	Upper Shillong (protected)	
0-10	10YR 4/3	Dark brown
10-20	10YR 4/3	Dark brown
20-30	10YR 4/4	Dark yellowish brown
	Upper Shillong (unprotected)	
0-10	5YR 4/6	Yellowish red
10-20	5YR 5/6	Yellowish red
20-30	5YR 5/6	Yellowish red

Texture

Texture of the soils at four study sites is markedly different (Fig. 3.5) and ranges from stony loamy sand to sandy clayey loam (Table 3.5). The proportion of clay generally increases with depth. The soil at Cherrapunji is very thin and

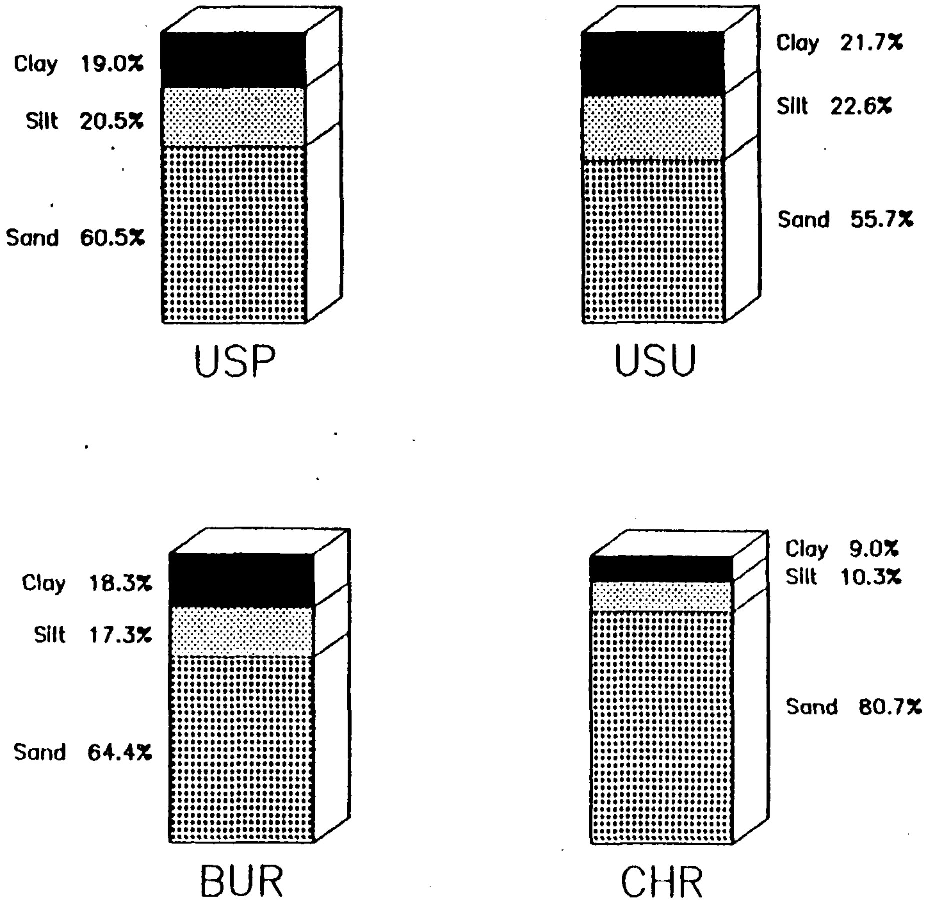


Fig. 3.5 Per cent distribution of sand, silt and clay in soil (0-30 cm) at Burnihat (BUR), Cherrapunji (CHR), and in protected (USP) and unprotected (USU) stands at Upper Shillong.

highly stony; this condition being attributable to exceptionally high rainfall and lack of protective vegetal cover. Soils of protected and unprotected stands at Upper shillong exhibit sandy loam and sandy clayey loam texture, respectively whereas the soil of Burnihat is sandy loam.

Table 3.5. Particle fractionation and texture class for three soil layers of the study sites.

	% of total		% of <2 mm fraction			
Depth (cm)	Stone (>5mm)	Gravel (5-2mm)	Sand (2-.02mm)	Silt (.02-.002mm)	Clay (<.002mm)	Texture class
			Burnihat			
0-10	...	0.6	63.0	19.8	17.2	SL
10-20	...	0.5	68.0	15.2	16.8	SL
20-30	...	0.1	62.2	16.8	21.0	SCL
Mean	...	**0.4**	**64.4**	**17.3**	**18.3**	**SL**
			Cherrapunji			
0-10	58.6	16.5	80.6	11.6	7.8	SLS
10-20	41.7	33.4	78.8	10.8	10.4	SLS
20-30	43.7	34.3	82.6	8.6	8.8	SLS
Mean	**48.0**	**28.1**	**80.7**	**10.3**	**9.0**	**SLS**
			Upper Shillong (protected)			
0-10	...	2.0	64.2	21.0	14.8	SL
10-20	...	2.0	57.6	21.6	20.8	SCL
20-30	...	2.6	59.6	19.0	21.4	SCL
Mean	...	**2.2**	**60.5**	**20.5**	**19.0**	**SL**
			Upper Shillong (unprotected)			
0-10	...	2.4	63.0	19.8	17.2	SL
10-20	...	2.0	53.6	24.6	21.8	SCL
20-30	...	3.0	50.6	23.4	26.0	SCL
Mean	...	**2.7**	**55.7**	**22.6**	**21.7**	**SCL**

SL= Sandy loam, **SCL**= Sandy clayey loam, **SLS**= Stony loamy sand

Bulk density

The bulk densities of the soils upto 16 cm depth are given in Table 3.6. The value is high at low altitude (Burnihat) and low at high altitude (Upper Shillong). The protected and unprotected stands at Upper Shillong did not show any appreciable difference in bulk density.

Table 3.6. Bulk density of soil (0-16 cm) of the study sites.

Site	Bulk density (g/cm^3)
Burnihat	1.42 ± 0.03
Cherrapunji	1.34 ± 0.04
Upper Shillong:	
protected	1.12 ± 0.04
unprotected	1.13 ± 0.07

Soil temperature

Soil temperature measured at each sampling date using soil thermometer is shown in Fig. 3.6. It showed strong significant variations due to month, site, depth and their

Table 3.7. Results of analysis of variance (fixed effects model) to test the null hypothesis (Ho) for changes in various physicochemical properties of the soils of the study sites among months, sites, depths and interactions thereof.

Source of variation	Degrees of freedom	Temperature	Moisture	pH	TEB	Organic matter
Month	12	1743.18**	61.79**	336.57**	27.06**	2011.58**
Site	3	2858.49**	782.18**	2524.60**	7009.90**	22730.54**
Depth	2	343.97**	9.08**	603.88**	561.60**	36235.46**
Month x Site	36	116.92**	11.15**	84.50**	11.08**	982.11**
Month x Depth	24	1.85*	3.67**	9.07**	1.15	152.28**
Site x Depth	6	0.28	2.58*	146.28**	30.51**	161.95**
Month x Site x Depth	72		2.53**	19.03**		163.36**

** = Significant at p<0.001 and * = Significant at p<0.05 level

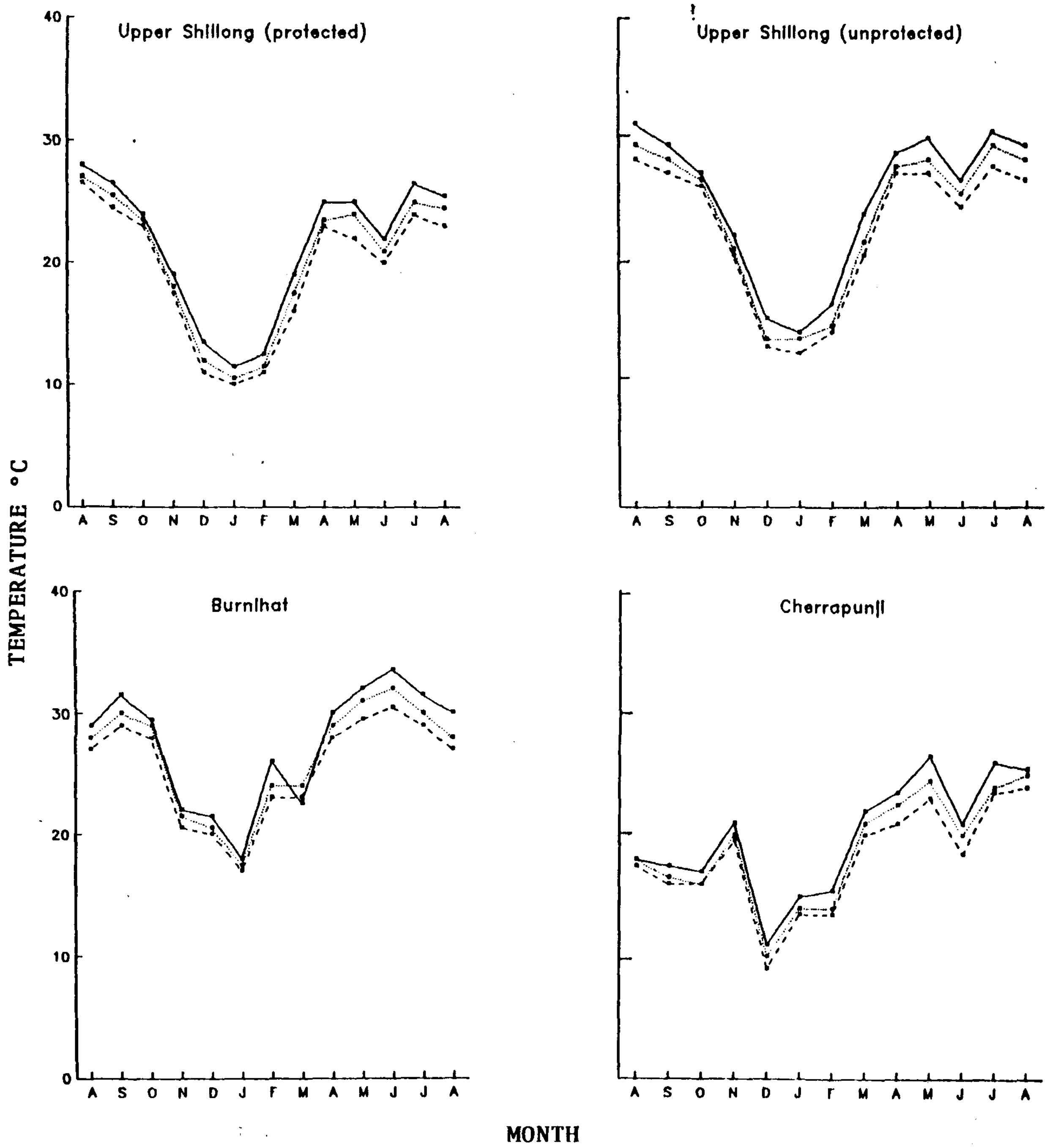


Fig. 3.6 Monthly variation in temperature (°C) in three soil layers in four grassland communities. Continuous line, 0-10 cm; dotted line, 10-20 cm; dashed line, 20-30 cm.

interactions (Table 3.7). Throughout the year, in general, soil temperature was high at Burnihat and low at Cherrapunji while it was in between at Upper Shillong. Soil temperature was always slightly higher in the unprotected stand than the protected one at Upper Shillong. It is interesting to note that the mid altitude site (Cherrapunji) generally showed low temperature if compared with the high altitude site (Upper Shillong) perhaps due to high relative humidity, rainfall and cloudiness. Seasonal trend reflects that the soil temperature at all the sites was low during winter period (December-January) and thereafter increased continuously upto May. With the onset of monsoon in June, soil temperature declined for a brief period and reached at its maximum in the later half of the rainy period.

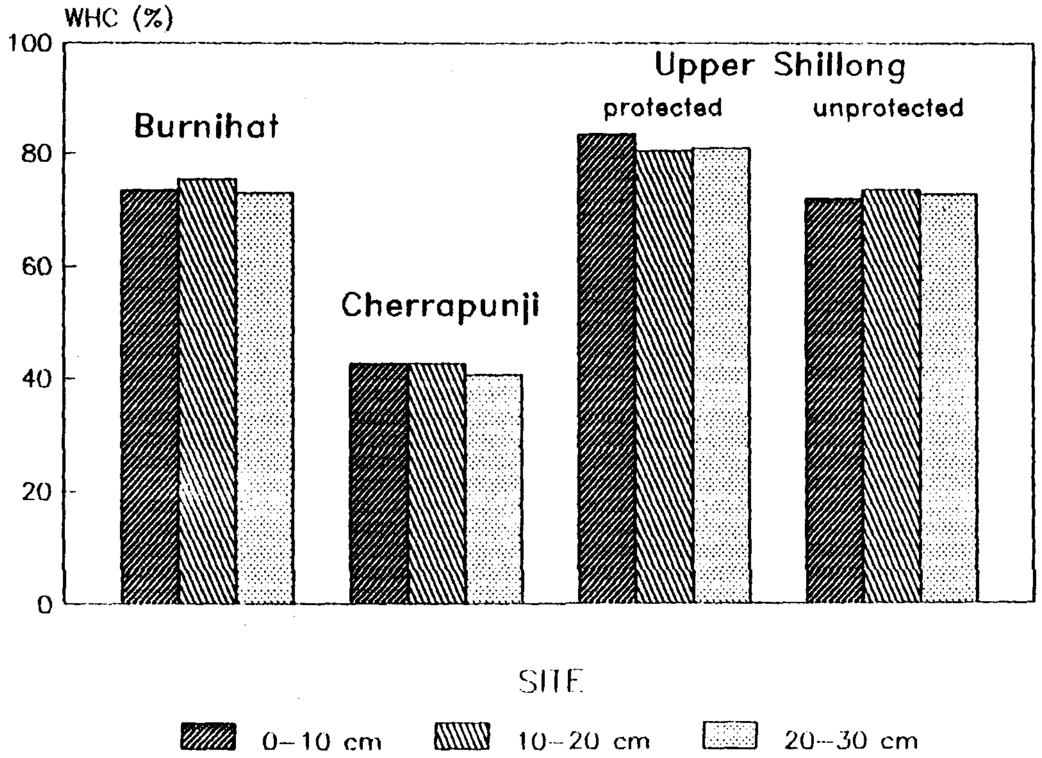


Fig. 3.7. Water holding capacity of three soil layers at the study sites.

Soil moisture

The water holding capacity was maximum at Upper Shillong (81.7 % in the protected and 72.8 % in the unprotected stand) and minimum at Cherrapunji (42 %) and it was 74 % at Burnihat. Depthwise variations were unapparent (Fig. 3.7).

Soil moisture quantified at each sampling date did not show any definite pattern either monthwise or depthwise (Fig. 3.8). However, variations due to month, site, depth and their interactions were statistically significant (Table 3.7).

The soil reaction (pH)

The soil at Cherrapunji is strongly acidic, whereas it is medium acidic at other sites. The unprotected stand at Upper Shillong is more acidic (mean pH 5.76) than the protected stand (mean pH 6.02). pH decreased with depth but showed minor increase at Cherrapunji. It showed a decrease in February and thereafter it increased upto the onset of monsoon (Fig. 3.9). Analysis of variance showed significant variations due to month, site, depth and interactions thereof (Table 3.7).

Cation exchange capacity (CEC)

Cation exchange capacity of soil decreased with depth at all the sites (Fig. 3.10). The decrease was more sharp between 0-10 and 10-20 cm depths at Upper Shillong. Similar trend was seen at lower depths at Burnihat and Cherrapunji. The CEC at the four sites showed the following pattern:

USP>BUR>USU>CHR

Total exchangeable bases (TEB)

Total exchangeable bases were maximum (4.02 meq 100g-1) at Burnihat and quite low at Cherrapunji (1.46 meq 100g-1). The

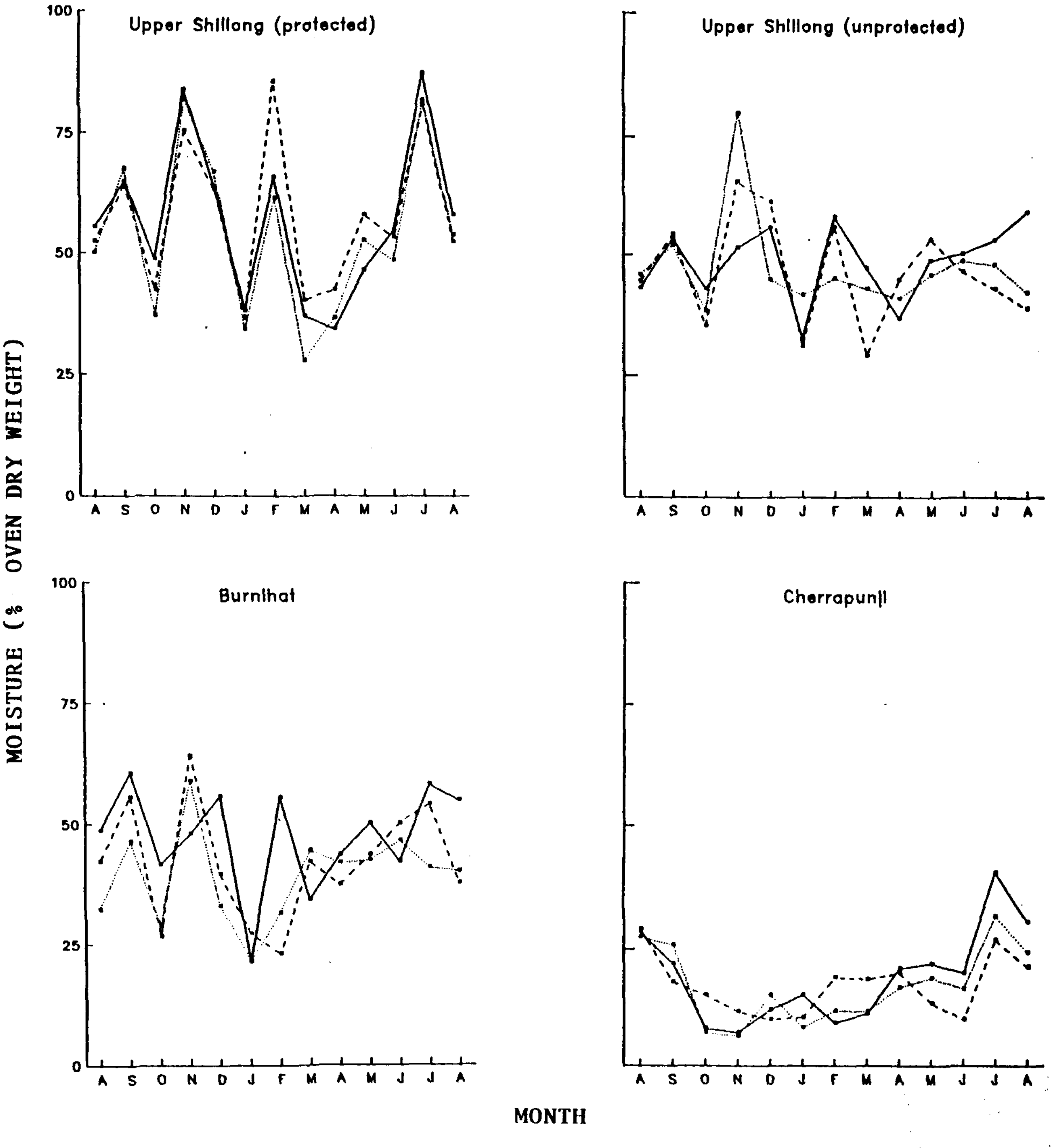


Fig. 3.8 *Monthly variation in soil moisture (% oven dry weight) in three soil layers in four grassland communities. Continuous line, 0-10 cm; dotted line, 10-20 cm; dashed line, 20-30 cm.*

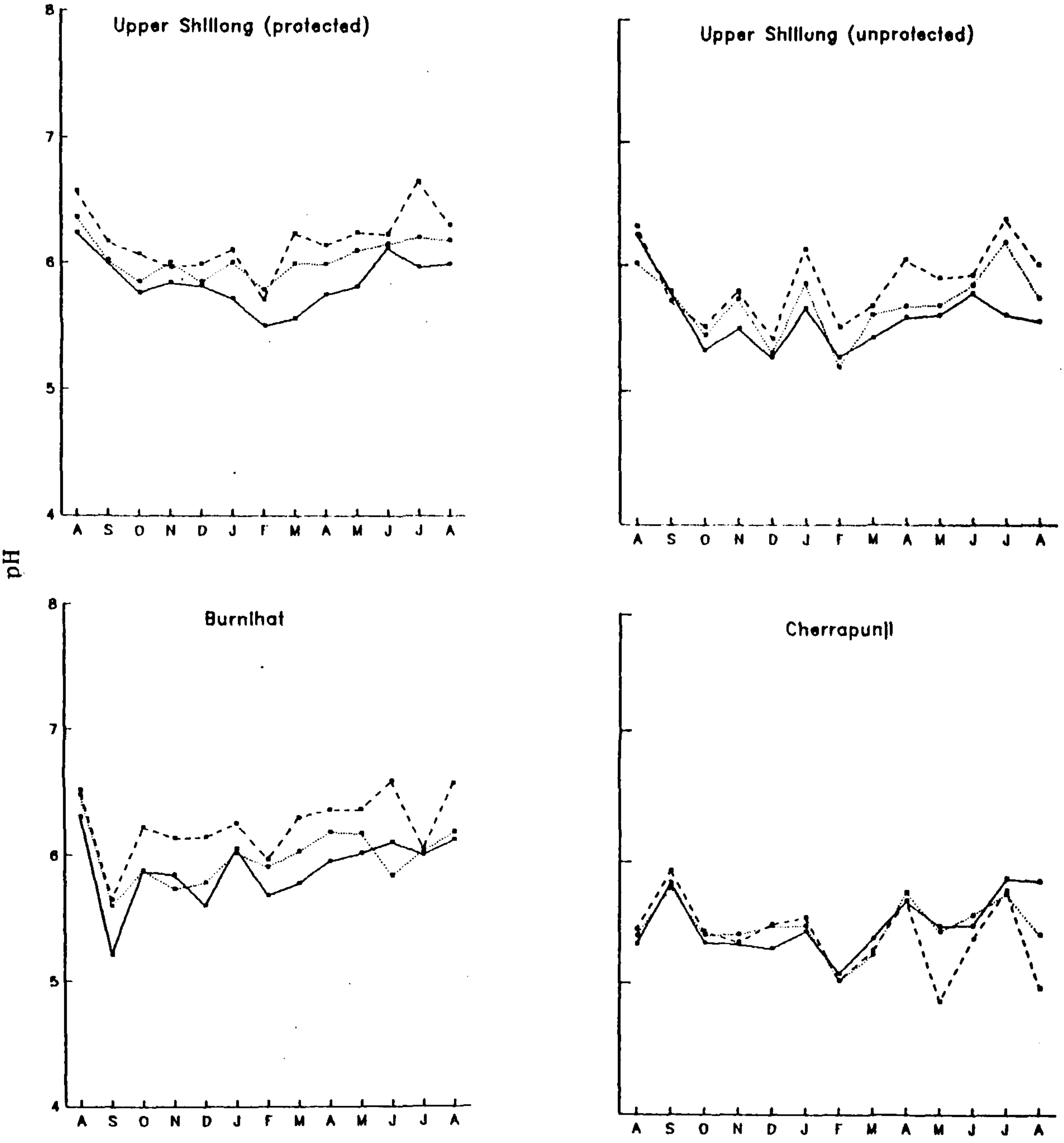


Fig. 3.9 Monthly variation in pH in three soil layers in four grassland communities. Continuous line, 0-10 cm; dotted line, 10-20 cm; dashed line, 20-30 cm.

value was higher for the protected stand (2.38 meq 100g-1) than the unprotected stand (1.41 meq 100g-1) at Upper Shillong. Seasonal variations are marked at all the sites (Fig. 3.11). The value was generally greater during the rainy months at all the sites. It bears a positive correlation with pH (R^2=0.389, p<0.01) according to the regression model:

$$\text{Log } Y = -4.79681 + 6.685242 \text{ Log } X$$

where, X is pH and Y is TEB (meq 100g-1).

Analysis of variance showed significant variations due to month, site, depth and interactions thereof (Table 3.7).

Base saturation

Base saturation, the proportion of the CEC occupied by TEB, is low at all the sites. The mean values were 35.9, 18.0,

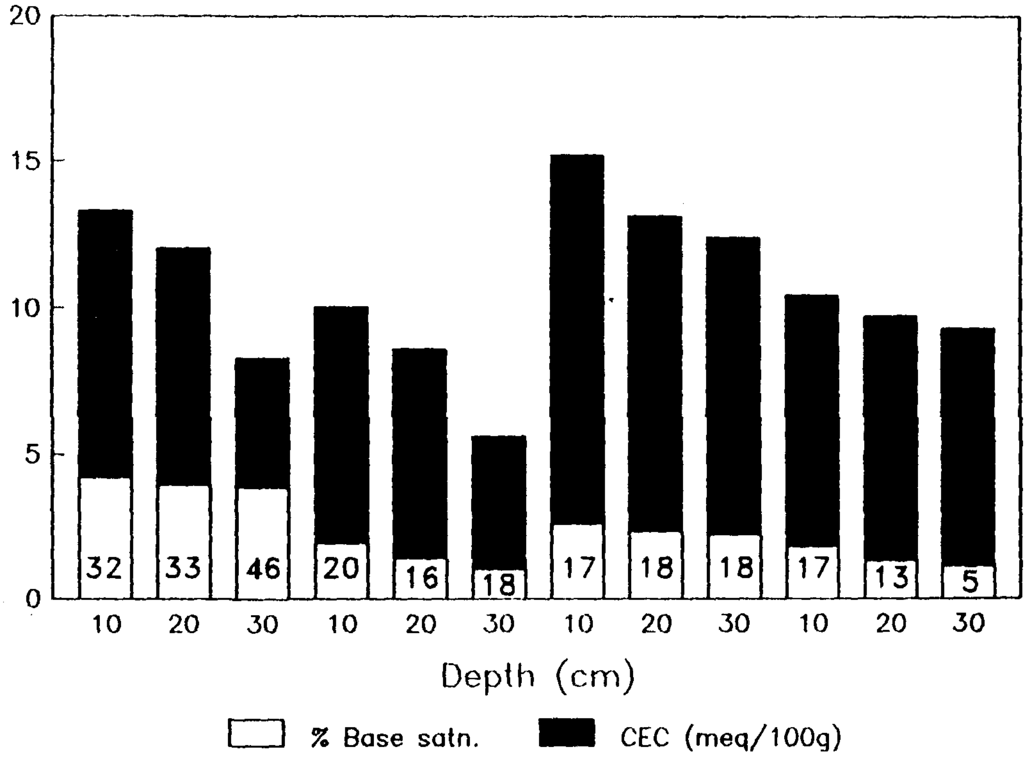


Fig. 3.10. Cation exchange capacity and base saturation in three soil layers of the study sites.

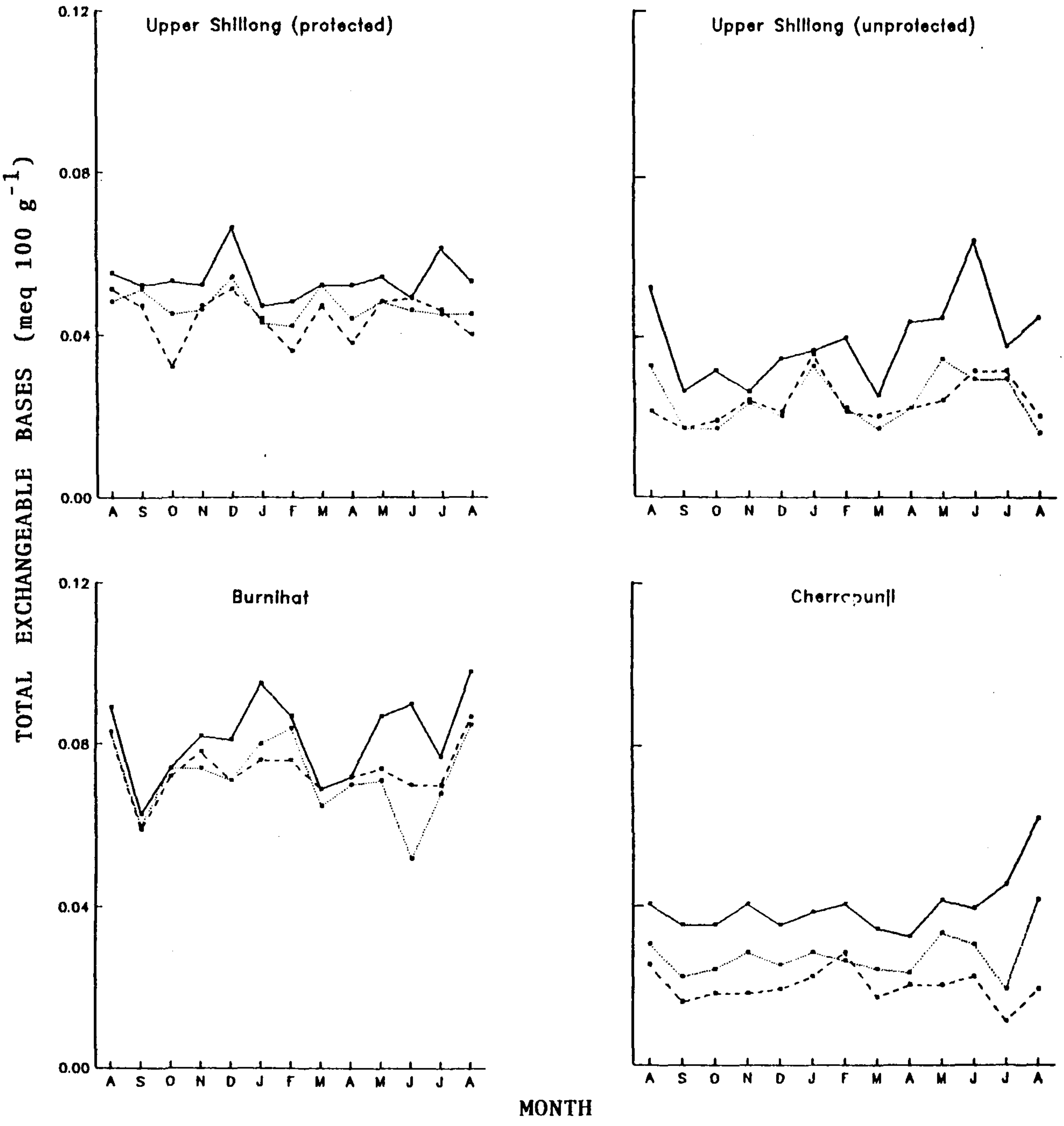


Fig. 3.11 Monthly variation in total exchangeable bases (meq 100g^{-1}) in three soil layers in four grassland communities. Continuous line, 0-10 cm; dotted line, 10-20 cm; dashed line, 20-30 cm.

17.6 and 14.4 % for Burnihat, Cherrapunji, and protected and unprotected stands at Upper Shillong, respectively. Depthwise variations in the base saturation are shown in Fig. 3.10. Among the sites, it is markedly high at Burnihat in comparison to the other sites.

Organic matter

Soil organic matter measured in terms of organic carbon was 1.72, 2.53, 3.50 and 2.90 % at Burnihat, Cherrapunji, and in protected and unprotected stands at Upper shillong. It declined with depth at all the sites (Fig. 3.12) and showed a positive relationship ($R^2=0.89$, $p<0.05$) with elevation according to the regression:

$$Y = 1.5811 + 0.00084 X$$

where, X is altitude (m) and Y is organic matter (%).

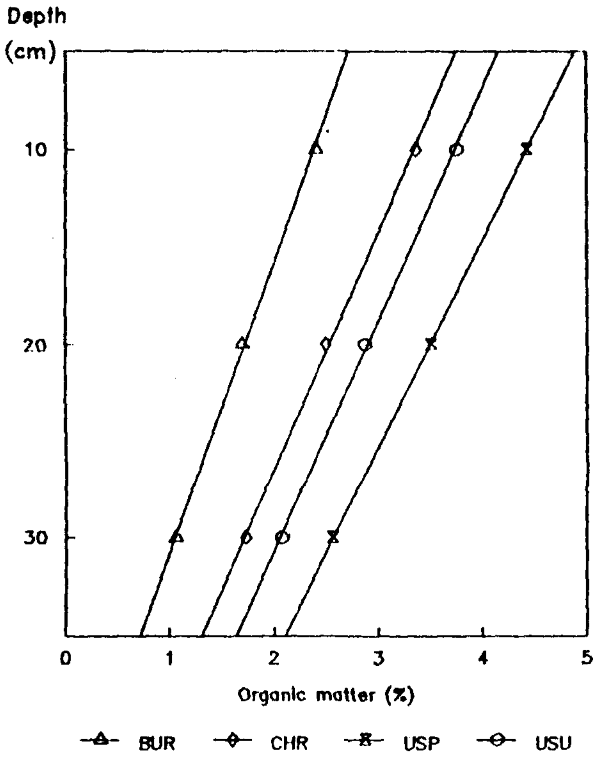


Fig. 3.12. Decrease in OM through depth.

Data presented in Fig. 3.13 showed wide variations due to month, site, depth and their interactions (Table 3.7).

VEGETATION

Natural vegetation

The natural vegetation of Meghalaya ranges from tropical deciduous to subtropical broadleaved wet hill forests (Champion & Seth 1968). The moist deciduous forests occurring at

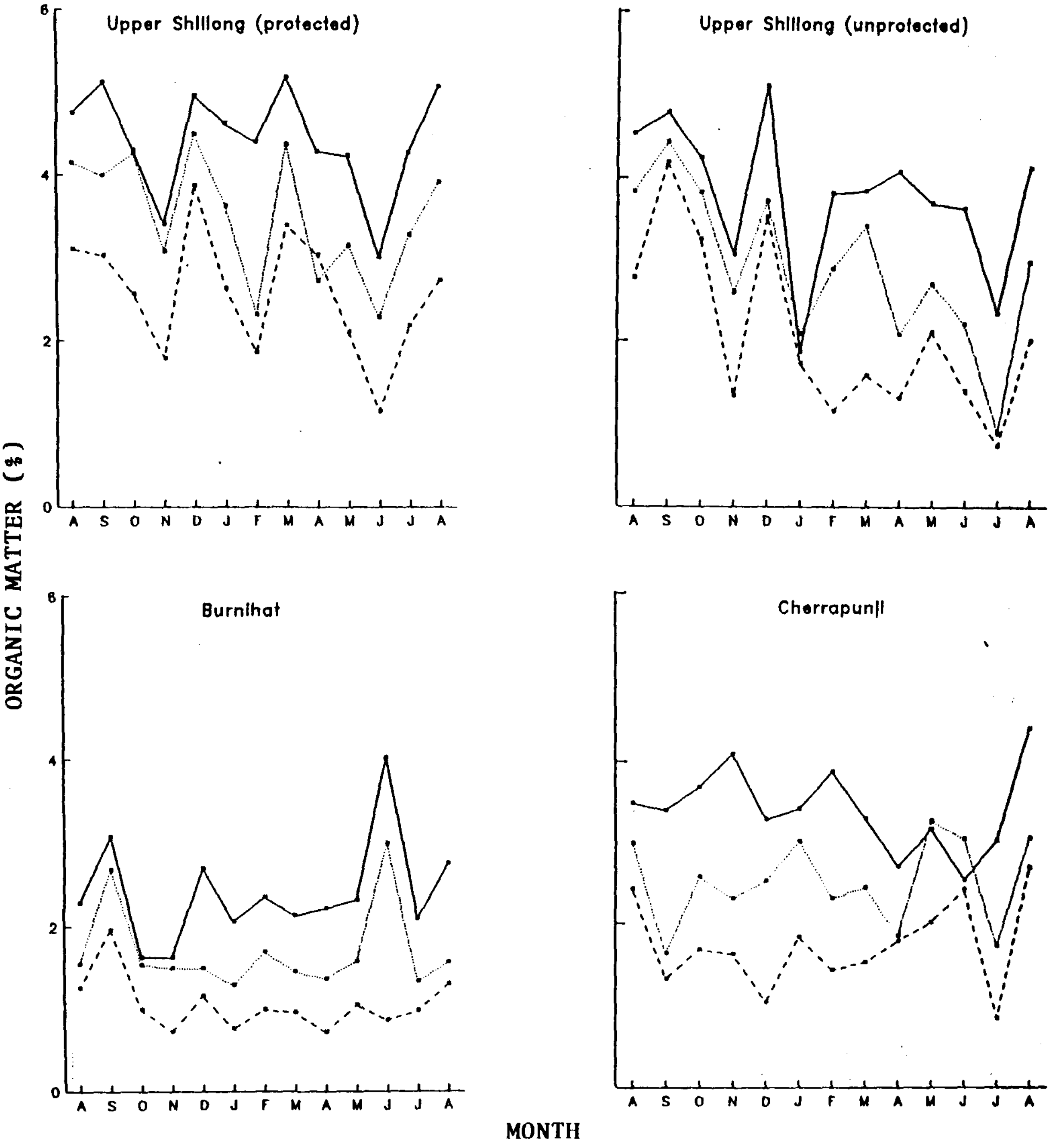


Fig. 3.13 Monthly variation in organic matter (%) in three soil layers in four grassland communities. Continuous line, 0-10 cm; dotted line, 10-20 cm; dashed line, 20-30 cm.

lower elevation in Khasi foot hills of Meghalaya have been termed as very moist sal bearing forests by Champion and Seth (1968). The dominant associates of sal (*Shorea robusta*) are *Schima wallichii*, *Adina cordifolia*, *Gmelina arborea*, *Dillenia pentagyna*, *Vitex pendacularis*, *Terminalia bellerica*, *Lagerstroemia parviflora*, *Artocarpus chaplasha*, *Premna* spp., *Amoora spectabilis*, *Michelia champaca* and *Dendrocalamus hamiltonii*. The common shrubs include *Litsea khasiana*, *Randia densiflora*, *Sterculia coccinea*, *Mesua ferrea*, *Alophylus serratus*, *Combretum decandrum* and *Anoma wallichii*. The ground flora consists of *Microstegium ciliatum*, *Imperata cylindrica*, *Eupatorium odoratum*, *Alpinia* spp., *Coffea* spp., *Carex* spp., *Axonopus compressus* and *Eragrostis uniloides*. Climbers are scarce and include *Butea parviflora* and *Vitis palmata*.

Cherrapunji is characterised by highly desertified landscape. However, there are two small patches of relict forests (Khiewtam 1986) which represent the broadleaved evergreen rain-forest type vegetation of earlier days. Of these two relict forest patches, one is a <u>sacred grove</u> of 6 square Km area protected by the local people for ceremonial purposes and the other is a <u>reserve forest</u> of about 4 square Km area protected by the village council. Sacred grove is believed to be the climax vegetation of the area but the reserve forest represents the sub-climax stage (Boojh and Ramakrishnan 1983). Besides, small patches of degraded forests of about 20 to 200 square meter area are also frequently found in the dykes of hillocks where soil thickness is relatively more and the microenvironment is favourable for tree growth. The important tree and shrub elements of Cherrapunji forest are: *Ligustrum robustrum*, *Castanopsis* spp., *Randia* spp., *Eleocarpus lanceaefolius*, *Engelhardtia spicata*, *Syzygium cumunii*, *Clerorodendron nutans*, *Drimycarpus dosycarpus*, *Phlogocanthus* spp., *Camellia caudata*, *Eurya acuminita*, *Lithocarpus dealbata*, *Quercus dealbata*, *Q. spicata* and *Viburnum sinensis*. The forest ground flora is composed of species like *Symplocos glomerata*, *Adiantum* spp., *Ariseama echinatum*, *Boehmeria platyphylla*, *Phlogocanthus* spp., *Thelypteris* spp., *Pteris* spp., *Carex baccans*, *Osbeckia capitata*, *Arundinella khaseana* and *Fimbristylis* spp. Orchids, climbers and mosses are frequent in the forest.

The climax vegetation of Upper Shillong is also a broadleaved evergreen forest but subtropical pine (*Pinus kesiya*) forest and grasslands are also found in the area (Pradhan 1981). The floristic composition of undisturbed broadleaved evergreen forest at Mawphlang, about 15 Km southwest of Upper Shillong at an elevation of 1900 m, has been described in detail (Hajra 1975; Khan 1986; Rao *et al*. 1990). It is an excellent example of repository of biological diversity. The tree layer of this forest is made up of *Quercus dealbata*, *Q. griffithii*, *Q. glauca*, *Schima khasiana*, *Myrica esculenta*, *Eurya japonica*, *Manglietia insignis*, *Rhododendron arboreum*, *Myrsine semierrata*, *Lindera pulcherrima*, *Prunus undulata*, *Pyrus* spp. etc. Shrub species include *Daphne shillong*, *Litsea elongata*, *Cinnamomum* spp., *Viburnum foetidum*, *V. sinensis*, *Ilex* spp. and *Symplocos chinensis*. The ground vegetation is mostly covered by *Arundinella* spp., *Osbeckia* spp., *Pteridium aquilinum*, *Smilax* spp., *Cyanotis vaga*, *Coffea khasiana*, *Brunella vulgaris*, *Commelina* spp., *Plantago major*, *Hypochaeris* *radicata* etc. Woody climbers, epiphytic orchids, ferns and mosses are abundantly found in the forest.

Degraded vegetation

Degradation is a relative term. It expresses the inferior status of an object always with reference to the other one of same kind and certainly superior to the previous one. The degree of degradation may be expressed as slightly-degraded, highly-degraded and/or extremely-degraded and so on. The term *degraded ecosystems* in the present study has been used strictly with reference to the climax vegetation of the concerned areas, In this context, the existing vegetation of Meghalaya is composed of plant communities representing various stages of degradation. Vast grassy areas in Meghalaya, particularly at Cherrapunji, dominated by grasses and herbaceous forbs are the representatives of the degraded ecosystem.

Major factors which seem responsible for the development of degraded ecosystems (grasslands) in Meghalaya are listed as under:

1) Tree cutting on a large scale for timber and fuel purposes.
2) Burning of slash and clearing of land for shifting cultivation and shortening of *jhum cycle*.
3) Mining activity for coal, limestone and sillimanite.
4) Exceptionally high rainfall of greater intensity causing the loss of top soil and depletion of nutrients from arable land and other exposed or sparsely vegetated areas.
5) Hilly terrain of the state which channelizes major part of rain water through overland flow and accelerates sediment loss.

6) Change in land use pattern related to developmental activities due to unprecedented rise in population within a framework of limited natural resources.

Burnihat grasslands have developed on *marginal lands* which according to Farnworth & Golley (1974) are areas not physically suitable for sustained agriculture or animal husbandry. The area of such land is not extensive.

The Cherrapunji grasslands, on the other hand, are extended over a vast area of land. Small isolated patches of degraded forests amidst the grassland imparts savanna like appearance to the landscape of Cherrapunji. These grasslands represent the extreme stage of land degradation and are more or less stable (Dabadghao & Shankarnarayan 1973). They have developed on acidic and highly impoverished shallow soil layer which cannot support the forest and are being maintained by regular grazing and burning of varying intensities.

The rolling grasslands at Upper Shillong are the consequences of human intervention in form of slash and burn agriculture. They are, at present, being maintained by annual sweeping fire and grazing by cattle.

Chapter 4

Methodology

Chapter 4

METHODOLOGY

SAMPLING TECHNIQUES

Community analysis

The phytosociological analysis of the community was done periodically at all the sites using appropriate number of randomly selected 50 x 50 cm quadrats. In each quadrat, number of individuals of all the species were counted. Each tiller was considered as an individual for grasses (Singh 1967). In case of creeping plants, any unit of plant having functional roots was considered as an individual (Singh 1969). Approximately 10-20 individuals of each species were measured for their basal diameter using a caliper. Species were identified in the herbaria of the Department of Botany, North-Eastern Hill University and Botanical Survey of India, Shillong. Plant species were grouped in different life-forms according to Raunkiaer (1934). The data thus collected were used to calculate density, basal cover (Misra 1968), importance value index (Curtis & McIntosh 1951), similarity index (Sørenson 1948), dominance index (Simpson 1949) and Shannon's index of general diversity (Margalef 1968).

Biomass measurement

Aboveground plant biomass was harvested by species at ground level using sharp scissors from randomly selected five 50 x 50 cm quadrats on each sampling date at all the sites. The coarse litter intermingled with the standing vegetation was carefully picked up before the harvest and gathered from the soil surface after the plant material had been sampled from the quadrats. For the estimation of the belowground biomass, an area of 10 x 10 cm was excavated from each of the harvested quadrats by 10 cm interval upto 30 cm depth.

All the above- and belowground samples were labelled and packed into polythene bags and brought to the laboratory. The aboveground herbage was sorted into live and dead shoots by species. The adhering soil particles from the litter samples were hand picked and , if required, the litter was washed through floatation method (Singh & Yadava 1974). The soil monoliths were transferred into buckets (5 l capacity) and filled with water to soak overnight. Next day, roots were washed with a fine jet of water over 2.0 and 0.5 mm screens, successively. Thereafter, the belowground mass collected over the sieve was transferred to a tray (46x32x7 cm) and filled approximately half with water. Both roots and rhizomes were sorted out into live (phytomass) and dead (necromass) components on the basis of pliability and degree of cohesion between cortex and periderm (Singh & Srivastava 1984). Dead roots were often dark in colour and wrinkled in contrast to the smooth and light coloured live roots. Separated samples were packed in newspaper sheets, labelled and dried in an oven at $60 \pm 5^{\circ}C$ to constant weight. The samples were grinded in a Wily mill and passed through 0.2 mm screen and stored in polythene bags for further analysis.

Soil sampling

For chemical analysis, soil samples were collected upto 30 cm depth by 10 cm intervals from the harvested quadrats. Three composite samples representing the three depths were made by pooling the five soil samples of respective depths. These pooled samples were often air-dried (but dried at 30-35^{o}C in an oven when sun was not frequently available) and passed through 2 mm mesh sieve and ground through 80 mesh screen. The finally screened soil samples were stored in polythene bags until analysis.

ANALYTICAL METHODS

Soil analysis

Colour of the air-dried soil samples was determined using Munsell soil Colour chart (Piper 1942).

Bulk density of soil cores taken *in situ* by using a soil corer (diameter 5.6 cm and length 16 cm) was determined according to Allen *et al.* (1974).

Water holding capacity measurement was carried in perforated circular copper cups with an internal diameter of 5.6 cm and a height of 1.6 cm (Piper 1942).

Texture was determined by hydrometer method (Kanwar & Chopra 1967) at the Soil Division, ICAR, Shillong.

Soil temperature was read at each sampling date on a soil thermometer by introducing it upto 10, 20 and 30 cm depths, respectively. The temperature was recorded at mid-day throughout the study period.

Soil moisture content was determined gravimetrically by taking a portion of fresh unsieved soil and the results were expressed on oven-dry weight basis (Allen *et al.* 1974).

Soil pH was determined electrometrically in the soil suspension (1:5 soil to water ratio) by a digital Systronics-335 pH meter.

Organic carbon was determined by rapid titration method (Walkley & Black 1934). Soil organic matter content was obtained by multiplying the organic carbon values with 1.724 based on the assumption that soil organic matter contains 58% of carbon (Allen *et al.* 1974).

Cation exchange capacity was determined by extracting the soil with M ammonium acetate (pH 7) followed by the displacement of NH_4^+-N with KCl and distillation with MgO (Allen *et al.* 1974).

Exchangeable cations were extracted with M ammonium acetate (pH 7) according to Allen *et al.* (1974). K was determined on a Perkin-Elmer 2380 *atomic absorption spectrophotometer* at Regional Sophisticated Instrumentation Centre (RSIC), Shillong. Total exchangeable bases (TEB) was the sum of metal cations (Allen *et al.* 1974).

Kjeldahl nitrogen was determined by digesting air-dried soil sample with conc. H_2SO_4 using K_2SO_4 + HgO catalyst mixture. The digest was distilled in micro-Kjeldahl distillation apparatus and titrated against 1/140 N HCl (Allen *et al.* 1974).

Extractable phosphorus was determined by phosphomolybdoblue colour method (Jackson 1958).

Plant analysis

Total nitrogen content in plant samples was determined by micro-Kjeldahl procedure using Tecator's Kjeltec auto 1030 nitrogen analyzer. Mixed acid digestion procedure (Allen *et al.* 1974) was followed for the determination of P and K. Phosphorus was determined by vanadomolybdophosphoric yellow colour method

(Jackson 1958). Potassium was determined on a Perkin-Elmer 2380 *atomic absorption spectrophotometer.*

Sufficient number of blanks and three replicates were run in each analysis. The air-dry moisture content of soil and plant samples was determined to express the final results on oven-dry weight basis. Blanks were subtracted wherever necessary.

COMPUTATIONAL PROCEDURES

Nutrient concentrations in various above- and belowground vegetation components were determined every month and multiplied with respective oven-dry mass to get the total nutrient amount. Nutrient uptake by vegetation was calculated by summing up the significant ($p<0.05$) positive increments in nutrient amounts present in total live tissues (in case of both above- and belowground) and concurrent increments, if any, in nutrient amounts in dead tissue on successive sampling dates following the approach of Singh & Yadava (1974), which they employed for calculation of biomass production. Sum of the uptake by above- and belowground vegetation yielded the estimate of total uptake.

Transfer of nutrients from live to dead aboveground tissue was calculated as:

$$\begin{array}{c}\text{Transfer of nutrient from}\\ \text{live to dead tissue}\end{array} = \begin{array}{c}\text{Initial nutrient amount}\\ \text{in live tissue}\end{array} + \begin{array}{c}\text{Uptake of nutrient by}\\ \text{aboveground vegetation}\end{array} - \begin{array}{c}\text{Final nutrient amount}\\ \text{in live tissue}\end{array}$$

Transfer of nutrients from aboveground dead to litter was:

$$\begin{array}{c}\text{Transfer of nutrient from}\\ \text{dead tissue to litter}\end{array} = \begin{array}{c}\text{Initial nutrient amount}\\ \text{in dead tissue}\end{array} + \begin{array}{c}\text{Transfer of nutrient}\\ \text{from live to dead}\end{array} - \begin{array}{c}\text{Final nutrient amount}\\ \text{in dead tissue}\end{array}$$

Release of nutrient from litter was considered as:

$$\text{Nutrient release from litter} = \text{Initial nutrient amount in litter mass} + \text{Transfer of nutrient from dead tissue to litter} - \text{Final nutrient amount in litter mass}$$

In the same way, transfer of nutrient from live belowground vegetation to dead and then the release from the latter were calculated as:

$$\text{Transfer of nutrient from live to dead belowground vegetation} = \text{Initial nutrient amount in live tissue} + \text{Uptake of nutrient by belowground vegetation} - \text{Final nutrient amount in live tissue}$$

$$\text{Release of nutrient from dead belowground vegetation} = \text{Initial nutrient amount in dead tissue} + \text{transfer of nutrient from live to dead} - \text{Final nutrient amount in dead tissue}$$

The sum of releases of nutrients from above- and belowground vegetation represented the total release of nutrients from the system.

Turnover of nutrients for above- and belowground vegetation was computed following Dahlman & Kucera (1965):

$$\text{Turnover} = \frac{\text{Uptake of nutrient over time } t}{\text{maximum standing state of the nutrient during time } t}$$

STATISTICAL TREATMENTS

Data were statistically analysed wherever necessary. Computer programs written in BASIC were used for computation purpose. Algorithms for regression analysis and analysis of variance were followed from Kendall & Stuart (1968), Ostle & Mensing (1975) and Chatterji & Price (1977).

Chapter 5

Community Structure

Chapter 5

COMMUNITY STRUCTURE

INTRODUCTION

The environmental degradation leads to adverse economic consequences that are pervasive and profound (Myers 1988). Decline and dieback of forests due to human activities is a global ecological problem associated with depletion of biodiversity and biological mining of soil nutrients (Muller-Dombois 1988). Disturbances and stress conditions are non-equilibrium processes and have significant ecosystem level consequences. They alter species interactions by changing the resource base and therefore affect the nature of organisation within a community (Bazzaz & Parrish 1982).

The Meghalaya state extends in the sub-Himalayan belt in northeast region of India. The landscape is largely occupied by a complex of successional communities representing various stages of degradation of climax moist deciduous forest at lower elevation and evergreen broadleaved forest at upper heights. Major factors responsible for the expansion of degraded land areas in Meghalaya include (i) clearing of land and burning of slash for shifting cultivation (Jhum) together with the shortening of jhum cycle, (ii) overexploitation of forests for timber and fuelwood purpose, (iii) long lasting or even permanent on-site and off-site disturbances caused by mining activity for coal, limestone and sillimanite which leaves behind gravely substrate difficult to revegetate because of low moisture and nutrient holding capacities, (iv) high rainfall of greater intensity causing the loss of topsoil and depletion of nutrients from arable land and other sparsely vegetated areas, (v) hilly terrain of the state which channelised major part of rainwater through overland flow and accelerates sediment loss, and (vi) change in landuse pattern related to developmental activities due to unprecedented rise in population within a framework of limited natural resources. Structure and dynamics of grasslands of arid, semiarid and subhumid bioclimatic zones of the country have been studied extensively and the data have been synthesized by Yadava & Singh (1977), Singh *et al.* (1979), Misra (1983), Singh *et al.* (1985) and Pandeya (1988). However, similar information on degraded plant communities in humid and perhumid regions of the country is limited.

This chapter analyses the structure and dynamics of three grassland communities which are distributed along an altitudinal gradient between 100-1900 m asl in Meghalaya and evaluates the influence of protection against cattle grazing and annual burning on the community attributes at a high altitude site.

RESULTS

Floristic composition

The grassland communities at three topographic positions included a total of 20 grasses, 4 sedges, 6 legumes and 40 other forbs (Table 5.1). Species content was maximum at Upper Shillong (32 species) followed by Burnihat (28 species) and Cherrapunji (15 species). All the sites recorded maximum number

Table 5.1. Floristic composition, life-form and mean importance value of species at Burnihat (BUR), Cherrapunji (CHR) and in protected (USP) and unprotected (USU) stands at Upper Shillong.

Species	Life form	Site BUR	 CHR	 USP	 USU
Grasses & sedges					
Arundinella benghalensis (Spreng.) Druce	Ch	-	5.8	-	-
Arundinella khaseana Nees	Ch	-	92.0	-	-
Arundinella nepalensis Trin.	Ch	-	-	79.2	102.1
Axonopus compressus (SW.) P.Beauv	H	43.4	-	-	-
Brachiaria villosa A.Camus	Th	20.6	-	5.7	1.5
Capillipedium assimile (Steud.) A.Camus	Ch	-	-	24.7	5.9
Chrysopogon aciculatus Trin.	H	0.6	-	-	-
Chrysopogon gryllus (L.) Trin.	Ch	-	60.6	-	-
Cynodon dactylon Pers.	H	25.1	-	-	-
Digitaria adscendens (H.B.K.) Henr.	Th	0.9	-	-	-
Eragrostiella leioptera (Stapf.) Bor	Ch	-	52.7	-	-
Eragrostis uniloides (Retz.) Nees ex Steud	Th	6.9	-	-	-
Eulalia trispicata (Schult.) Henr.	Ch	-	48.9	-	-
Fimbristylis dichotoma (L.) Vahl	Th	-	13.8	-	4.3
Fimbristylis miliacea (L.) Vahl	Th	7.6	-	-	-
Imperata cylindrica (L.) P.Beauv	Ch	45.3	-	62.4	38.9
Kyllinga brevifolia Rottb.	Th	10.2	-	-	-
Paspalum conjugatum Berg.	Th	7.1	-	-	-
Paspalum dilatatum Poir.	Ch	-	-	-	0.6
Paspalum orbiculare Forst.	Th	-	0.3	-	-
Pennisetum clandestinum Hochst. ex Chiov.	H	-	-	7.4	-
Pycreus globosus (All.) Reichb.	Th	3.0	-	-	-
Saccharum spontaneum L.	Ch	-	-	1.8	0.8
Setaria glauca P.Beauv	Th	60.7	-	-	-
Legumes					
Crotalaria striata DC.	Ch	0.2	-	-	-
Desmodium triflorum DC.	H	12.5	-	-	-
Eriosema chinense Vogel.	Ch	-	1.5	0.3	0.2
Indigofera sequipedalis C.B.Clarke	Ch	-	-	0.7	9.8
Mimosa pudica L.	Ch	8.7	-	-	-
Trifolium repens L.	H	-	-	16.5	-

continued

Table 5.1 continued

Other forbs

Ageratum conyzoides L.	Th	9.3	-	-	-
Alternanthera sessilis Br.	Th	2.9	-	-	-
Anaphalis adnata DC.	Th	-	-	1.4	1
Anaphalis contorta (D.Don) Hk.f.	Ch	-	-	5.8	9.
Anemone rivularis Ham.	G	-	-	15.1	15.
Anotis wightiana Hk.f.	G	-	1.1	-	-
Brunella vulgaris L.	Ch	-	-	1.0	0.
Centella asiatica (L.) Urb.	H	3.0	0.7	8.9	11.
Commelina diffusa Burm.	Th	8.8	-	-	-
Cyanotis vaga (Lour.) Schult.	G	-	0.7	14.5	7.
Drymaria cordata Willd.	H	1.3	-	-	-
Duchesnea indica (Andr.) Focke.	H	-	-	5.8	9.
Erigeron linifolius Willd.	Ch	-	-	11.9	-
Eriocaulon cristatum Mart.	Th	-	0.4	-	0.
Eupatorium odoratum L.	Ch	3.1	-	-	-
Fagopyrum esculentum Moench	Th	-	-	0.4	-
Galinsoga parviflora Cav.	Th	0.4	-	-	-
Galium mollugo L.	L	-	-	0.4	-
Galium rotundifolium L.	H	-	-	2.2	1.
Gentiana quadrifaria Clark non Bl.	Th	-	2.3	-	-
Gnaphalium leuto-album L.	Th	-	-	0.3	-
Hedychium coronarium Koeing ex Retz.	G	-	-	0.4	-
Hypochaeris radicata L.	G	-	-	4.3	1.
Lactuca gracilis DC.	Th	-	-	1.5	-
Mikania micrantha H.B.K.	H	8.2	-	-	-
Murdannia nudiflora (L.) Brenan.	Th	2.5	-	-	-
Myriactis nepalensis Less.	G	-	-	0.7	5.
Osbeckia capitata Benth.	Th	-	17.8	-	-
Osbeckia crinita Benth.	Ch	-	-	6.3	21.
Oxalis corniculata L.	H	0.7	-	3.2	0.
Plantago major L.	G	-	-	5.4	1.
Plectranthus coetsa Ham.	Ch	-	-	0.6	1.
Polygonum bistorta L.	G	-	1.6	-	-
Polygonum capitatum Ham.	G	-	-	-	0.
Polygonum flaccidum Meissn	Ch	3.4	-	-	-
Pteridium aquilinum (L.) Kuhn.	Ch	-	-	7.6	41.
Richardsonia pilosa H.B.K.	Th	0.8	-	-	-
Rubus ellipticus J.E.Smith	Ch	-	-	1.6	2.
Rungia parviflora Nees	Th	2.5	-	-	-
Smilax aspera L.	L	-	-	2.0	1.1

-= Absence, Th= Therophyte, G= Geophyte, H= Hemicryptophyte, Ch= Chamaephyte, L= Lianas, of species during rainy season; Burnihat-June and July, Cherrapunji- July and Upper Shillong- September. The period showing minimum species richness, however, varied at different sites; it was September at Burnihat, January-February at Cherrapunji and March at Upper Shillong. The percentage of annual species in the community declined from 54 at Burnihat to 15 at Upper Shillong. Conversely, the proportion of the perennials increased in the community and showed a significant positive relationship ($p<0.01$) with altitude (Table 5.3). At all the sites, legumes were poorly represented; only one at Cherrapunji and three at Burnihat and Upper Shillong (Table 5.2). The non-leguminous forbs were 23 at Upper Shillong, 13 at Burnihat and 7 at Cherrapunji. Sorenson's similarity index did not show any marked similarity among the communities (Table 5.4).

Table 5.2. Number of species in various species groups at Burnihat (BUR), Cherrapunji (CHR) and in protected (USP) and unprotected (USU) stands at Upper Shillong.

	SITE			
Species group	BUR	CHR	USP	USU
Grasses & sedges	12	7	6	7
Legumes	3	1	3	2
Other forbs	13	7	23	19
Annuals	15	5	5	4
Perennials	13	10	27	24
Total species	28	15	32	28

Table 5.3. Relationship between altitude (m) and mean temperature (^{o}c) with relative distribution of plant growth forms in the degraded communities of Meghalaya.

Growth form (Y)	Abiotic variable (X)	Regression equation	Correlation coefficient	p
Perennial	Altitude	$Y=42.89+0.021X$	0.989	0.01
Chamaephyte	Altitude	$Y=17.64+0.014X$	0.961	0.05
Chamaephyte	Mean temperature	$Y=111.39-3.871X$	-0.979	0.05
Therophyte	Altitude	$Y=57.11-0.021X$	-0.989	0.01
Therophyte	Mean temperature	$Y=-72.83+5.252X$	0.909	0.10

Table 5.4. Matrix of similarity coefficients among grassland communities at Burnihat (BUR), Cherrapunji (CHR) and in protected (USP) and unprotected (USU) stands at Upper shillong.

	Site			
Site	BUR	CHR	USP	USU
BUR	1	0.0465	0.1333	0.1428
CHR		1	0.1276	0.2790
USP			1	0.8000
USU				1

Life-form spectrum

Comparison of life-form spectrum with that of the Raunkiaer's normal spectrum (Table 5.5) revealed higher percentages of therophytes (4 times), hemicryptophytes and chamaephytes, and absence of geophytes at Burnihat. At Cherrapunji and Upper Shillong, chamaephytes and geophytes were 4-5 times more while the proportion of hemicryptophytes was lower

Table 5.5. Comparison of life-form spectrums of grassland communities of Meghalaya with that of other bioclimatic zones of India.

	Life-form					
Bioclimatic zone	Th	G	H	Ch	L	Authors
Arid						
Extreme arid region	49.0	2.0	6.0	9.0	2.0	1
West Indian desert	40.0	3.4	15.5	18.9	7.8	2
Semiarid						
Pilani	69.0	9.0	6.0	9.0	-	3
Sagar	51.0	18.3	18.3	16.3	-	4
Subhumid						
Kurukshetra	62.5	6.2	18.7	10.4	-	5
BHU, Varanasi	68.8	7.8	20.3	3.1	-	6
Naugarh, Varanasi	70.2	6.3	19.1	4.2	-	7
Amara, Varanasi	56.5	13.0	17.3	13.0	-	8
Berhampur	48.6	5.7	14.3	25.7	-	9
Humid						
Dehradun	44.6	3.6	-	43.0	-	10
Burnihat	53.6	-	28.6	17.8	-	Present study
Upper Shillong:						
protected	15.6	18.8	18.8	40.6	2.0	- do -
unprotected	14.3	21.4	14.3	46.4	3.6	- do -
Superhumid						
Cherrapunji	33.3	20.0	6.7	40.0	-	- do -
Meghalaya	34.3	13.0	17.1	32.9	3.0	- do -
Raunkiaer's normal	13.0	4.0	26.0	9.0	-	11

1= Merita & Bhandari (1980), 2= Das & Sarup (1951), 3= Gill (1975), 4= Pandeya (1964), 5= Singh & Yadava (1974), 6= Singh (1967), 7= Singh & Ambasht (1975), 8= Srivastava (1977), 9= Misra & Misra (1979), 10= Srivastava *et al.* (1980), 11= Raunkiaer (1934)

and that of therophytes was more or less equal to the values of Raunkiaer's normal spectrum. The proportion of chamaephytes in the community increased significantly with altitude ($p<0.05$) and showed a significant negative relationship with temperature ($p<0.05$) while therophytes showed a reverse trend (Table 5.3).

Density and Basal cover

Monthly variation in stand density was significant at Burnihat ($p<0.01$) and Cherrapunji ($p<0.05$) but insignificant at Upper Shillong (Table 5.6). At Burnihat and Cherrapunji, density declined from mid-rainy season to winter season, thence increased more or less constantly and reached at its maximum in the rainy season. At Upper Shillong, however, a sudden increase in the density in December disrupted this trend. Mean stand density was 1046, 667 and 733 plants m^{-2} at Burnihat, Cherrapunji and Upper Shillong, respectively. Among the perennial species, *Imperata cylindrica*, *Cynodon dactylon* and *Desmodium triflorum* at Burnihat, *Chrysopogon gryllus*, *Eragrostiella leioptera* and *Osbeckia capitata* at Cherrapunji, *Arundinella nepalensis* and *Anemone rivularis* at Upper Shillong (both in protected and unprotected stands) and *Osbeckia crinita* in the unprotected stand attained maximum density during the rainy season (Table 5.7). Species showing winter (December) peaks are *Axonopus compressus* at Burnihat, *Capillipedium assimile* in the protected and *Pteridium aquilinum* and *I. cylindrica* in the unprotected stand at Upper Shillong. Some species like *Setaria glauca* at Burnihat, *Arundinella khaseana* and *Eulalia trispicata* at Cherrapunji and *Trifolium repens* in the protected stand at Upper Shillong showed higher density during summer (March-April) period. Rest of the species exhibited highest density in the later half of the monsoon period (August-September) at all the sites.

Table 5.6. Monthly variation in stand density (plants m^{-2}) and basal cover (cm^{2} m^{-2}) in the four grassland communities.

	Burnihat		Cherrapunji		Upper Shillong			
					Protected		Unprotected	
Month	DE	BC	DE	BC	DE	BC	DE	BC
AUG	2297 (42)	77.9 (0.8)	882 (20)	61.9 (1.3)	780 (7)	69.1 (1.2)	613 (17)	46.7 (1.3)
SEP	1494 (24)	61.8 (0.5)	801 (29)	76.6 (1.6)	738 (13)	48.3 (0.6)	551 (10)	46.5 (0.9)
DEC	1326 (28)	48.5 (0.5)	638 (10)	32.3 (0.9)	969 (16)	42.1 (1)	529 (9)	42.1 (1.1)
JAN	622 (27)	26.5 (1.3)	322 (8)	17.1 (0.3)	601 (17)	30.4 (0.8)	354 (4)	24.2 (0.2)
FEB	594 (17)	22.4 (0.9)	750 (30)	44.8 (1.9)	660 (11)	28.6 (0.6)	0	0
MAR	920 (17)	29.2 (0.5)	727 (9)	42.2 (0.3)	643 (22)	29.1 (1.1)	190 (3)	7.1 (0.1)
APR	710 (11)	24.9 (0.6)	617 (6)	33.1 (0.3)	800 (29)	32.9 (1.4)	407 (15)	15.5 (0.5)
MAY	600 (18)	26.7 (0.9)	588 (10)	41.2 (0.6)	812 (23)	37.4 (1.2)	288 (5)	13.7 (0.2)
JUN	790 (17)	43.7 (0.9)	626 (27)	55.2 (1.3)	754 (19)	41.2 (1)	361 (10)	26.5 (0.7)
JUL	1103 (41)	54.9 (1.4)	712 (13)	49.8 (0.7)	568 (8)	31.2 (0.5)	381 (10)	30.3 (0.8)
LSD$_{0.05}$	418	14.4	288	16.8	285	15.7	156	11.8

DE= Density & BC= Basal cover
Values in parentheses denote standard error

With significant variation ($p<0.01$) through months, basal cover was attuned with density (Table 5.6). Mean stand basal cover was 41.7, 45.4, and 39.0 cm^{2} m^{-2} at Burnihat, Cherrapunji and Upper Shillong, respectively. Basal cover per

Table 5.7. Monthly variation in density (m^{-2}) of some important species of four grassland communities in Meghalaya.

Species	Aug	Sep	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
				Burnihat						
Axonopus compressus	278.4	206.4	334.4	139.2	152.8	103.2	106.4	50.4	120.8	104.8
Imperata cylindrica	421.6	305.6	84.8	157.6	153.6	135.2	140.8	89.6	113.6	113.6
Setaria glauca	47.2	9.6	501.6	141.6	105.6	437.6	235.2	147.2	270.4	344.8
Cynodon dactylon	416.0	38.4	44.0	76.8	71.2	99.2	44.8	87.2	27.2	26.4
Desmodium triflorum	101.6	11.2	6.4	...	9.6	16.8	31.2	77.6	28.8	44.0
Other species	1032.2	923.2	355.2	107.2	100.8	128.0	151.4	148.4	229.6	469.0
				Cherrapunji						
Arundinella khaseana	248.0	184.0	223.2	111.2	283.2	252.8	246.4	230.4	246.4	268.0
Chrysopogon gryllus	176.8	177.6	128.0	52.0	81.6	72.0	27.2	84.0	104.0	115.2
Eragrostiella leioptera	144.0	292.0	160.8	82.4	275.2	117.6	128.0	132.8	194.4	144.8
Eulalia trispicata	152.8	69.6	88.0	68.0	104.8	220.8	155.2	75.2	54.4	87.2
Osbeckia capitata	36.8	42.4	4.0	4.0	...	24.8	37.6	39.2	20.0	36.8
Other species	123.2	35.2	33.6	4.8	5.6	39.2	22.4	26.4	7.2	60.0
				Upper Shillong (protected)						
Arundinella nepalensis	374.4	208.0	270.4	94.4	154.4	132.0	298.4	239.2	298.4	227.2
Imperata cylindrica	240.0	96.0	240.8	180.8	140.0	184.8	250.4	224.0	151.2	139.2
Capillipedium assimile	...	69.6	207.2	104.8	92.0	139.2	53.6	56.8	65.6	60.8
Trifolium repens	22.4	...	37.6	12.8	51.2	95.2	44.8	126.4	47.2	36.0
Anemone rivularis	36.0	72.0	22.4	7.2	4.8	39.2	34.4	24.8	32.8	20.8
Other species	107.2	292.8	190.4	200.8	217.6	52.8	118.4	140.8	159.2	84.0
				Upper Shillong (unprotected)						
Arundinella nepalensis	296.8	152.8	224.8	139.2	Burning	98.4	154.4	174.4	175.2	172.8
Imperata cylindrica	98.4	80.8	181.6	82.4	Burning	40.8	32.0	4.8	20.0	69.6
Pteridium aquilinum	18.4	23.2	36.8	20.8	Burning	5.6	28.0	4.0	13.6	23.2
Osbeckia crinita	70.4	52.8	4.8	...	Burning	...	42.4	36.8	49.6	31.2
Anemone rivularis	24.0	62.4	10.4	4.8	Burning	10.4	12.0	28.8	28.0	...
Other species	104.8	179.2	70.4	106.4	Burning	35.2	138.4	39.2	74.4	84.0

thousand plants, a measure to explain the monthly variation in the growth behaviour of constituent species, showed (Fig. 5.1) an interesting pattern. It showed a rising trend with the onset of rainy season, attaining peak in August-September, and then decreased until summer (April) but with a slight increase for a

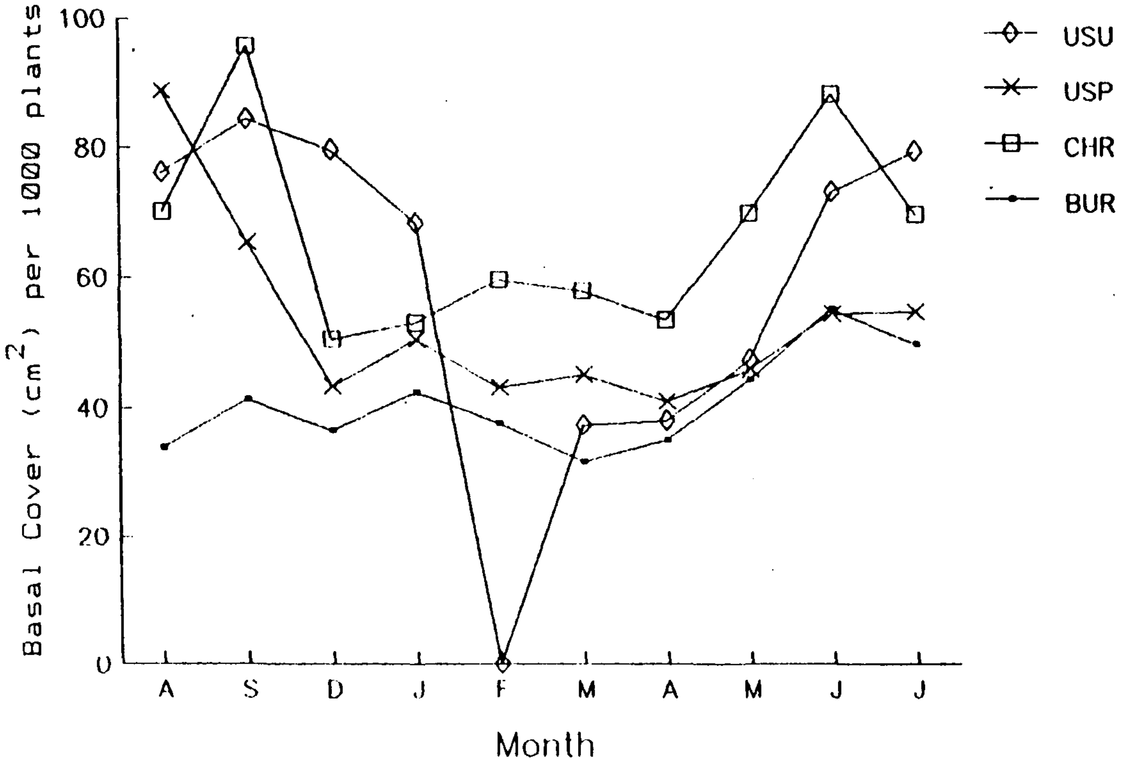


Fig. 5.1 Seasonal variation in basal cover (cm^2) per thousand plants at Burnihat (BUR), Cherrapunji (CHR), and in protected (USP) and unprotected (USU) stands at Upper Shillong.

brief period during winter (December-January). The average values were 40.9, 66.9 and 53.3 cm^2 per thousand plants at Burnihat, Cherrapunji and Upper Shillong, respectively.

Importance value and species-abundance relationships

Mean importance values reveal that *Setaria glauca* at Burnihat, *Arundinella khaseana* at Cherrapunji and *Arundinella nepalensis* at Upper Shillong were the dominant species (Table 5.1). *Imperata cylindrica* and *Axonopus compressus* at Burnihat; *Chrysopogon gryllus, Eragrostiella leioptera* and *Eulalia trispicata* at Cherrapunji and *I. cylindrica* and *Capillipedium assimile* at Upper Shillong were other important species. Distribution of importance value among various species groups showed dominance of grasses at all the sites with variable importance of other forbs (Fig. 5.2). The legumes were less important in all the communities.

The dominance distribution curve at Cherrapunji fits more or less the geometric series of the niche pre-emption model (Motomura 1932) whereas curves at other sites partially approach Preston's (Preston 1948) lognormal distribution (Fig. 5.3). These curves indicate the pattern how the species of a community share the available resources. They lucidly indicate that in all the four stands, only a few species shared major dominance and a large number of less successful species had relatively low importance value in the community. At Cherrapunji, 85 % of the importance value was shared by four grass species only. At Burnihat and Upper Shillong, first ranked four species apportioned approximately 60 % of the importance value. In the unprotected stand at Upper Shillong, however, this value

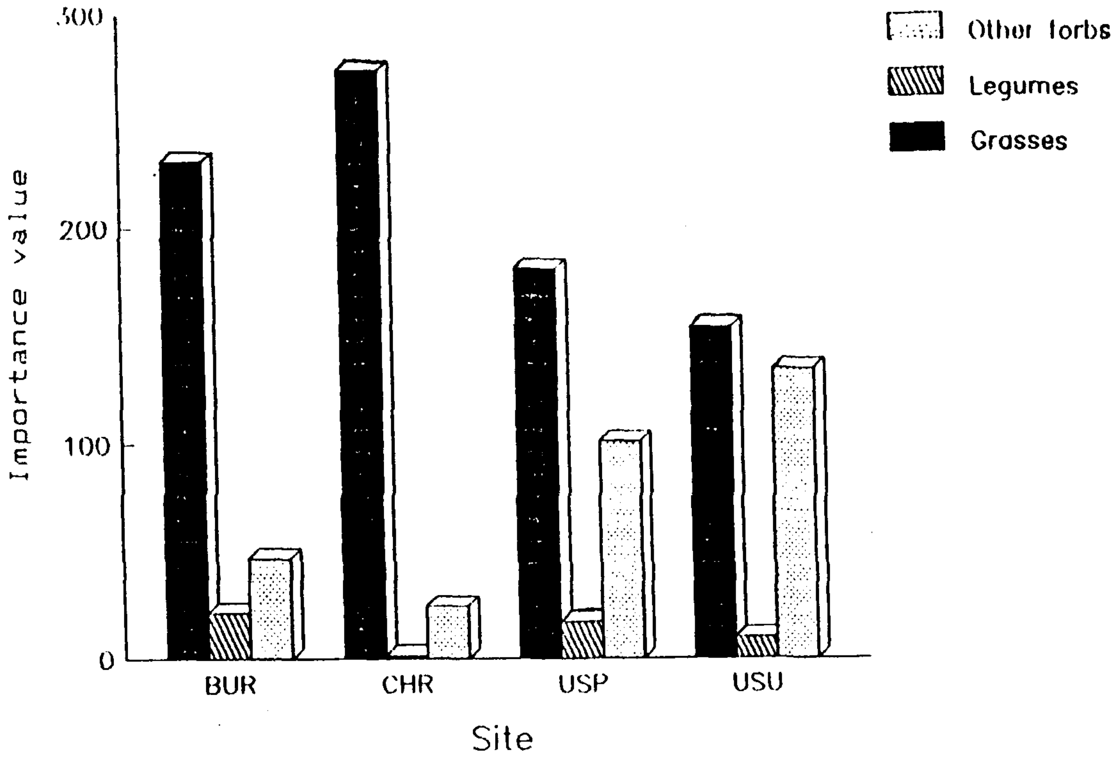


Fig. 5.2 *Distribution of importance value among grasses, legumes and other forbs at Burnihat (BUR), Cherrapunji (CHR), and in the protected (USP) and unprotected (USU) stands at Upper Shillong.*

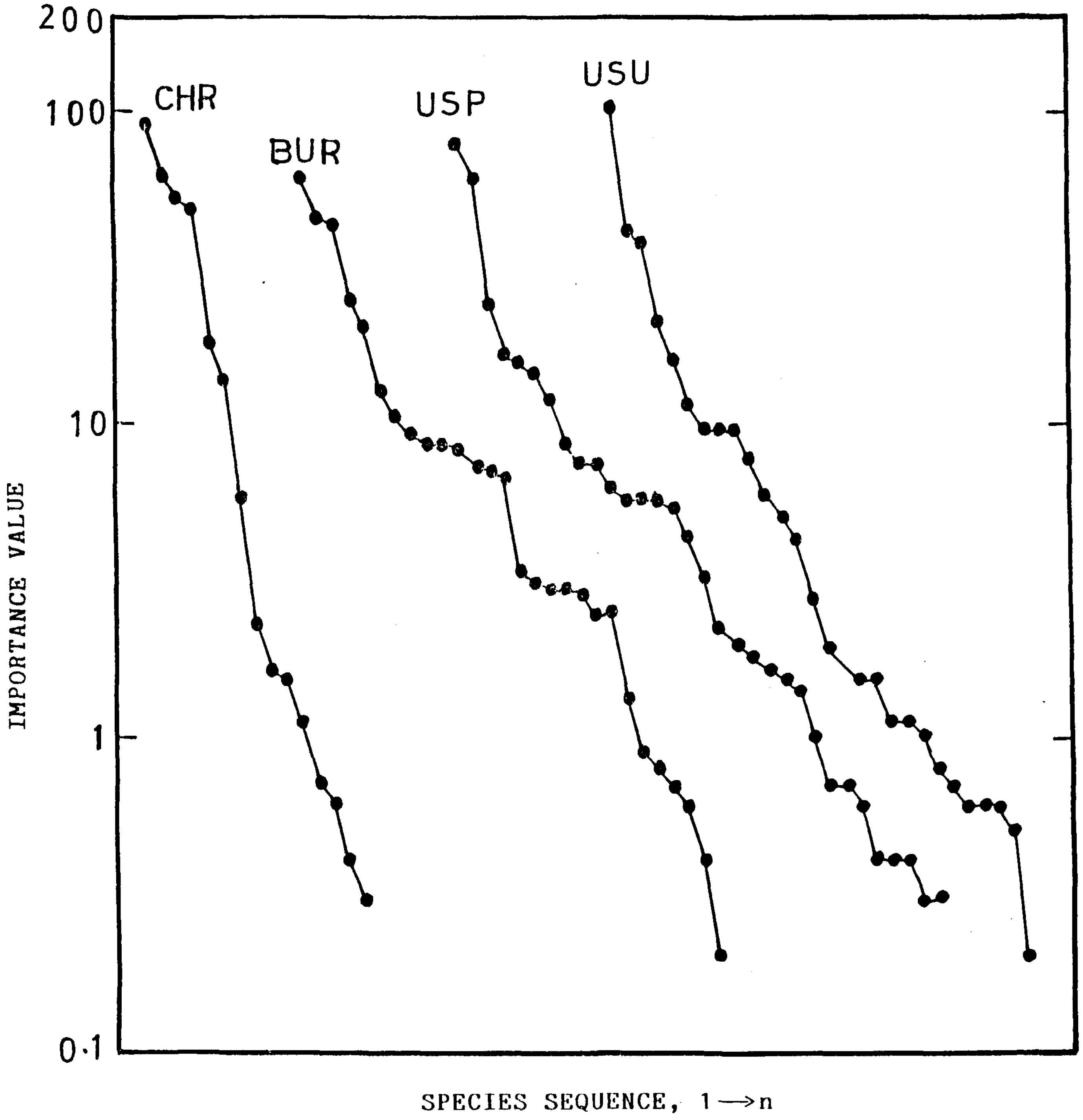


Fig. 5.3 Relative abundance curves for Burnihat (BUR), Cherrapunji (CHR), and protected (USP) and unprotected (USU) stands at Upper Shillong.

increased to 68 % of which about 34% was expressed by *Arundinella nepalensis* alone.

Dominance and diversity

The dominance and diversity indices varied throughout the year in all the communities. The monthly values of Shannon's general diversity index (H') and Simpson's index of dominance (cd) were inversely correlated at all the sites (Fig. 5.4). The relationship explains about 55, 94 and 82 per cent variability at Burnihat, Cherrapunji and Upper Shillong, respectively. Nevertheless, the mean value revealed highest diversity at Upper Shillong (2.31±0.05) followed by Burnihat (2.28±0.03) and Cherrapunji (1.74±0.05); the reverse being true for the dominance index.

Protected vs unprotected stand

Comparison of the protected and unprotected stands at Upper Shillong reveals that protection provided to the vegetation against mild cattle grazing and annual surface burning during dry winter period resulted into increase in species richness (Table 5.2), stand density (Table 5.6) and basal cover (Table 5.6) in the community. Proportion of the legumes also increased in the protected stand (Fig.5.2). However, there was no marked change in the life-form composition of the two stands (Table 5.5). Sorenson's similarity index showed 80 per cent similarity between the two (Table 5.4). The diversity increased and concomitantly dominance decreased after protection (Fig. 5.4). Analysis of the distribution of importance value among various species groups (Fig. 5.2) indicates a distinct increase in IVI of other forbs such as *P. aquilinum* and *O. crinita* in the

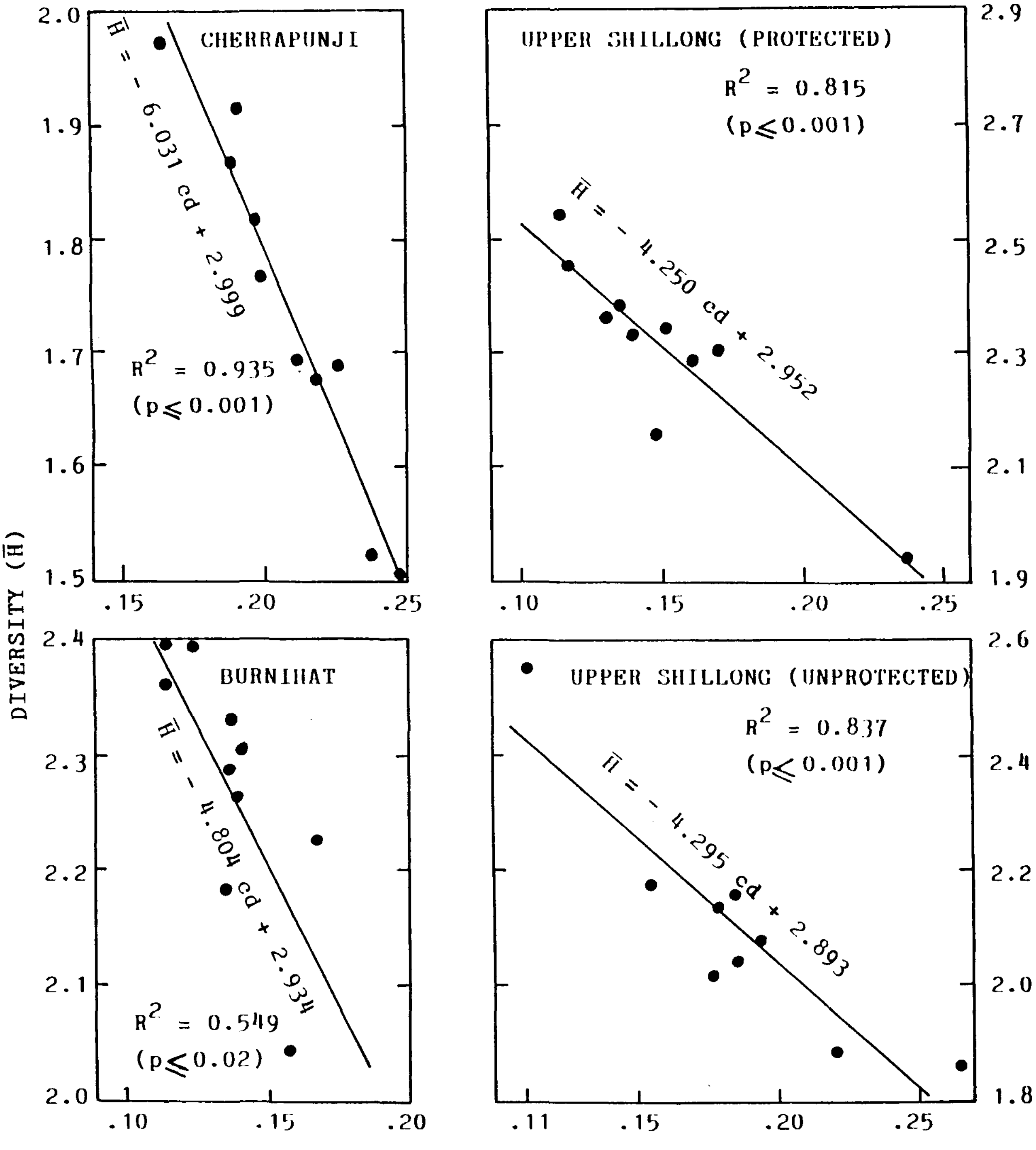


Fig. 5.4 Relationship between species diversity ($\bar{H}$) and dominance (cd) in the four grassland communities of Meghalaya.

unprotected stand. A perennial grass *A. nepalensis* though dominant in both the stands, had higher importance value in the unprotected stand (Table 5.1). A legume *Trifolium repens* was recorded only in the protected stand.

DISCUSSION

The grassland vegetation on degraded landforms of Meghalaya is habitat-specific having a marked relationship with altitude, soil characteristics and biotic factors. The plant community developed on highly degraded site at Cherrapunji had about one-half of the number of species recorded at other sites. The unprotected stand at Upper Shillong which was affected by cattle grazing and annual burning during dry winter period also showed low species richness (28 species) compared to the protected stand which had 32 species. Decline in the species number due to climatic stress is the obvious response of the community reported by several workers (Shankar and Saxena 1980; Yeaton 1988). Ramakrishnan & Ram (1988) have also reported low species content at Cherrapunji. Increase in species richness after protection against disturbances is in conformity with the results of Naik and Mishra (1974). At higher elevation of Meghalaya, degraded plant communities exhibited dominance of perennial species whereas annuals were abundant in moist tropical areas at Burnihat. Several studies have shown abundance (60-70%) of the annual species in tropical situations. Other forbs were fairly high in number. Seasonality in species distribution i.e., maximum species in rainy season and minimum in dry winter is common in monsoon grasslands (Kumar and Joshi 1972; Singh and

Yadava 1974).

Raunkiaer's biological spectrum though not considered suitable by certain workers for tropical plants, has been widely used for ecological classification of plants and is valuable in expressing differences and similarities among the communities. The grassland at Burnihat was exposed to different types of biotic stresses such as cattle grazing and mowing before the commencement of the study. The high value of therophytes in this community could therefore be an indicator of biotic stress (Bharucha and Dave 1944; Cain 1950; Pandeya 1953; Singh and Ambasht 1975). Severe and relatively prolonged winter at Upper Shillong and excessive rainfall together with high wind speed during winter at Cherrapunji seem to be the main causes responsible for increase in chamaephytes and decline in therophytes in these communities. Dramatic increase in chamaephytes with altitude has also been shown at Clova, Scotland and in Alps at Poschiavo (Raunkiaer 1918), at Mt. Cook, New Zealand (Allan 1937), and at Clavering Island, Greenland (Gelting 1934). Similarly, a steady decline in the percentage of therophytes conforms with the view of Cain (1950). Higher percentages of geophytes at Cherrapunji and in the protected and unprotected stands at Upper Shillong may be due to the survival of these species against grazing and burning pressures because of the hidden, subsurface position of their perennating buds. Cain (1950) has also reported that drier steppes have smaller percentages of hemicryptophytes than do steppes occurring in high rainfall areas. Lower percentage of hemicryptophytes at Cherrapunji, therefore, apparently does not follow the trend reported by Cain (1950), but a close examination of soil properties indicates that the soil remains dry about five months in an annual seasonal cycle during postmonsoon period between November to March due to highly gravely and coarse-textured soil which retains low moisture content (*ca.* 7%) and has lower water holding capacity. This might explain the lower percentage of hemicryptophytes in the community in spite of high rainfall at this site. The high percentage of therophytes in subhumid grasslands of India and a decrease toward extreme climatic conditions (Table 5.5), associated with increase in chamaephytes are quite understandable. It is very likely that indistinct seasonality in perhumid regions like Meghalaya lowers the therophytic element in the flora. Singh and Yadava (1974) are of the opinion that distribution of rainfall throughout the year in humid and perhumid areas is more congenial to perennial growth and, therefore, increases the percentage of chamaephytes. On the other hand, in extremely arid areas where rainfall is very less (*ca.* 120 mm), sandy soil does not retain appreciable amount of water for a longer period to allow germination and subsequent growth of the annuals. Perennial species with their massive bodies are successful.

With weak significant variation through months, stand density as well as species content did not exhibit a strong seasonal trend similar to other Indian grasslands, probably due to the prevailing climate in Meghalaya which is favourable for plant growth during most part of the year. Basal cover per thousand plants which serves as a measure of growth of individual species in the community increased with the advent of monsoon. After the rainy season was over, it started decreasing but showed a slight increase during winter. It suggests that during growth period total basal cover of the stand increases not only due to increase in density but also because of increase in absolute basal cover of individuals. In the unprotected stand at Upper Shillong, cover increased continuously after burning due to rapid growth of plants. Average basal cover per thousand plants showed the trend CHR>USU>USP>BUR. This suggests that stressed condition created either due to heavy rainfall and infertile soil at Cherrapunji or burning and grazing in the unprotected stand at Upper Shillong favoured the growth of such species, which tend to have relatively higher basal cover. This trend is also correlated with the change in the relative abundance of different life-forms in the community from therophytes at Burnihat to chamaephytes at Cherrapunji and Upper Shillong.

Distribution of importance value in various species groups endorses the grassy nature of the sites with varying degree of abundance of other forbs. The associated non-grass species varied from site to site, presumably due to varying soil type, elevation and stress conditions. The vegetation of Burnihat and Cherrapunji is dominated by single plant life-form i.e., grasses whereas at Upper Shillong non-grass species also form a conspicuous part of the vegetation. The site exposed to grazing and burning at Upper Shillong had lower percentage of grasses as compared to the protected one indicating selective herbivory by cattle resulting into modification in composition of the community due to increase in non-palatable forbs. The low proportion of legumes in all the communities does not corroborate the feature of tropical grasslands where coexistence of grasses, sedges and legumes is expected (Medina 1985). Legumes might not be an important element of the community found in the soil where extremely low P level and the high mobility of the aluminium ion hinder the formation of effective N fixing symbiosis (Medina 1985). Low level of extractable phosphorus in 0-30 cm layer of the soils (<2 mm size) of the presently investigated sites (Burnihat-3.8, Cherrapunji-1.2, Upper Shillong protected-2.1 and unprotected-1.9 Kg/ha) and acidic reaction (pH=5.5-6) could cause high aluminium mobility in the soil. This might be the probable reason for the poor growth of legumes in these communities.

The steepness of species rank-log abundance curve at Cherrapunji indicates concentration of dominance in a few species. From the most abundant to the least abundant, species pre-empt the available resources successively with each species utilizing a more or less constant fraction of the resources remaining corroborating the niche pre-emption hypothesis. Plant communities occurring in severe environments with small number of species well fit in the geometric series of niche pre-emption model (Poole 1974) originally suggested by Motomura (1932). The curves at Burnihat and Upper Shillong partially approach toward Preston's lognormal distribution (Preston 1948) since dominance was shared by relatively large number of species at these sites. In general, only 3-4 species express the substantial fraction (60-85%) of the importance value at all the sites (Fig. 5.4).

Protection of the site against grazing and annual fire modify the composition of the community by causing a shift in dominance. Dominance of two non-palatable forbs viz., *Osbeckia crinita* and *Pteridium aquilinum* and a grass *Arundinella nepalensis* declined after protecting the site while that of *Imperata cylindrica* increased in the grassland at Upper Shillong. Similar influence of fire has been observed in a *Stipa-Andropogon* community by Hadley (1970) and in a *Solidago-A. gerardii* community by Kucera & Koelling (1964). A study of the abundance of bracken fern (*Pteridium aquilinum*) made on an African plateau grassland (Lemon 1968) showed 3.2 stipes m^{-2} on burned, heavily grazed areas in contrast to 0.6 and 0.8 stipes m^{-2} on unburned and burned lightly grazed areas, respectively. We also found about 3 fold stipes on burned, light grazed area as compared to unburned ungrazed area. This suggests that bracken fern has an adaptive strategy for its growth over the area prone to burning and grazing. If these disturbances unabated, the site may eventually be converted into bracken-grassland.

According to Odum (1985) stress influences community structure by decreasing diversity and increasing dominance. This holds true for the Cherrapunji where edaphic and climatic stresses operating for a long time have favoured the growth of few stress-tolerant perennial grasses such as *Arundinella khaseana, Chrysopogon gryllus, Eragrostiella leioptera* and *Eulalia trispicata* giving rise to high dominance and low equitability in the community. The hypothesis that increasing species diversity in the community leads to increased stability (Margalef 1963; McNaughton 1967) does not seem to be tenable for Cherrapunji. In spite of high dominance, this particular community appears to be fairly stable. Dabadghao & Shankarnarayan

(1973) and Ramakrishnan *et al.* (1981) have also emphasized the stable nature of Cherrapunji grassland. The factors which seem to control the stability of Cherrapunji grassland are the exceptionally high rainfall (>1100 cm per annum) and annual burning of vegetation before the advent of monsoon. Adverse effects of these extreme climatic and anthropogenic factors on soil degradation are further intensified by the undulating topography of the area. As a result, the soil on hill tops and slopes up to rooting zone of the vegetation is highly sandy and acidic with relatively low water holding capacity and cation exchange capacity. Annual species which establish mainly through seeds are unsuccessful here while those perennating through persistent subterranean stem stocks predominate the site. Findings of Zangeral and Bazzaz (1983) that rhizome-derived

Table 5.8. Changes in species content and other attributes of grassland communities as related to the variations in site characteristics and soil properties.

	Site characteristics			Soil parameter				Community attributes			
Site	Rainfall (mm)	Mean temp. (°c)	Altitude (m)	WHC	CEC	pH	OM	S	D	cd	H'
Burnihat	2871	24.2	100	74.0	11.2	6.04	1.72	28	1046	0.14	2.28
Cherrapunji	16247	18.1	1300	41.9	8.1	5.49	2.53	15	667	0.21	1.74
Upper Shillong											
protected	3268	17.7	1900	81.7	13.5	6.02	3.50	32	733	0.15	2.31
unprotected	3268	17.7	1900	72.8	9.8	5.76	2.90	28	408	0.19	2.10

WHC= Water holding capacity (%), CEC= Cation exchange capacity (meq $100g^{-1}$),
OM= Organic matter (%), S= Species content, D= Density (plants m^{-2}),
cd= Simpson's index of dominance and H'= Shannon's diversity index.

plants are more successful than those resulting from the seedlings on nutrient-poor soils also lend support to our observations at Cherrapunji. Thus highly degraded and infertile soil under constant influence of heavy rainfall at Cherrapunji supports a species-poor but more stable community strengthening the argument of MacMahon (1980) that extremes of environmental conditions encourage the species which have already been adapted to the prevailing conditions. On the contrary, the communities which are developed on fertile soil in relatively low rainfall areas of the state show high species diversity and better growth of vegetation and are more dynamic. Slight increase in diversity and decrease in dominance after protection of the site at Upper Shillong (Table 5.8) is in sharp contrast with the findings of Milchunas *et al.* (1990) who have recorded increase in diversity with increasing level of perturbation in shortgrass steppe. In the present case, increased diversity in the protected stand is a function of equitability rather than species richness.

A comparison of analytical parameters of these communities with the grasslands found elsewhere in India reveals that the community at Burnihat is similar to the mixed grassland of subhumid region at Kurukshetra (Singh & Yadava 1974) in its growth form composition, species richness, density and coverage whereas the communities at Cherrapunji and Upper Shillong are different from other grasslands of the country in having higher percentage of chamaephytes and indistinct seasonal variation in species content and diversity.

Chapter 6

Nitrogen cycling

Chapter 6

NITROGEN CYCLING

INTRODUCTION

The major event in nutrient cycling within an ecosystem is the transfer of nutrients from soil to vegetation compartment. The soil nutrient pool is replenished by decomposition of litter and belowground parts. Nevertheless, a significant amount of nutrients is always locked up in the above- and belowground mass of the plant community. In grassland ecosystem, a massive transfer of nutrients takes place from live to dead compartment both in aboveground and belowground parts due to marked seasonality in growth behaviour of constituent species. The nutrients stored in the standing dead compartment may reside there for varying length of time, but eventually, they are transferred to the soil either with litter fall or with root detritus. Mineralization of litter and root detritus supplies nutrients to the available nutrient pool in soil. This internal cycle suffers many inputs and outputs (Clark *et al.* 1980).

Nitrogen cycling is an important functional attribute of the grassland ecosystem since forage production in many grasslands is limited by the current supply of nitrogen (Green & Cowling 1960; Power & Alessi 1971; Gustschick 1981). Although a major portion of nitrogen in the system is retained by soil, plants in many cases have to suffer inadequacy of nitrogen for uptake. McGarity (1959) and Bruce (1965) reported that the grass swards on cleared rainforest soils of north-eastern tropical and subtropical Australia suffers from nitrogen deficiency even though the soils contain 8,000-10,000 Kg N ha-1 in the rooting Zone. Slow rate of mineralization also limits availability of nitrogen in grasslands (Date 1973).

Using tracer nitrogen (^{15}N), Clark (1977) recognised four pathways through a combination of which the annual nitrogen requirement is met in ungrazed blue grama grassland. These nitrogen supplying mechanisms are: a) internal translocation of nitrogen stored in belowground plant parts over winter to new growth in the next season, b) mineralization of easily decomposable organic nitrogen compounds such as certain herbage components, root exudates, exfoliates, and shortlived unsuberized roots, c) mineralization of organic nitrogen synthesized by microorganisms subsisting on energy rich easily decomposable materials, and d) polymerization of organic compounds and formation of humic nitrogen which provide a slow feedback to the nitrogen pool in soil.

The voluminous data on nitrogen cycling from temperate grasslands have been compiled by Bazilevich & Titlyanova (1980). The tropical grasslands in India have received less attention in this regard and so far only a few studies have been carried out on the nitrogen cycling (Pandey 1976; Billore & Mall 1976, 1985; Mishra 1979; Yadava 1980; Tiwari 1985; Agrawal & Tiwari 1987; Chaturvedi *et al.* 1988; Pandey & Singh 1990). Studies on the functional attributes of grasslands of Meghalaya are very much limited and as such there is no study on the nitrogen cycle.

In this chapter, nitrogen cycling has been described in three grassland communities of Meghalaya on the basis of data collected on i) accumulation and distribution of nitrogen in different vegetation components and soil, ii) nitrogen uptake from soil, its transfer to various aboveground and belowground components, and iii) its release to soil through litter and belowground dead phytomass. Besides discussing the overall influence of climate and edaphic factors, effect of protection from burning and grazing on nitrogen accumulation and cycling at a high altitude site has also been evaluated.

RESULTS

Nitrogen concentration in soil and vegetation

Soil

The time series data on nitrogen concentration (%) in soils of three study sites are given in Table 6.1. Three factorial multivariate analysis of variance showed significant variation in the nitrogen concentration ($p<0.01$) due to month, site and depth (Table 6.2). The variations due to site and depth were much stronger than the variation through months. During the study period, nitrogen concentration ranged from 0.165 to 0.184, 0.103 to 0.132 and 0.083 to 0.096 at Burnihat; 0.165 to 0.190, 0.147 to 0.163 and 0.101 to 0.116 at Cherrapunji; 0.294 to 0.334, 0.233 to 0.263 and 0.158 to 0.184 in the protected and 0.224 to 0.253, 0.178 to 0.208 and 0.140 to 0.166 in the unprotected stand at Upper Shillong, respectively, in 0-10, 10-20 and 20-30 cm soil layers.

The LSD values revealed significant intersite variations ($p<0.05$) in nitrogen concentration (Fig 6.1); the maximum concentration being at Upper Shillong followed by

Table 6.1. Monthly variation in total N concentration (%) in three soil layers of four grassland communities.

	Burnihat			Cherrapunji			Upper Shillong					
							protected			unprotected		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
MONTH	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30
AUG'88	.168	.114	.095	.165	.157	.114	.334	.240	.181	.240	.207	.160
SEP	.171	.117	.095	.170	.159	.105	.306	.259	.178	.230	.208	.164
OCT	.171	.117	.092	.174	.152	.108	.305	.256	.159	.237	.205	.158
NOV	.166	.111	.091	.180	.162	.102	.322	.260	.162	.236	.198	.157
DEC	.180	.115	.092	.183	.153	.105	.307	.263	.167	.229	.197	.166
JAN'89	.171	.107	.096	.184	.163	.110	.306	.253	.171	.230	.190	.145
FEB	.168	.103	.085	.181	.152	.102	.294	.245	.158	.253	.191	.154
MAR	.165	.103	.084	.181	.150	.101	.328	.259	.180	.239	.183	.152
APR	.166	.108	.083	.176	.147	.111	.316	.262	.184	.249	.185	.143
MAY	.169	.115	.085	.182	.160	.113	.313	.241	.176	.247	.184	.142
JUN	.184	.132	.084	.190	.162	.116	.326	.236	.163	.229	.192	.153
JUL	.173	.120	.090	.179	.147	.116	.312	.233	.165	.224	.178	.161
AUG	.178	.113	.094	.171	.154	.115	.315	.237	.174	.240	.178	.147

Cherrapunji and Burnihat. At Upper Shillong, the protected stand had significantly higher value ($p<0.01$) than the unprotected stand. On an average basis, the value in the former stand was higher by a factor of 1.26 as compared to the latter stand. At all the sites, nitrogen concentration decreased with increasing depth (Fig. 6.1).

Table 6.2. Results of three-factorial (replicated) analysis of variance (fixed effects model) to test null hypothesis (Ho) for variations in soil nitrogen concentration along months, sites, depths and their interactions.

Variation	d.f.	SS	MS	F
General mean	1	14.796910	14.796910	...
Month	12	0.002061	0.000172	7.52**
Site	3	0.991126	0.330375	14461.36**
Depth	2	0.694310	0.347155	15195.85**
Month x Site	36	0.009449	0.000262	11.49**
Month x Depth	24	0.005000	0.000208	9.12**
Site x Depth	6	0.077959	0.012993	568.74**
Mon x Site x Dep	72	0.012291	0.000171	7.47**
Residual	312	0.007128	0.000023	...
TOTAL	468	16.596240	0.035462	...

** = Significant at $p<0.01$

Vegetation

Belowground parts:

Nitrogen concentration in belowground parts showed monthly fluctuation with some distinctive patterns (Fig. 6.2). In order to further clarify the pattern of variation through sampling dates, the means were calculated for live root and rhizome for those months along which concentration did not vary significantly ($p>0.01$). The corresponding months were also taken for calculating means for dead roots and rhizome. At Burnihat,

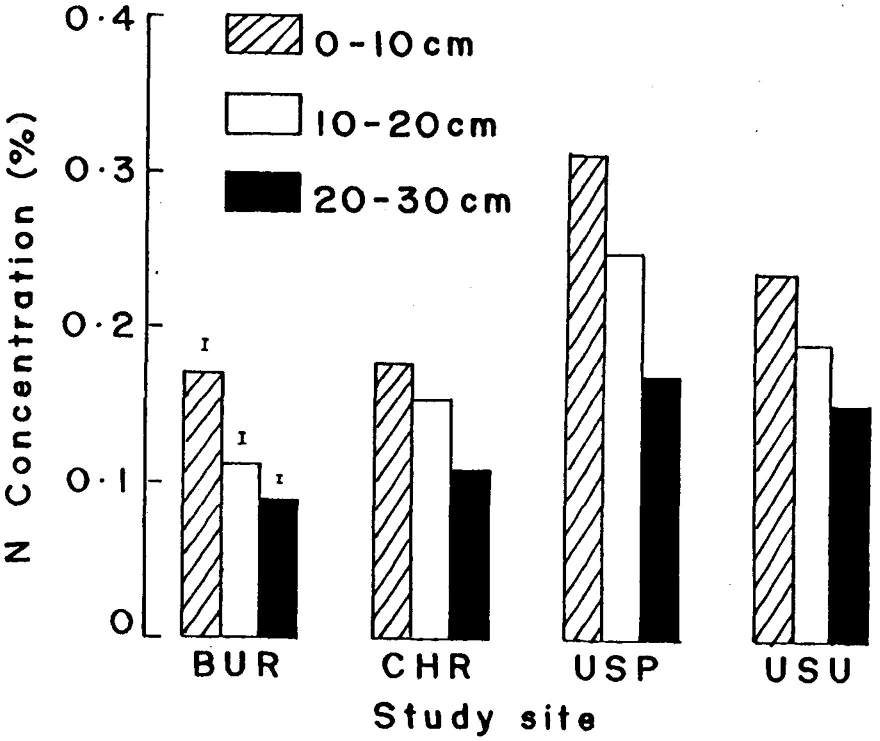


Fig. 6.1 *Mean monthly concentration (%) of nitrogen in three soil layers of four grassland communities. LSD (5%) is shown by vertical line. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

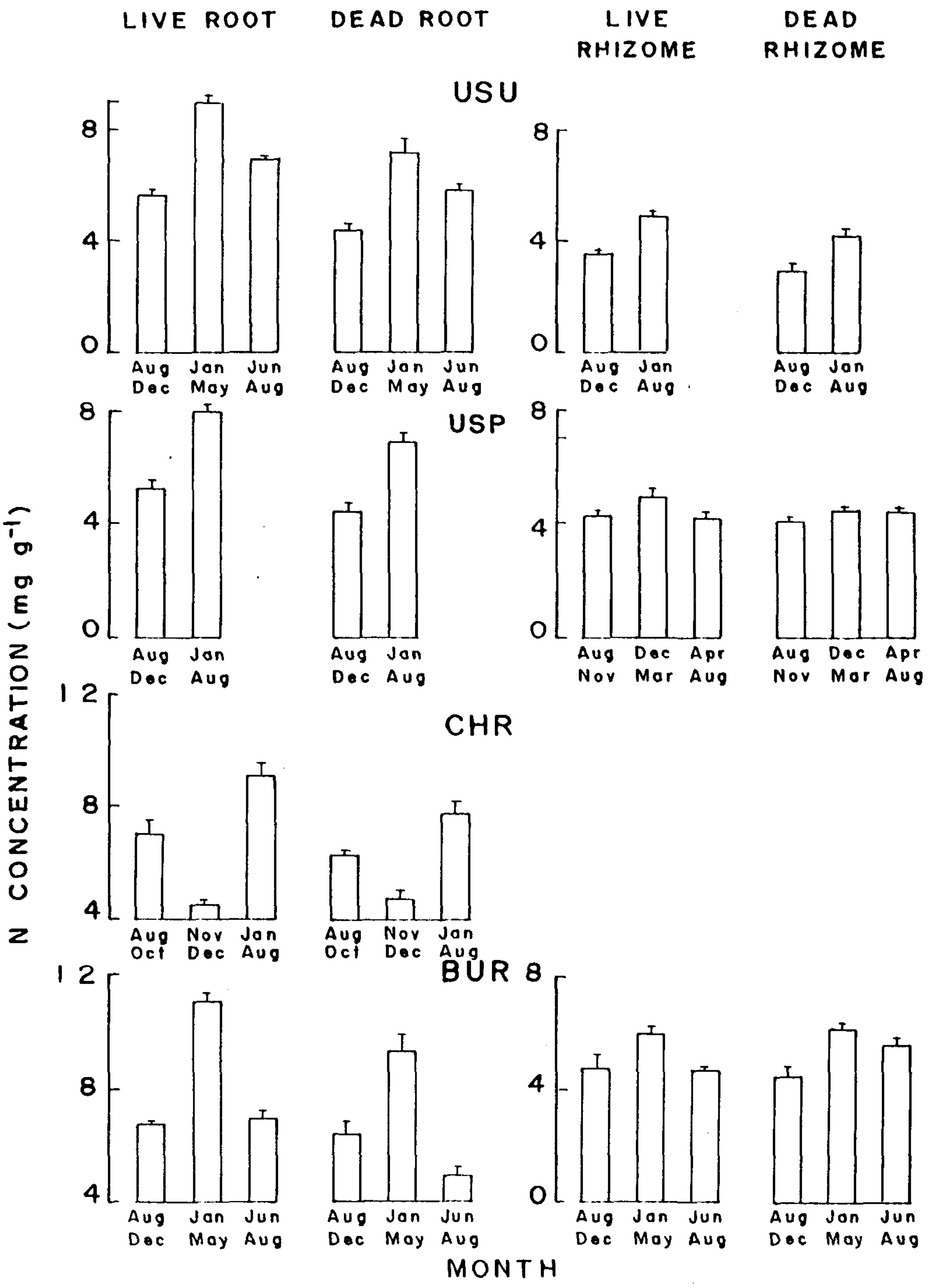


Fig. 6.2 Periodic fluctuation in nitrogen concentration (mg g^{-1}*) in the belowground components of four grassland communities. Standard errors represented by vertical lines denote variability between months indicated below the histograms. The months which showed no significant difference (*$p > 0.01$*) were pooled to calculate the periodic mean. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

during January to May, nitrogen concentration in live root and live rhizome was 1.6 and 1.3 times greater, respectively than during rest of the year. Live root peaked in January and live rhizome in February. At Cherrapunji, live roots showed higher nitrogen concentration (about 1.5 times) during January to August; the peak being in February. It may be recalled that live roots at this site included rhizome fraction also. In the protected stand at Upper Shillong, nitrogen concentration in live root was 1.5 times more during January to August than during the remaining months in the year. The live rhizome showed similar trend for a brief period, i.e., between January and March. Both root and rhizome peaked in March. At Upper Shillong, monthly trend of nitrogen concentration in live root was similar in the protected and the unprotected stands.

Table 6.3. Mean monthly concentration of N (mg g-1) in the belowground components of grassland communities at four sites.

	Root		Rhizome		
Site	Live	Dead	Live	Dead	**LSD**
Burnihat	8.47	7.29	5.24	5.39	**1.12**
Cherrapunji	7.89*	6.99*	--	--	**1.39**
Upper Shillong Protected	7.03	5.97	4.65	4.33	**0.75**
Unprotected	7.22	5.78	4.36	3.67	**0.84**
LSD	**1.30**	**1.11**	**0.64**	**0.59**	

LSD - Least Significant Difference at p<0.05
* includes rhizome also

Mean monthly nitrogen concentration was significantly different between various belowground components and it was higher in live root than live rhizome and dead root and rhizome. However, difference between live and dead rhizomes was insignificant ($p>0.05$). The live rhizome had significantly lower concentration than the live and dead root at all the sites. The highest nitrogen concentration in root (live & dead) was found at Burnihat, which was significantly ($p<0.05$) greater than that recorded at Upper Shillong. Cherrapunji showed the value which was between those recorded for the other two sites and did not differ significantly from either. Similarly, in rhizome (live & dead), concentration at Burnihat was greater than Upper Shillong. For the live and dead rhizomes, difference between protected and unprotected stands was insignificant.

Aboveground parts:

Nitrogen concentration in live shoot showed significant ($p<0.01$) monthly fluctuation (Fig. 6.3) in all the communities. The maximum nitrogen level at Burnihat was noticed in November when majority of plants attained maturity, after which it declined through winter months and showed an increase in May due to initiation of fresh growth in rainy season. In the subsequent months, i.e., June and July it again declined. At Cherrapunji, nitrogen concentration in live shoot did not vary significantly from August to October, decreased slightly during winter months and again increased in March. Similarly, March and April showed greater nitrogen concentration in live shoot in both the stands at Upper Shillong. In dead shoot monthly variation in nitrogen concentration was indistinct at all the sites. Monthly values of

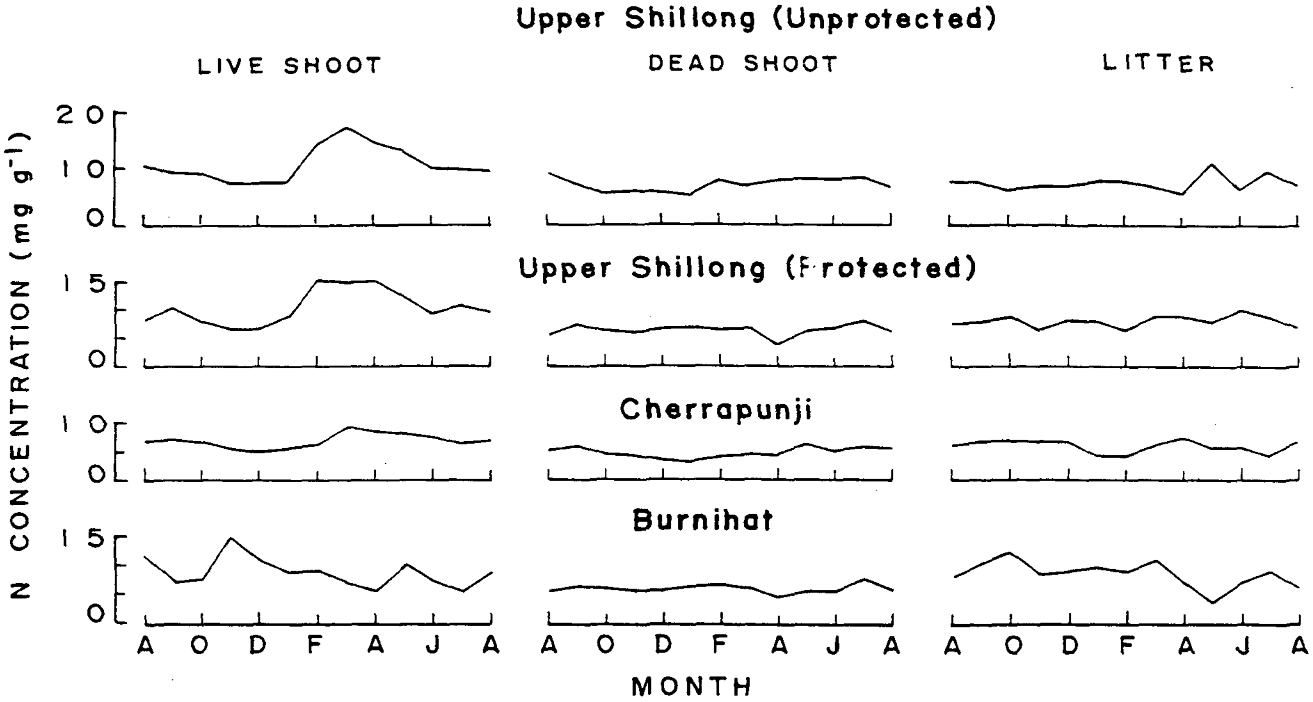


Fig. 6.3 Monthly variation in nitrogen concentration (mg g^{-1}) in live shoot, dead shoot and litter mass in four grassland communities.

nitrogen concentration in litter also did not exhibit marked seasonal pattern.

Table 6.4. Mean monthly concentration of N (mg g-1) in live shoot, dead shoot and litter components of grassland communities at four sites.

Site	Live shoot	Dead shoot	Litter	LSD
Burnihat	9.34 ± 0.71	6.24 ± 0.21	8.79 ± 0.58	**1.29**
Cherrapunji	7.30 ± 0.33	5.16 ± 0.27	6.28 ± 0.30	**0.72**
Upper Shillong Protected	10.76 ± 0.78	6.52 ± 0.34	8.21 ± 0.32	**1.26**
Unprotected	10.97 ± 0.85	7.48 ± 0.35	7.68 ± 0.40	**1.38**
LSD	**1.66**	**0.71**	**0.97**	

± SE denotes variability through months
LSD - Least Significant Difference at $p<0.05$

Mean monthly nitrogen concentration was greater in live shoot than in dead shoot and litter at all the sites (Table 6.4). The concentration in litter was, however, more than that in dead shoot. Concentration of nitrogen in shoot and root (live + dead) showed different trends in the three communities. In shoot, highest value was recorded at Upper Shillong followed by Burnihat and Cherrapunji whereas in root, the maximum concentration of nitrogen was recorded at Burnihat and minimum at Upper Shillong.

Accumulation of nitrogen in soil and vegetation compartments

Soil

There were significant seasonal differences in soil nitrogen capital ($p<0.05$) at Burnihat and in the unprotected stand at Upper Shillong (Table 6.5). At Burnihat, total nitrogen

Table 6.5. Seasonal variation in total N capital (Kg ha-1) in 0-30 cm soil layer at four study sites.

Season	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected	**LSD**
Late rainy (Aug'88-Oct)	7592	8697	14776	12053	**281**
Winter (Nov-Feb)	7426	8882	14533	11724	**380**
Summer (Mar-May)	7174	8805	15056	11494	**380**
Early rainy (Jun-Aug'89)	7781	8999	14400	11347	**320**
LSD	**280**	**NS**	**NS**	**270**	
Mean	**7488**	**8847**	**14679**	**11661**	

LSD - Least Significant Difference at $p<0.05$
NS - Differences are not significant

content declined during summer, but again it increased in the subsequent rainy season. In the unprotected stand, the value was slightly greater during late rainy season as compared to other seasons. At Cherrapunji and in the protected stand, however, nitrogen content in soil remained constant throughout different seasons. The intersite differences were highly significant ($p< 0.001$) in all the seasons. On the basis of mean monthly values, sites could be arranged in the following order: protected (14,679)>unprotected (11,661)>Cherrapunji (8,847)>Burnihat (7,488 Kg N ha-1).

Vegetation

Belowground compartments:

Throughout the year, nitrogen storage in the dead phytomass was many times lower than that in the live phytomass at all the sites (Fig. 6.4). At Burnihat, the seasonal values in the live compartment gave a bimodal curve; one summit was seen in September and the other in May. From September onwards the value declined until March and then increased rapidly to attain second peak in May, after which it again declined during June and July. The dead parts showed greater accumulation during later part of rainy season. At Cherrapunji also, the peak in the live compartment was noted in September. Accumulation decreased from September to December and then increased slightly to attain the second peak during February. In the dead compartment, accumulation was more during late rainy season than in other months. Similar trend was noticed at Burnihat. In the protected stand at Upper Shillong, nitrogen accumulation in live compartment showed a multimodal trend. The value increased consistently from November to February, and then decreased until May. Subsequently, a rapid growth in this compartment was recorded in June and July. The accumulation in dead belowground compartment at this site was maximum during August to October and minimum during November-December. In rest of the months, however, it was more or less constant. In the unprotected stand also, the seasonal values showed a multimodal curve. Nitrogen accumulation in live root decreased from August to December and then increased rapidly during January. In the month of February when aboveground vegetation was burned, the value declined slightly, but a corresponding increase took place in the dead compartment. Seasonal dynamics of nitrogen stored in the dead compartment was similar to that observed in the protected stand, except that the

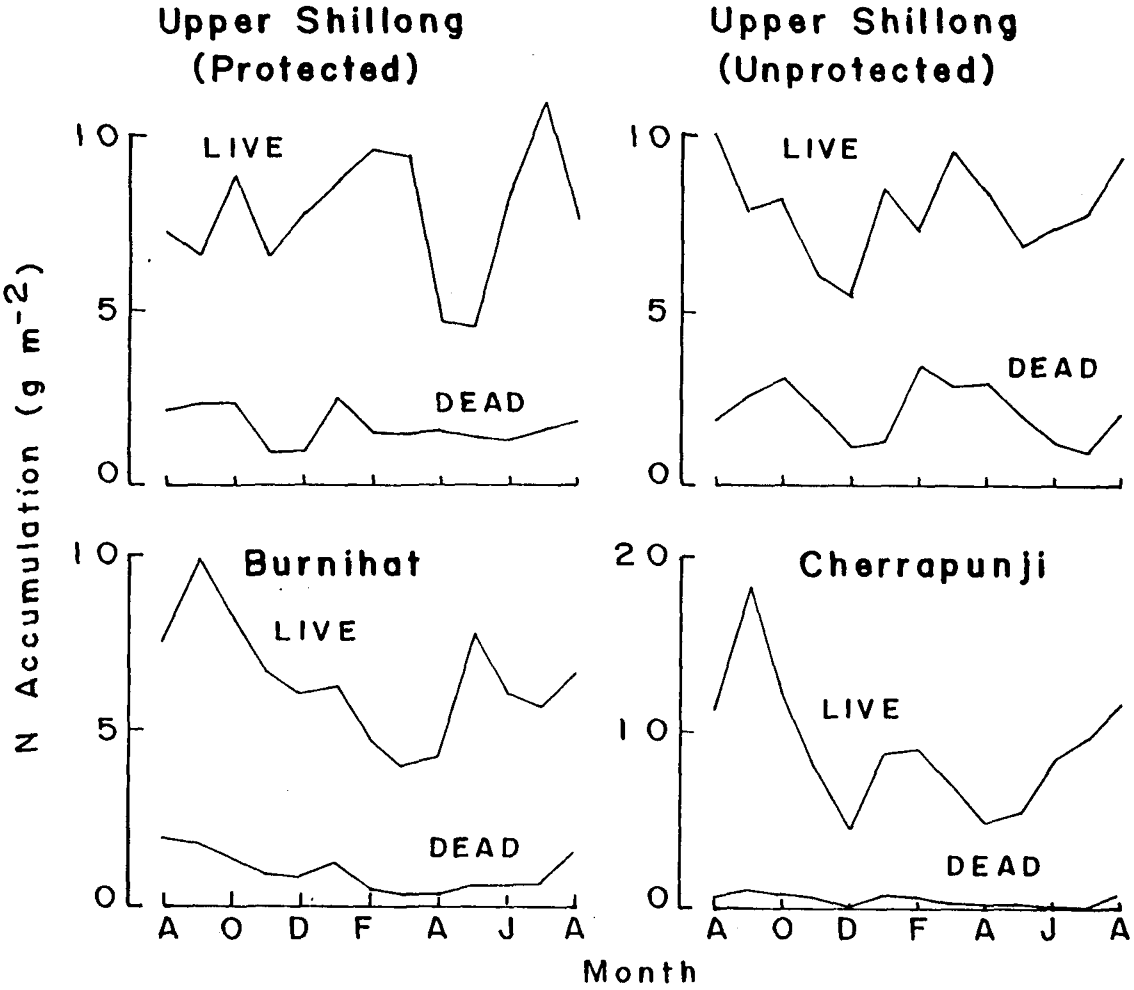


Fig. 6.4 Monthly variation in standing state of nitrogen ($g\ m^{-2}$) in live and dead components of the belowground phytomass in four grassland communities.

decline in the standing state was more rapid from April to July.

Seasonal values of nitrogen accumulation in total belowground phytomass at three soil depths showed that a major portion of nitrogen was present in upper (0-10 cm) layer of soil at all the sites (Fig. 6.5). Accumulation of nitrogen declined sharply at lower depths. At Burnihat and Cherrapunji, the middle and lower layers, however, showed slightly higher values during early rainy season in the protected stand and during late rainy and winter seasons in the unprotected stand at Upper Shillong.

Proportional allocation of nitrogen in total root and rhizome and total live and dead fractions of phytomass revealed that at all the sites and in all the seasons, a major portion of nitrogen was present in the live compartment (Table 6.6). Storage in the dead compartment was highest (about 20 %) in the unprotected stand at Upper Shillong and lowest (<5 %) at Cherrapunji. In this case, seasonality was not well marked, nevertheless, values were greater during late rainy season at all the sites except in the unprotected stand which showed higher accumulation during summer and lower in other seasons.

Table 6.6 further revealed that root stored a major portion of nitrogen at all the sites. The accumulation in rhizome was most prominent in the protected stand. At Cherrapunji, separation of root and rhizome could not be done, therefore, separate data for these compartments are not available. At Burnihat, rhizome compartment was prominent during rainy season, whereas in the protected stand at Upper Shillong it showed higher accumulation during winter and summer seasons. In the unprotected stand, however, the seasonal trend was not clear.

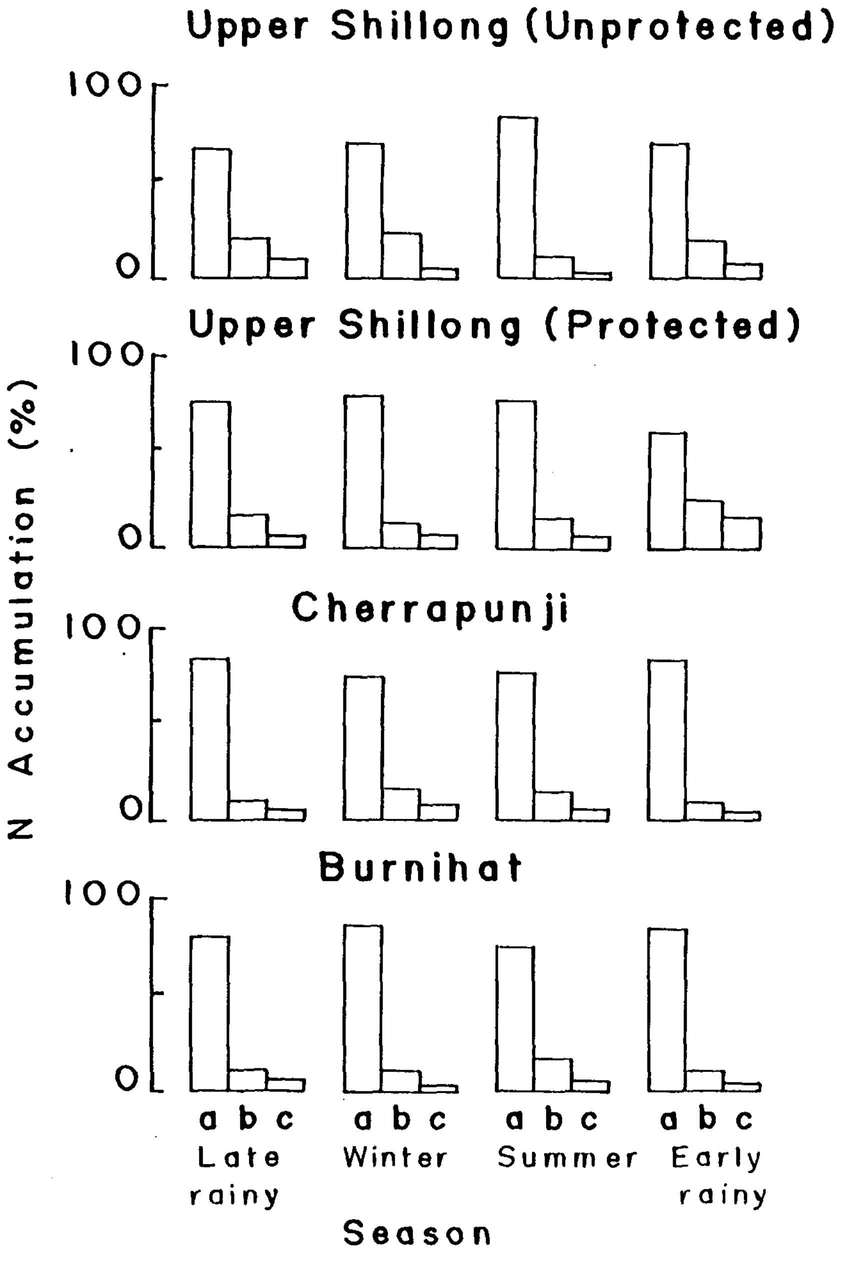


Fig. 6.5 *Seasonal variation in nitrogen accumulation in belowground phytomass at three soil depths; 0-10 (a), 10-20 (b) and 20-30 cm (c) in four grassland communities.*

Table 6.6. Seasonal variation in proportional allocation of N in different components of belowground phytomass in four grassland communities.

Belowground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Root	79.8	90.9	89.3	81.0
Rhizome	20.2	9.1	10.7	19.0
Live	83.5	87.7	93.2	86.8
Dead	16.5	12.3	6.8	13.2
		CHERRAPUNJI*		
Live	94.9	95.4	97.3	97.4
Dead	5.1	4.6	2.7	2.6
		UPPER SHILLONG (PROTECTED)		
Root	82.9	73.1	66.0	85.7
Rhizome	17.1	26.9	34.0	14.3
Live	76.1	84.7	80.6	83.5
Dead	23.9	15.3	19.4	16.5
		UPPER SHILLONG (UNPROTECTED)		
Root	91.8	89.8	91.6	88.0
Rhizome	8.2	10.2	8.4	12.0
Live	77.7	77.3	75.7	84.6
Dead	22.3	22.7	24.3	15.4

* Separate data for root and rhizome are not available

Aboveground compartments:

Monthly changes in nitrogen accumulation in live shoot, dead shoot and litter compartments are shown in Fig. 6.6. Live shoot showed maximum accumulation during August at Burnihat and Cherrapunji and during September in both the stands at Upper Shillong. It decreased from September onwards, reaching its minimum value in February/March. After winter season, when the

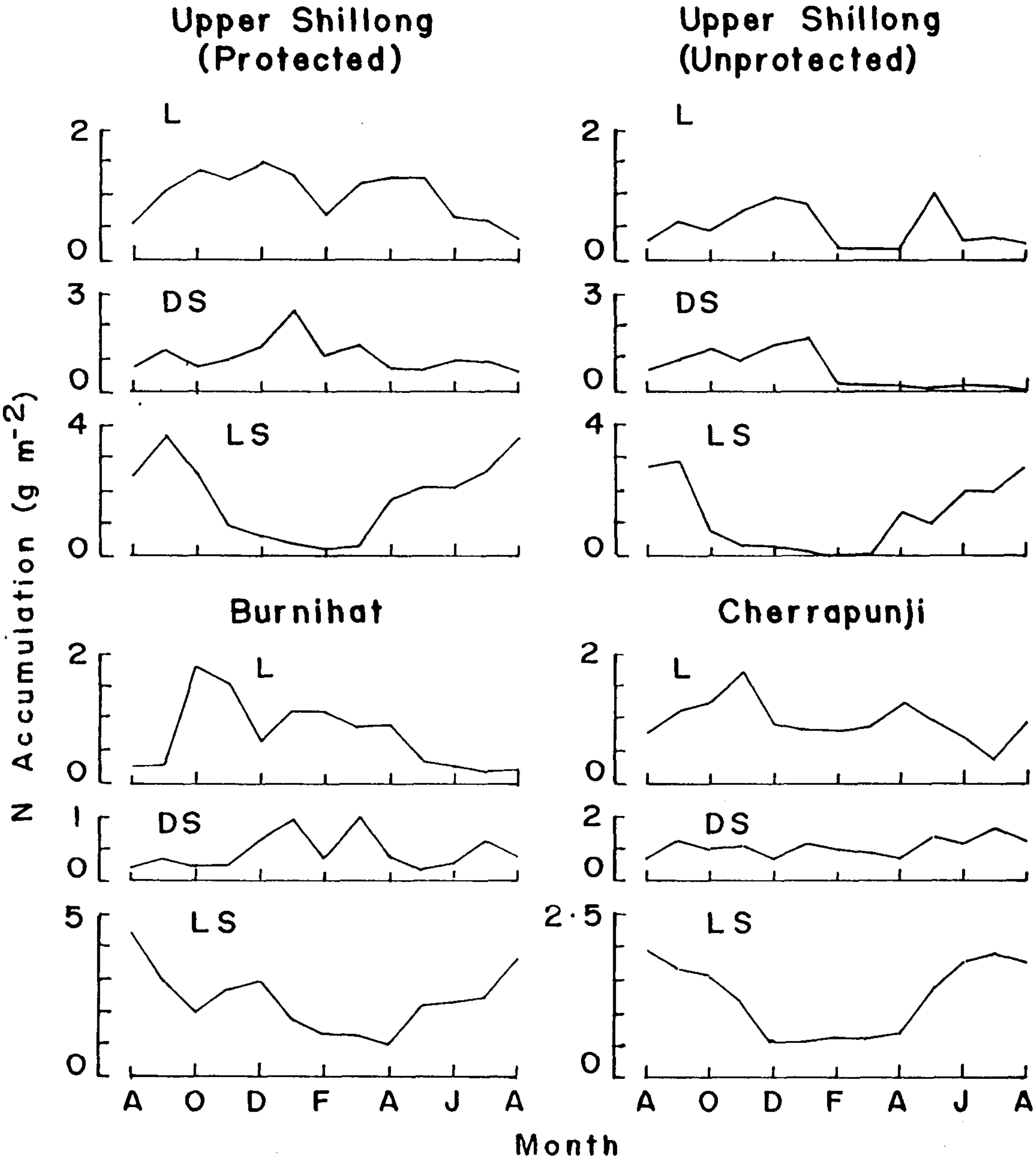


Fig. 6.6 Monthly variation in nitrogen accumulation (g m^{-2}) in live shoot (LS), dead shoot (DS) and litter (L) mass in four grassland communities.

vegetation showed rapid growth during spring, the nitrogen content in live shoot again increased sharply.

Except Cherrapunji, nitrogen content in dead shoot increased from August and attained its peak during January at all the sites. By that time, most of the plants in the community senesce and die. After January, nitrogen content in this compartment declined. In the unprotected stand, a sudden drop in nitrogen accumulation in dead shoot during February was due to burning of vegetation. At Cherrapunji, standing state of nitrogen in dead shoot was more or less constant throughout the year.

Nitrogen content in litter increased from August and attained peak in November/December at all the sites. During winter and spring (summer) seasons, it remained more or less constant and then declined rapidly during rainy season. However, due to burning of vegetation in the unprotected stand at Upper Shillong, accumulation in this compartment declined significantly in February and then remained so upto April. From April to May, there was a rapid gain of nitrogen in this compartment.

Data presented on seasonal basis (Table 6.7) reveal that at Burnihat nitrogen accumulation in shoot gradually declined from rainy to summer season. At Cherrapunji and Upper Shillong, it increased during ensuing summer and rainy season. The dead shoot accumulated relatively higher proportion of nitrogen during winter season at Burnihat and Upper Shillong. Seasonal trend was indistinct at Cherrapunji. The litter compartment followed the trend of dead shoot.

Proportional allocation of nitrogen showed that at Burnihat 57-81 % of the total standing state in shoot was present

Table 6.7. Seasonal variation in N accumulation (g m-2) and its proportional distribution (values in parentheses) in live shoot, dead shoot and litter in four grassland communities. ±SE denotes variability through months.

Aboveground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Live shoot	3.10 ±0.71 (74.4)	2.24 ±0.38 (57.3)	1.58 ±0.30 (60.2)	2.85 ±0.44 (80.8)
Dead shoot	0.28 ±0.04 (6.7)	0.56 ±0.16 (14.4)	0.35 ±0.09 (13.3)	0.46 ±0.11 (13.0)
Litter	0.79 ±0.51 (18.9)	1.11 ±0.19 (28.3)	0.69 ±0.18 (26.5)	0.22 ±0.03 (6.2)
		CHERRAPUNJI		
Live shoot	1.71 ±0.12 (45.5)	0.72 ±0.16 (25.8)	0.89 ±0.24 (30.1)	1.80 ±0.04 (46.3)
Dead shoot	1.01 ±0.17 (26.8)	0.99 ±0.10 (35.4)	1.04 ±0.21 (34.9)	1.39 ±0.16 (35.8)
Litter	1.05 ±0.14 (27.7)	1.08 ±0.22 (38.8)	1.04 ±0.10 (35.0)	0.69 ±0.16 (17.9)
		UPPER SHILLONG (PROTECTED)		
Live shoot	2.92 ±0.41 (59.8)	0.53 ±0.15 (16.4)	1.41 ±0.55 (38.8)	2.81 ±0.49 (66.2)
Dead shoot	0.96 ±0.16 (19.6)	1.52 ±0.34 (46.7)	0.94 ±0.23 (25.9)	0.87 ±0.10 (20.4)
Litter	1.01 ±0.24 (20.5)	1.20 ±0.17 (36.9)	1.28 ±0.03 (35.3)	0.57 ±0.10 (13.4)
		UPPER SHILLONG (UNPROTECTED)		
Live shoot	2.11 ±0.70 (58.3)	0.22 ±0.07 (10.5)	0.84 ±0.40 (55.7)	2.27 ±0.27 (81.4)
Dead shoot	1.01 ±0.18 (28.0)	1.14 ±0.32 (55.0)	0.17 ±0.03 (11.5)	0.20 ±0.02 (7.0)
Litter	0.49 ±0.09 (13.7)	0.72 ±0.17 (34.6)	0.49 ±0.29 (32.8)	0.32 ±0.02 (11.6)

in the live fraction (Table 6.7). This was followed by litter compartment which stored 6-26 % of total aboveground accumulation. Proportion in dead shoot never exceeded 14 %. At Cherrapunji, allocation of nitrogen in the three compartments was more equitable, but they could be ranked as live shoot>dead shoot> litter. At Upper Shillong, seasonal differences were quite prominent. In both the stands at this site, relative accumulation

Table 6.8. Monthly variation in N accumulation (g m-2) in belowground and aboveground compartments of the grassland community at Burnihat.

Month	Belowground	Aboveground		Total	
		LS+DS	LS+DS+L		
	(a)	(b)	(c)	(a+b)	(a+c)
Aug'88	9.47	4.66	4.91	14.12	14.38
Sep	11.64	3.21	3.50	14.85	15.14
Oct	9.45	2.28	4.09	11.73	13.53
Nov	7.43	2.97	4.51	10.40	11.95
Dec	6.78	3.70	4.33	10.48	11.12
Jan'89	7.37	2.72	3.85	10.09	11.22
Feb	5.18	1.81	2.93	6.98	8.10
Mar	4.25	1.88	2.72	6.13	6.97
Apr	4.49	1.54	2.44	6.03	6.93
May	8.38	2.34	2.68	10.72	11.06
Jun	6.60	2.64	2.91	9.24	9.51
Jul	6.27	3.17	3.34	9.43	9.61
Aug	8.32	4.13	4.34	12.45	12.66

LS - Live Shoot; DS - Dead Shoot; L - Litter

in live shoot declined from about 59 % in late rainy season to about 11-16 % in winter season. From the point of view of nitrogen accumulation, the compartments could be ranked as live shoot>dead shoot>litter.

Throughout the year nitrogen accumulation in belowground parts was greater than the aboveground component at all the sites (Tables 6.8 to 6.11). In both the compartments

Table 6.9. Monthly variation in N accumulation (g m-2) in below-ground and aboveground compartments of the grassland community at Cherrapunji.

Month	Belowground	Aboveground		Total	
		LS+DS	LS+DS+L		
	(a)	(b)	(c)	(a+b)	(a+c)
Aug'88	11.77	2.66	3.45	14.44	15.22
Sep	19.26	2.94	4.05	22.20	23.31
Oct	12.68	2.58	3.82	15.26	16.49
Nov	8.40	2.28	4.01	10.68	12.41
Dec	4.57	1.23	2.17	5.80	6.74
Jan'89	9.33	1.72	2.57	11.06	11.90
Feb	9.25	1.60	2.42	10.84	11.66
Mar	7.05	1.52	2.41	8.57	9.46
Apr	4.88	1.45	2.68	6.33	7.56
May	5.58	2.82	3.80	8.39	9.38
Jun	8.58	2.95	3.71	11.53	12.29
Jul	9.76	3.56	3.94	13.32	13.70
Aug	12.38	3.04	3.97	15.42	16.36

LS - Live Shoot; DS - Dead Shoot; L - Litter

Table 6.10. Monthly variation in N accumulation (g m-2) in below ground and aboveground compartments in the protected grassland community at Upper shillong.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c
Aug'88	9.42	3.25	3.81	12.66	13.2
Sep	8.99	5.02	6.09	14.01	15.0
Oct	11.26	3.35	4.72	14.61	15.9
Nov	7.44	1.96	3.23	9.40	10.6
Dec	8.82	1.98	3.51	10.80	12.3
Jan'89	11.26	2.90	4.18	14.17	15.44
Feb	11.18	1.34	2.07	12.52	13.25
Mar	10.89	1.71	2.94	12.60	13.84
Apr	6.31	2.53	3.82	8.85	10.13
May	5.97	2.79	4.11	8.77	10.08
Jun	5.98	3.03	3.71	9.01	9.69
Jul	10.12	3.61	4.26	13.72	14.38
Aug	12.92	4.39	4.75	17.31	17.67

LS - Live Shoot; DS - Dead Shoot; L - Litter

accumulation was low from February to April. Mean monthly value of standing state of nitrogen in belowground parts was significantly lower at Burnihat than the other sites ($p<0.05$), but the difference between Cherrapunji and Upper Shillong was insignificant (Table 6.12). At Upper Shillong, however, storage in belowground phytomass was more in the unprotected stand than the protected stand.

The trend of nitrogen accumulation in shoot (live +

Table 6.11. Monthly variation in N accumulation (g m-2) in belowground and aboveground compartments in the unprotected grassland community at Upper shillong.

Month	Belowground	Aboveground		Total	
		LS+DS	LS+DS+L		
	(a)	(b)	(c)	(a+b)	(a+c)
Aug'88	12.01	3.42	3.76	15.43	15.78
Sep	10.48	3.91	4.57	14.39	15.05
Oct	11.32	2.03	2.51	13.35	13.82
Nov	8.36	1.32	2.14	9.68	10.50
Dec	6.66	1.85	2.83	8.51	9.47
Jan'89	9.87	1.97	2.81	11.83	12.68
Feb	10.89	0.28	0.50	11.17	11.39
Mar	12.46	0.26	0.46	12.72	12.92
Apr	11.37	1.60	1.81	12.98	13.18
May	9.03	1.16	2.22	10.19	11.26
Jun	8.67	2.21	2.53	10.88	11.20
Jul	8.86	2.21	2.56	11.07	11.42
Aug	11.60	2.97	3.26	14.57	14.86

LS - Live Shoot; DS - Dead Shoot; L - Litter

dead) was different. At Cherrapunji, the value was less than those of Burnihat and Upper Shillong protected stand but it did not differ much between the latter two sites. In the unprotected stand, accumulation in shoot was significantly lower than the protected stand. Belowground compartment showed a reverse trend in this regard. The pattern of nitrogen accumulation at different sites did not change even if the nitrogen content of litter was added to the values of shoot. Mean standing state of nitrogen in shoot biomass (live + dead) showed a significant positive relationship ($r=0.98$, $p<0.01$) with altitude according to the following regression:

$$Y = 10.174 + 0.001\ X$$

where, Y is the nitrogen content (g m-2) and X is the altitude (m).

When litter was added to shoot, the significance level declined to $p<0.10$. Total (aboveground + belowground) nitrogen accumulation was minimum at Burnihat and maximum at Upper Shillong.

Table 6.12. Mean monthly accumulation of N (g m-2) in total belowground and aboveground compartments of four grassland communities.

Site	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Burnihat	7.36 ± 0.59	2.85 ± 0.26	3.58 ± 0.22	10.20 ± 0.76	10.94 ± 0.73
Cherrapunji	9.50 ± 1.10	2.33 ± 0.21	3.31 ± 0.20	11.83 ± 1.22	12.81 ± 1.22
Upper Shillong protected	9.27 ± 0.63	2.91 ± 0.29	3.94 ± 0.27	12.19 ± 0.74	13.21 ± 0.70
unprotected	10.12 ± 0.47	1.94 ± 0.30	2.46 ± 0.32	12.06 ± 0.57	12.58 ± 0.53
LSD	NS	0.63	0.62	NS	NS

LS - Live Shoot; DS - Dead Shoot; L - Litter
LSD - Least Significant Difference at $p<0.05$
± SE denotes variability through months
NS - Variation not significant

Belowground/aboveground ratio

This ratio was more than unity throughout the year at all the sites (Fig. 6.7), thereby indicating relatively greater nitrogen accumulation in the belowground phytomass in all the

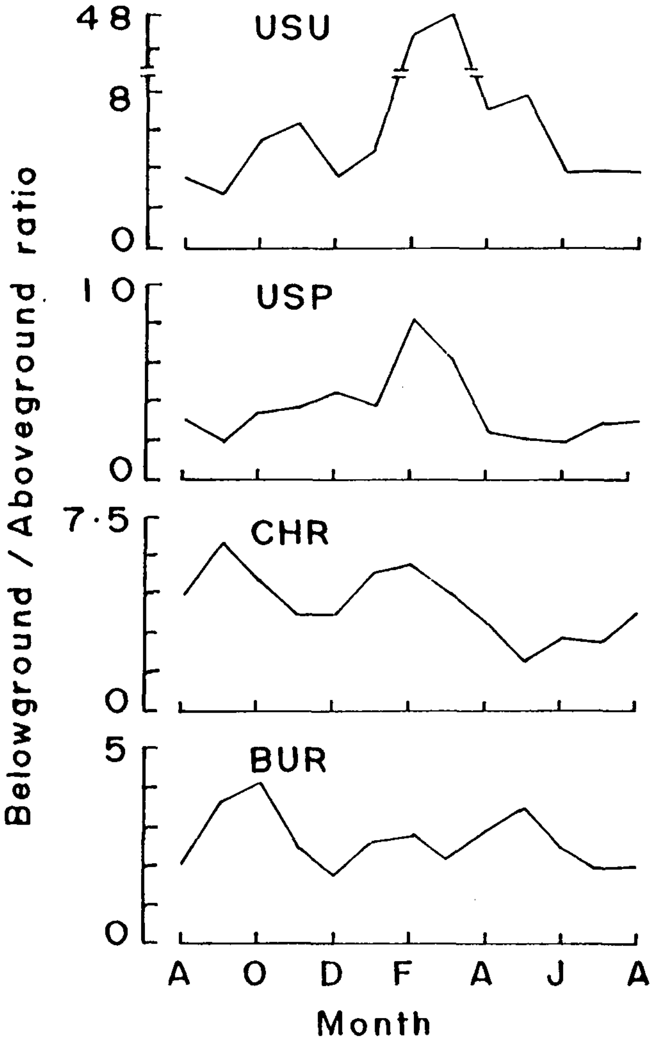


Fig. 6.7 *Monthly variation in the ratio of nitrogen accumulation in belowground and aboveground compartments of four grassland communities. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

communities. At Cherrapunji and Upper Shillong, the ratio was more during January to March compared to other months, mainly because of senescence and death of aerial parts. At Burnihat, similar seasonal pattern was not observed, probably because the aboveground vegetation did not show complete senescence at this site during winter season. The mean monthly ratio was 2.58, 4.07, 3.18 and 5.22 at Burnihat, Cherrapunji, and in protected and unprotected stands at Upper Shillong, respectively.

Proportional distribution of nitrogen in soil and vegetation components

Of the total nitrogen present in the plant-soil system in four grassland communities, more than 98 % was in soil and only 1 to 1.5 % participated in biological circulation (Table 6.13). A major portion of nitrogen locked in the community biomass was reflected in the belowground compartments, particularly in the live fraction (root + rhizome). Differences in the distribution pattern of nitrogen in the compartments (as per cent of total in each compartment) was analysed through a two-way factorial multivariate analysis of variance. The analysis was run with all six compartments, viz., live shoot , dead shoot, litter, live belowground, dead belowground and soil. The results showed that the distribution pattern of nitrogen was significantly influenced by site ($p<0.01$) and compartment ($p<0.01$) and so was the effect of interaction between site and compartment ($p<0.05$). As pointed out by Bokhari & Singh (1975), this analysis may prohibit a fair conclusion since the amount of nitrogen present in the soil was more than 100 times greater than in the other compartments. Therefore, soil was excluded in second analysis, but the results remained unchanged.

Table 6.13. Proportional distribution of N in plant/soil system of four grassland communities. Values are based on means across the months (Aug'88 to Aug'89).

Component	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected
Aboveground vegetation	0.38	0.26	0.08	0.07
Live	0.32	0.14	0.07	0.06
Dead	0.06	0.12	0.01	0.01
Litter	0.10	0.11	0.07	0.04
Belowground vegetation	0.96	1.06	0.63	0.86
Live	0.84	1.02	0.51	0.68
Dead	0.12	0.04	0.12	0.18
Total vegetation	1.44	1.43	0.78	0.97
Soil*	98.56	98.57	99.22	99.03

* Total organic nitrogen

Uptake, transfers and release of nitrogen

Total annual nitrogen uptake varied from 136.9 to 231.7 Kg ha-1 among the four sites (Table 6.14). Approximately two-third of the total uptake at Burnihat and Upper Shillong was reflected in belowground parts. At Cherrapunji, significance of belowground parts was still greater as uptake by belowground parts accounted for 87 % of total uptake in the community.

At Burnihat, 16 % more nitrogen was transferred from live shoot to dead shoot as compared to the uptake by the live shoot. Rate of transfer of nitrogen from dead shoot to litter and its release from the litter were almost equal to the inputs to

Table 6.14. Annual[*] uptake, transfers and release of N (Kg ha-1) in four grassland communities.

	Burnihat	Cherrapunji	Upper Shillong	
Flow			protected	unprotected
Uptake in ANP	44.86	29.95	66.41	47.66
Uptake in BNP	91.99	201.75	139.86	98.90
Total uptake	136.87	231.70	206.27	146.56
Transfer from live to dead shoot	51.89	31.91	54.01	46.65
Transfer from dead shoot to litter	50.14	26.21	55.02	52.13
Transfer from live to dead root	100.10	197.08	101.89	106.07
Release from litter	50.64	24.68	56.99	52.69
Release from dead root	103.43	195.64	104.78	103.06
Total release	154.07	220.32	161.77	155.75
% Recycle (Total release x 100/Total uptake)	112.6	95.1	78.4	106.3

* No. of days: Burnihat-382; Cherrapunji-379; Upper Shillong-406
ANP -Aboveground Net Production; BNP -Belowground Net Production

the respective compartments (Fig. 6.8). In the belowground parts transfer of nitrogen from live to dead compartment exceeded about 91 % of the total belowground uptake. The release from the dead compartment was more than the input to this compartment, resulting thereby a net loss of 9 % compared to the total nitrogen uptake from the belowground compartment (Table 6.15).

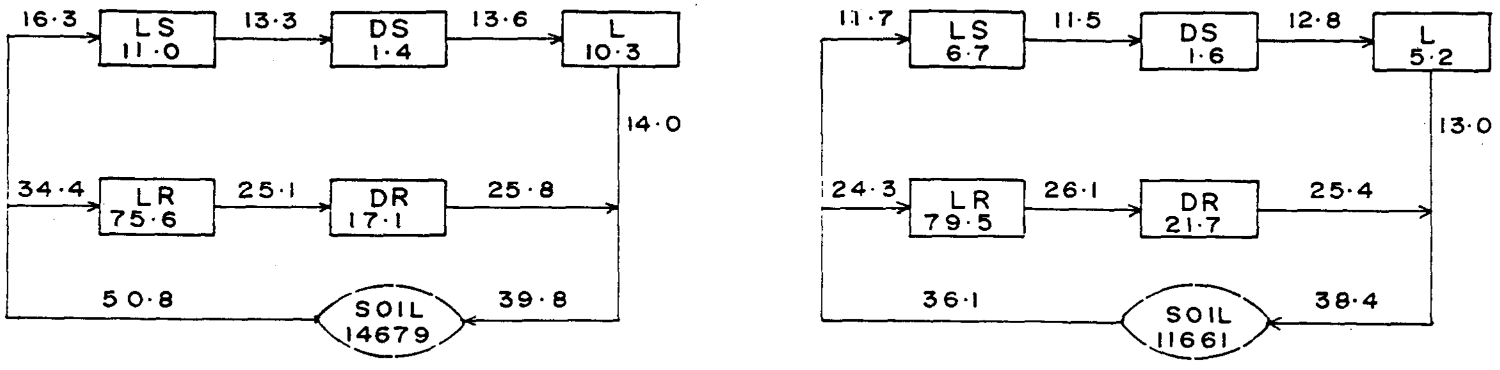
At Cherrapunji, nitrogen transfer from live shoot to dead shoot was about 7 % more than the uptake. Transfers from dead shoot to litter and then release from litter were 18 and 6 % less, respectively, as compared to the inputs to the respective compartments. Thus about 2 % of total annual uptake was retained in the aboveground vegetation during the study period (Table 6.15). In the belowground parts retention was about 3 % of the total annual uptake; two-third of which was locked up in the live component and rest in the dead fraction.

Table 6.15. Uptake, release and retention calculated as per cent of total uptake.

	Uptake in		Release from		Retention in	
Site	AG	BG	AG	BG	AG	BG
Burnihat	33	67	37	76	-4	-9
Cherrapunji	13	87	11	84	2	3
Upper Shillong protected	32	68	28	51	4	17
unprotected	33	67	36	70	-3	-3

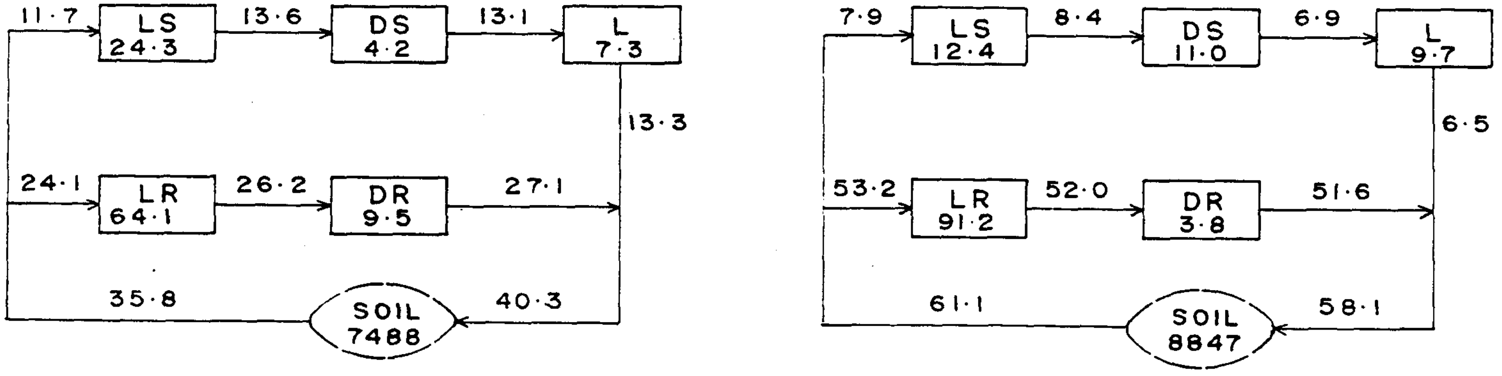
AG - Aboveground; BG - Belowground

In the protected stand at Upper Shillong, nitrogen uptake by shoot exceeded (19 %) than its transfer from live to dead shoot compartment. However, the transfer of nitrogen from dead shoot to litter and then its release from the litter was slightly higher than the input into respective compartments. Finally, about 4 % of total annual nitrogen uptake was retained



Upper Shillong (Protected)

Upper Shillong (Unprotected)



Burnihat

Cherrapunji

Fig. 6.8 *Mean standing state of nitrogen in vegetation, litter and soil compartments and net flux rates in four grassland communities of Meghalaya. Values within boxes are mean standing state (Kg* ha^{-1}*) and those on arrows are net flux rates (mg* m^{-2} d^{-1}*). (LR - Live root; DR - Dead root; LS - Live shoot; DS - Dead shoot and L - Litter).*

in shoot during the study period. In the unprotected stand, almost all uptake was transferred from live shoot to litter through dead shoot compartment and during the study period about 3 % more nitrogen than the total uptake was lost by shoot.

The transfer of nitrogen from live to dead belowground compartment was 27 % less than the uptake in the protected stand at Upper Shillong. The release from the dead belowground compartment was 3 % more than the input. Total input and output of nitrogen in belowground compartment showed a net retention of 17 %; a major portion of which was present in the live compartment. In the unprotected stand, on the other hand, transfer from live to dead belowground compartment was 7 % more than uptake. The release from the dead compartment was, however, relatively less (3 %) than the input. Total input and output showed a net loss of nitrogen both from above- and belowground compartments of the community.

Nitrogen turnover and cycling

The turnover rate (k) indicates relative mobility of a compartment. Nitrogen turnover rate for litter compartment was greater than aboveground as well as belowground compartments at all the sites (Table 6.16). At Burnihat, nitrogen turnover rate in aboveground parts was faster than the belowground compartment. This trend was reversed at Cherrapunji. At Upper Shillong, in the protected stand, turnover rate of nitrogen was almost equal in the two compartments. However, in the unprotected stand, belowground compartment showed much rapid turnover rate than the aboveground compartment. At the community level, nitrogen turnover rates were not strikingly different among the sites;

they ranged between 0.90 to 0.99. Comparison of turnover rates between protected and unprotected stand revealed that the protection against annual burning and cattle grazing increased the rate for litter compartment but decreased the same for belowground parts. At the community level, however, the two stands exhibited similar rates.

Table 6.16. Nitrogen turnover rates for aboveground and belowground vegetation and litter compartments in four grassland communities.

Site	Turnover rate (k)			
	Belowground	Aboveground	Litter	Total
Burnihat	0.79	0.91	1.18	0.90
Cherrapunji	1.05	0.74	1.11	0.99
Upper shillong protected	1.08	1.09	1.09	0.97
unprotected	0.79	1.04	1.61	0.93

The flux rates of nitrogen varied widely over sites (Fig. 6.8). The rate of total uptake and release was maximum at Cherrapunji. At Burnihat and in the unprotected stand at Upper Shillong, the flux rates were of nearly similar magnitude. In the protected stand, however, the uptake rate was almost equal to that in the unprotected stand. At all the sites, flux rates through belowground vegetation components were higher than those through aboveground vegetation.

DISCUSSION

Despite large differences in the standing state of nitrogen in soil and species composition between the communities, intersite variation in nitrogen concentration in belowground component was insignificant. Lower concentration of nitrogen in dead root than in the live fraction indicates a substantial withdrawal of nitrogen following senescence, corroborating the results of Chaturvedi *et al.* (1988). However, relatively higher nitrogen concentration in root than rhizome is obviously related to their greater metabolic activity than the latter which is primarily a storage organ. Seasonal pattern in nitrogen concentration was also similar at all the sites. Significantly lower concentration during August to December roughly corresponded with the active period of biomass production, thereby, indicating the possibility of retranslocation and/or dilution of nutrient resources within the plant body during this part of the year.

Markedly lower nitrogen concentration in live shoot, dead shoot and litter at Cherrapunji is apparently related to the species composition of the community, which is dominated by hardy and unpalatable grasses like *Arundinella khaseana, Chrysopogon gryllus, Eulalia trispicata* and *Eragrostiella leioptera* (Dabadghao & Shankarnarayan 1973). Apart from the nature of constituent species, soil conditions, particularly lower moisture regime during most part of the year and acidic pH of the coarse-textured soil might have adversely influenced the availability of nitrogen to plants. Among other sites, however, variations in nitrogen concentration in different tissues were not significant in spite of dissimilarities in the species composition and wide variations in total nitrogen reserve in the soil. The overall trend of nitrogen concentration in vegetation compartments was live shoot>litter>dead shoot. Greater concentration of nitrogen in litter than in dead shoot may be due to rapid loss of carbohydrates during early phase of decomposition and/or net immobilization of nitrogen in associated microbial cells during the course of litter decomposition (Swift *et al.* 1979; Melillo *et al.* 1982). Floate (1970) studied decomposition of pasture grasses under laboratory conditions and found that as decomposition proceeded, carbon was progressively lost and there was a net increase in mineral nitrogen throughout the study period of 12 weeks. Ram & Ramakrishnan (1988a) also reported a net gain of nitrogen upto 160 % during the first few months of litter decomposition on the soil surface at Cherrapunji. They hypothesized that this increase might be because of various reasons such as fixation, absorption of ammonia, throughfall input and immobilization through microbes. Reports from other Indian grasslands show that the nitrogen concentration declines continuously as the aboveground plant parts die or senesce and convert to litter (Mishra 1979; Billore & Mall 1985; Chaturvedi *et al.* 1988). This decline has been attributed to the withdrawal of nitrogen from shoot following senescence and to the weathering and leaching processes. Greater nitrogen level in live shoot during spring season (February-May) at Cherrapunji and Upper Shillong could be ascribed to the new flush of shoot growth after chilly winter. At Burnihat, nitrogen level in shoot at the end of rainy season was more than that during spring when majority of species were in the vegetative growth; presumably because of its greater accumulation in matured reproductive organs.

Greater allocation of biomass and nutrients to the belowground parts is regarded as an efficient mechanism for survival under stress conditions (Grime 1979). According to Chapin (1980), this is an adaptive strategy of plants to maximize the root surface area for uptake so that they need not always depend on their high nutrient absorption capacity (Nye 1977; Nye & Tinker 1977). The allocation pattern of dry matter to aboveground and belowground parts of the community plays a vital role in the proportional distribution of nutrients in the compartments. In spite of the fact that nitrogen concentration between the two components was not much different, belowground phytomass accumulated 67-80 % of the total nitrogen content in the community. This is evidently related to the higher allocation of organic matter to the belowground parts. Findings of a study carried out at Cherrapunji by Ram & Ramakrishnan (1988b) reveal that species like *Chrysopogon*, *Eragrostiella*, *Arundinella* and *Ischaemum* apportion more biomass to the belowground organs. Different environmental factors seemed to have favoured higher allocation of nitrogen in belowground parts at different sites. At Cherrapunji, edaphic factors particularly low moisture level which declines to 6-7 % during November to March and highly gravely and coarse-textured (76 % particles being over 2 mm size) acidic soil and prolonged severe winter for about five months influenced the composition of the community. Conversely, biotic stresses in the form of annual burning of vegetation during dry winter period, mild cattle grazing and severe winter were more important at the high altitude site, i.e., Upper Shillong. The communities at the two sites although differed in species composition, both of them were dominated by chamaephytes. Thus dominance of chamaephytic flora in both the communities was the chief cause of greater allocation of biomass to the belowground parts. Further, when the community was protected from grazing and burning, there was a decline in the proportion of biomass to the belowground parts from 80 to 70 %. The climatic conditions at Burnihat are different from those at Cherrapunji and Upper Shillong because of low annual rainfall and relatively higher winter temperature. One-half of the community forming species were annuals at this site which resulted into lower accumulation in belowground biomass. Therefore, it is reasonable to assume that those environmental conditions and biotic stresses which favoured accumulation of biomass in belowground parts were also responsible for greater nitrogen storage in this compartment. Greater nutrient allocation to belowground system tightens the cycling process and helps conserve nutrients in the biotic component of the ecosystem. Why more reserves are allocated to root growth compared to shoot growth under low level of nutrient availability remains unclear. Brouwer (1966) suggested that because root meristems are closer to the nutrient supply, they receive a disproportionately greater share of nutrients and consequently, grow more rapidly than the shoot meristems until the nutrient:carbohydrate ratio increases to the point where carbohydrate becomes more limiting to their growth, then shoot meristems being closest to the source of carbohydrate grow disproportionately. Although Brouwer's hypothesis is the framework of several simulation models of plant growth that predict distribution of nutrients and carbohydrates between roots and shoots (Baldwin 1976), it is not entirely consistent (Clarkson *et al.* 1978).

Seasonal dynamics of nitrogen in belowground compartment also varied over the sites. Peak accumulation at the end of rainy season emphasizes that nutrient accumulation was related to the growth of vegetation. Burnihat, however, did not show a marked seasonal trend because of lack of distinct flushes of growth as observed at other two sites. At this site, because of mild winter and relatively high humidity even during summer months, growth of plants in the community continued almost throughout the year. Unlike Burnihat, at Cherrapunji and Upper Shillong, winter season was marked by the senescence or death of aboveground parts of majority of species in the community. A slight increase in nitrogen storage in the belowground parts at these two sites during winter, therefore, indicates the possibility of transfer of nitrogen from senescing shoot to the perennating organs belowground. During winter, at Upper Shillong almost all the aboveground parts died, whereas at Burnihat some shoot growth continued due to relatively higher temperature. With the onset of growing season in March-April, new flush of growth started with the emergence of seedlings of annual species and sprouting of new shoot from perennating organs. This resulted into a rapid increase of nitrogen in shoot during this period which continued almost until the end of rainy season.

Besides, seasonal variation, proportional allocation of nitrogen in live belowground and aboveground components was related to altitude. The former showed a weak positive correlation with altitude but the latter was negatively correlated (Table 6.17).

Table 6.17. Relationship between altitude and perennials in the community and per cent distribution of nitrogen in aboveground and belowground biomass in the grassland communities of Meghalaya.

Dependent variable (Y)	Independent variable (X)	Regression equation	Correlation coefficient	p
% N in BGB	Altitude	$Y = 64.618 + 0.010\ X$	0.91	0.10
% N in BGB	Perennials	$Y = 43.744 + 0.480\ X$	0.94	0.10
% N in AGB	Altitude	$Y = 22.324 - 0.008\ X$	-0.98	0.05
% N in AGB	Perennials	$Y = 37.176 - 0.359\ X$	-0.95	0.05

Change in species composition in the community also influenced the storage of nitrogen in the aboveground live phytomass as is evident from a significant positive correlation between nitrogen content in live shoot and proportion of perennial species in the community. Annual burning and mild cattle grazing were other important factors which influenced standing state of nitrogen in aboveground and belowground compartments of the community.

Nitrogen cycling within the four grassland communities presented in Fig. 6.8 reveals maximum uptake rate in the Cherrapunji community, which has developed on an apparently degraded and nutrient impoverished soil. Similarly, rate of nitrogen input to the soil through decaying belowground and aboveground detritus was also higher in this community. Conversely, the communities which have developed on apparently more fertile soils either at the lower or higher elevations of Meghalaya exhibited considerably lower uptake and release rates. Thus the grassland community at Cherrapunji is different from other two communities of Meghalaya in being more dynamic in respect of internal nitrogen cycling. Although in all the communities, a major portion of nitrogen was channelised through belowground compartment, its role was more important in the Cherrapunji grassland.

In general, nitrogen turnover rate was nearly twice faster than that recorded in the semiarid grassland at Ujjain (Billore & Mall 1985). This is obviously related to the prevailing climate of the region which not only favours better plant growth but also increases the rate of decomposition of dead plant material. Differences in species composition between the communities seem to have played minor role in this regard, since the turnover values showed little variation among the three sites. However, relatively higher nitrogen turnover rates in litter and aboveground compartments in the unprotected stand may be attributed to grazing and burning, while faster nitrogen turnover in the belowground compartment at Cherrapunji compared to aboveground parts is ascribed chiefly to the higher proportion of live roots.

A comparison of uptake, release and recycle of nitrogen in the grassland communities of Meghalaya with those from other ecoclimatic zones of India reveals that nitrogen uptake by shoot is more in dry subhumid grasslands, while in the semiarid and

Table 6.18. Nitrogen uptake, release (Kg ha-1 Yr-1) and recycling (%) in Indian grasslands.

	Uptake			Release			Recycle			
Grassland type	AG	BG	Total	AG	BG	Total	AG	BG	Total	Author(s)
					Semiarid grasslands					
Ratlam	28.7	28.8	58.4	16.5	12.8	29.3	57.3	43.2	50.2	Billore & Mall (1976)
Kurukshetra	285.8	12.2	410.0	173.8	116.1	289.8	60.8	93.4	70.7	Yadava (1980)
Ujjain										Billore & Mall (1985)
Zero grazed	201.8	62.6	264.4	34.1	50.4	84.5	16.9	80.5	32.0	
Light grazed	115.9	35.2	151.1	8.4	42.1	50.5	7.2	119.6	33.4	
Moderate grazed	78.9	49.1	128.0	7.8	26.7	34.5	9.9	54.4	27.0	
Heavy grazed	58.6	62.5	121.1	14.2	21.6	35.8	24.2	34.6	29.6	
					Dry-subhumid grasslands					
Kanpur										Mishra (1979)
Protected	261.0	84.5	345.5	14.6	77.2	91.8	5.6	91.4	26.6	
Semiprotected	159.7	55.6	215.3	7.2	50.2	57.4	4.5	90.3	26.7	
Opengrazed	86.5	32.7	119.2	4.1	29.6	33.7	4.7	90.5	28.3	
Varanasi (BHU)										Pandey (1976)
Winter burn	229.0	40.3	270.2	7.7	13.3	21.0	3.4	33.0	7.8	
Winter+Summer burn	286.8	39.1	325.9	9.1	20.0	29.2	3.2	51.2	9.0	
Protected	196.8	31.1	227.9	8.8	6.1	15.0	4.5	19.6	6.6	
Varanasi										Pandey & Singh (1990)
1-Yr Old field	225.0	393.0	618.0	165.0	398.0	563.0	73.3	101.3	91.1	
2-Yr Old field	434.0	422.0	856.0	403.0	388.0	791.0	92.9	91.9	92.4	
3-Yr Old field	97.0	354.0	451.0	11.0	41.0	52.0	11.3	11.6	11.5	
					Himalayan grasslands					
Pauri										Tiwari (1985)
Erianthus	44.8	42.6	87.4	5.0	42.7	47.7	11.2	100.2	54.6	
Arundinella	31.4	24.1	55.5	2.8	27.4	30.2	8.9	113.7	54.4	
Garhwal										Agrawal & Tiwari (1987)
Open grazed	13.4	9.3	22.6	7.6	1.9	9.6	57.2	20.9	42.3	
Protected	58.0	12.8	70.9	46.9	13.8	60.7	80.8	107.4	93.2	
Winter burn	17.1	4.6	21.7	9.8	2.1	11.9	57.0	46.0	54.7	
Winter+Summer burn	19.2	9.1	28.3	11.3	2.3	13.6	59.0	25.5	48.2	
Champhi (Nainital)	23.0	10.2	33.2	18.1	7.6	25.7	78.7	74.5	77.4	Chaturvedi *et al.* (1988)
					Humid grasslands					
Burnihat	44.9	92.0	136.9	50.6	103.4	154.1	112.9	112.4	112.6	*This study*
Cherrapunji	30.0	201.8	231.7	24.7	195.6	220.3	82.4	97.0	95.1	--do--
Upper Shillong										
protected	66.4	139.9	206.3	57.0	104.8	161.8	85.8	74.9	78.4	--do--
unprotected	47.7	98.9	146.6	52.7	103.1	155.8	110.6	104.2	106.3	--do--

humid grasslands, more than half of the nitrogen uptake is reflected in the underground net production. Lamotte & Bourlière (1983) while reviewing the studies on energy flow and nutrient cycling in tropical savannas, stated that most of these studies in tropical situations have been carried out in India and there is extreme insufficiency of data from humid bioclimatic zone. They found that, on an average, the annual plant uptake of nitrogen from soil ranges from 30 Kg ha-1 Yr-1 to 260 Kg ha-1 Yr-1 in the International Biological Programme (IBP) and Man and Biosphere (MAB) sites in India. The values presented in Table 6.18 indicate that the plant uptake of nitrogen in the grassland community may be as high as 410 Kg ha-1 Yr-1 at Kurukshetra (Yadava 1980) and it may still be greater (856 Kg ha-1 Yr-1) in old field plant communities which represent the early successional stage of grassland community in dry subhumid part of the country (Pandey & Singh 1990). The amount of uptake of nitrogen in humid grasslands of Meghalaya ranges between 137 to 206 Kg ha-1 Yr-1 and is well within the limits predicted by Lamotte & Bourlière (1983).

Lamotte & Bourlière (1983) further reported that the amount of nitrogen that returns to the soil each year ranges from 20 Kg ha-1 Yr-1 in semiarid grasslands to between 100 and 150 Kg ha-1 Yr-1 in subhumid and humid grasslands, reaching a maximum of 180 Kg ha-1 Yr-1 in the fenced savanna of the Chandraprabha sanctuary (Singh *et al.* 1979). Data presented in Table 6.18 also show that the release of nitrogen is more in semiarid savannas than in the Himalayan and dry subhumid grasslands. In humid grasslands of Meghalaya 154 to 220 Kg ha-1 Yr-1 returns to the soil annually through plant detritus. Recycling rate of nitrogen is generally greater in dry subhumid and humid grasslands than in the semiarid grasslands. Recycling rate of nitrogen is generally less in semiarid and dry subhumid grasslands than in Himalayan grasslands. The humid grasslands in sub-Himalayan belt in Meghalaya possess recycle rate more than what have been reported earlier from other bioclimatic zones of the country.

Chapter 7

Phosphorus cycling

Chapter 7

PHOSPHORUS CYCLING

INTRODUCTION

The phosphorus cycle provides a valuable index to the levels and types of biological activity in an ecosystem, since photosynthesis and microbial turnover in decomposing litter need adequate levels of phosphorus in specialised biochemical forms (Cole *et al.* 1977). Phosphorus is second only to nitrogen limiting plant growth. Unlike nitrogen, phosphorus cycle is closed, i.e., no substantial gains or losses occur from the system over a time scale of few years of study (Odum 1969). In soil, phosphorus occurs in both organic and inorganic forms and is absorbed by plant roots from the soil solution immediately surrounding the root depending upon the demands set by the growth and normal functioning of plant parts as well as external supply of phosphorus (Cole *et al.* 1977). Other nutrients also affect phosphorus uptake by plants mainly through their effects on growth and metabolism. The effects of nitrogen on phosphorus uptake are best known. Cole *et al.* (1963) correlated phosphorus uptake by roots with their nitrogen content, while beneficial effects of mycorrhizal fungi on the phosphorus uptake by plants were demonstrated by Mosse (1973).

The dynamics of phosphorus transport within plants depends on the activity of meristematic tissue within newly developing organs and phenological stage of the plant species. The major operational constraint in phosphorus translocati that a minimum level of phosphorus should be maintained within the exporting tissue, for example, in grasses no translocation of phosphorus from roots below a minimum level of approximately 0.05 % phosphorus can be expected. Similarly beyond an upper limit (approximately 0.5 %) of phosphorus concentration in roots, phosphorus translocation does not increase further (Cole *et al.* 1977).

During senescence and death of plant parts, a part of phosphorus is withdrawn and is redistributed among the more active plant parts for conservation purposes and the rest is transferred to litter or root detritus. The release of organic phosphates from plant residues into inorganic phosphate which is the essential step in phosphorus cycling within the ecosystems, is largely controlled by microbial activity.

Unlike carbon and nitrogen, phosphorus is not distributed in gaseous form in the biosphere, therefore, its biogeochemical cycling is not as effective as that of carbon and nitrogen. As the lithosphere is the only source and reservoir of phosphorus, the supply of available phosphorus in soil is continuously diminishing and its replenishment becoming gradually difficult.

The understanding of phosphorus cycle in tropical grasslands of India is fragmentary. So far only a few studies are available on the phosphorus cycling (Billore & Mall 1976, 1985; Chaturvedi *et al.* 1988). The humid grasslands of Meghalaya have not been investigated from this viewpoint.

This chapter comprises data regarding i) phosphorus accumulation and distribution in different vegetation and soil compartments, ii) uptake by vegetation and its transfer to various aboveground and belowground components, and iii) release of phosphorus to soil from litter and belowground detritus. The effect of protection of community from grazing and annual burning on phosphorus accumulation and transfers within the community has also been studied.

RESULTS

Phosphorus concentration in vegetation and soil

Soil

Time series data on extractable phosphorus concentration (ug g-1) in soil by 10 cm intervals to a depth of 30 cm for the study sites are given in Table 7.1. Three factorial multivariate analysis of variance showed significant effect in the phosphorus concentration ($p<0.01$) due to month, site and depth (Table 7.2). The effects of site and depth were much stronger than the variation through months. During the study period, phosphorus concentration ranged from 0.80 to 1.45, 0.63 to 1.34 and 0.47 to 1.28 at Burnihat, 0.92 to 2.21, 0.77 to 1.77 and 0.59 to 1.27 at Cherrapunji, 0.69 to 1.16, 0.46 to 0.79 and 0.43 to 0.73 in the protected and 0.52 to 1.35, 0.23 to 1.14 and 0.20 to 0.96 in the unprotected stand at Upper Shillong, respectively, in 0-10, 10-20 and 20-30 cm soil layers.

Differences in phosphorus concentration of soil between Burnihat and protected and unprotected stands at Upper Shillong were insignificant (Fig. 7.1). However, Cherrapunji had significantly ($p<0.01$) greater concentration than the other sites. At all the sites, phosphorus concentration decreased through depth.

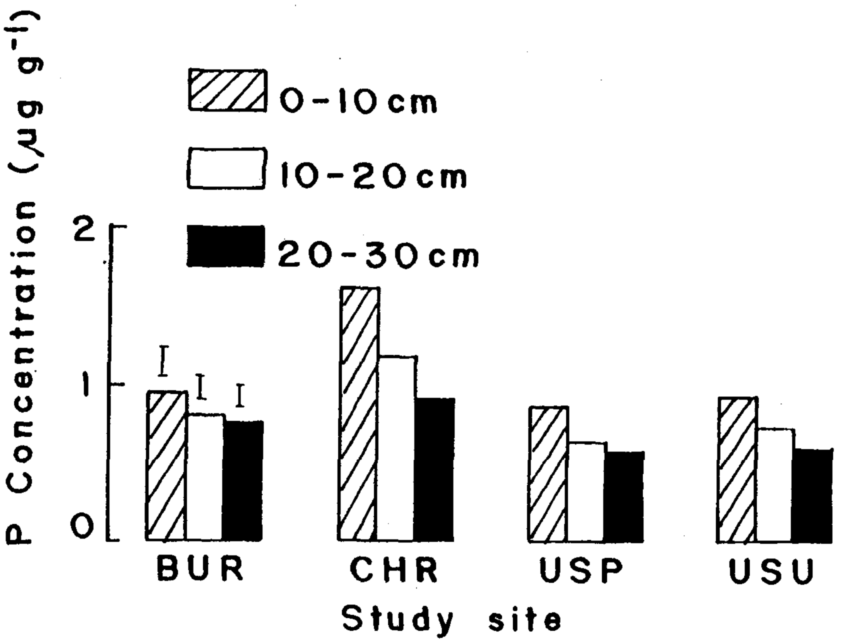


Fig. 7.1 *Mean monthly concentration (µg g^{-1}) of extractable phosphorus in three soil layers of four grassland communities. LSD (5%) is shown by vertical line. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

Table 7.1. Monthly variation in extractable P concentration (ug g-1) in three soil layers of four grassland communities.

	Burnihat			Cherrapunji			Upper Shillong					
							protected			unprotected		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
MONTH	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30
AUG	0.82	0.64	0.68	1.96	1.45	1.27	0.92	0.79	0.73	1.24	1.14	0.94
SEP	0.83	0.63	0.56	1.72	1.45	1.01	0.90	0.68	0.56	1.07	0.98	0.96
OCT	0.97	0.69	0.62	1.93	1.54	0.97	0.91	0.59	0.58	1.15	1.06	0.79
NOV	1.45	1.34	1.28	2.06	1.28	0.99	1.03	0.76	0.67	1.08	0.94	0.82
DEC	0.98	0.84	0.79	1.69	1.10	0.85	1.16	0.71	0.68	1.35	0.84	0.75
JAN	0.87	0.82	0.76	1.55	0.77	0.60	0.76	0.58	0.55	0.77	0.77	0.65
FEB	0.95	0.91	0.88	1.27	0.92	0.73	0.77	0.61	0.53	0.76	0.72	0.64
MAR	0.93	0.79	0.72	1.23	0.94	0.76	0.69	0.64	0.51	0.52	0.32	0.28
APR	0.81	0.65	0.47	0.92	0.81	0.59	0.72	0.46	0.43	0.55	0.23	0.20
MAY	0.80	0.78	0.73	1.12	0.86	0.76	0.69	0.56	0.53	0.72	0.53	0.25
JUN	1.02	0.85	0.70	1.43	1.12	0.95	0.78	0.75	0.68	0.98	0.68	0.52
JUL	0.90	0.86	0.89	2.17	1.45	1.25	0.88	0.70	0.64	1.02	0.75	0.58
AUG	1.05	0.89	0.91	2.21	1.77	1.27	1.04	0.74	0.64	1.08	0.72	0.66

Table 7.2. Results of three-factorial (replicated) analysis of variance (fixed effects model) to test null hypothesis (Ho) for variations in soil phosphorus concentration along months, sites, depths and their interactions.

Variation	d.f.	SS	MS	F
General mean	1	0.000004	0.000004	...
Month	12	0.000000	0.000000	514.86**
Site	3	0.000000	0.000000	3354.18**
Depth	2	0.000000	0.000000	2701.49**
Month x Site	36	0.000000	0.000000	119.28**
Month x Depth	24	0.000000	0.000000	15.88**
Site x Depth	6	0.000000	0.000000	261.52**
Mon x Site x Dep	72	0.000000	0.000000	13.32**
Residual	312	0.000000	0.000000	...
TOTAL	468	0.000004	0.000000	...

** = Significant at $p<0.01$

Vegetation

Belowground parts:

Phosphorus concentration in belowground parts showed monthly fluctuation with some distinctive patterns (Fig. 7.2). In order to further clarify these patterns, means were calculated for live roots and rhizome for those months along which the concentration did not vary significantly ($p>0.01$). The corresponding months were taken for calculating means for dead roots and rhizome also, irrespective of significant difference. At Burnihat, periodic variation in phosphorus concentration was not significant in live roots but in live rhizome it was greater during January to April than rest part of the year. At Cherrapunji, phosphorus concentration in live roots was greater during October to February. It may be recalled that live root at this site included rhizome also. In the protected and unprotected stands at Upper Shillong, phosphorus concentration in live root

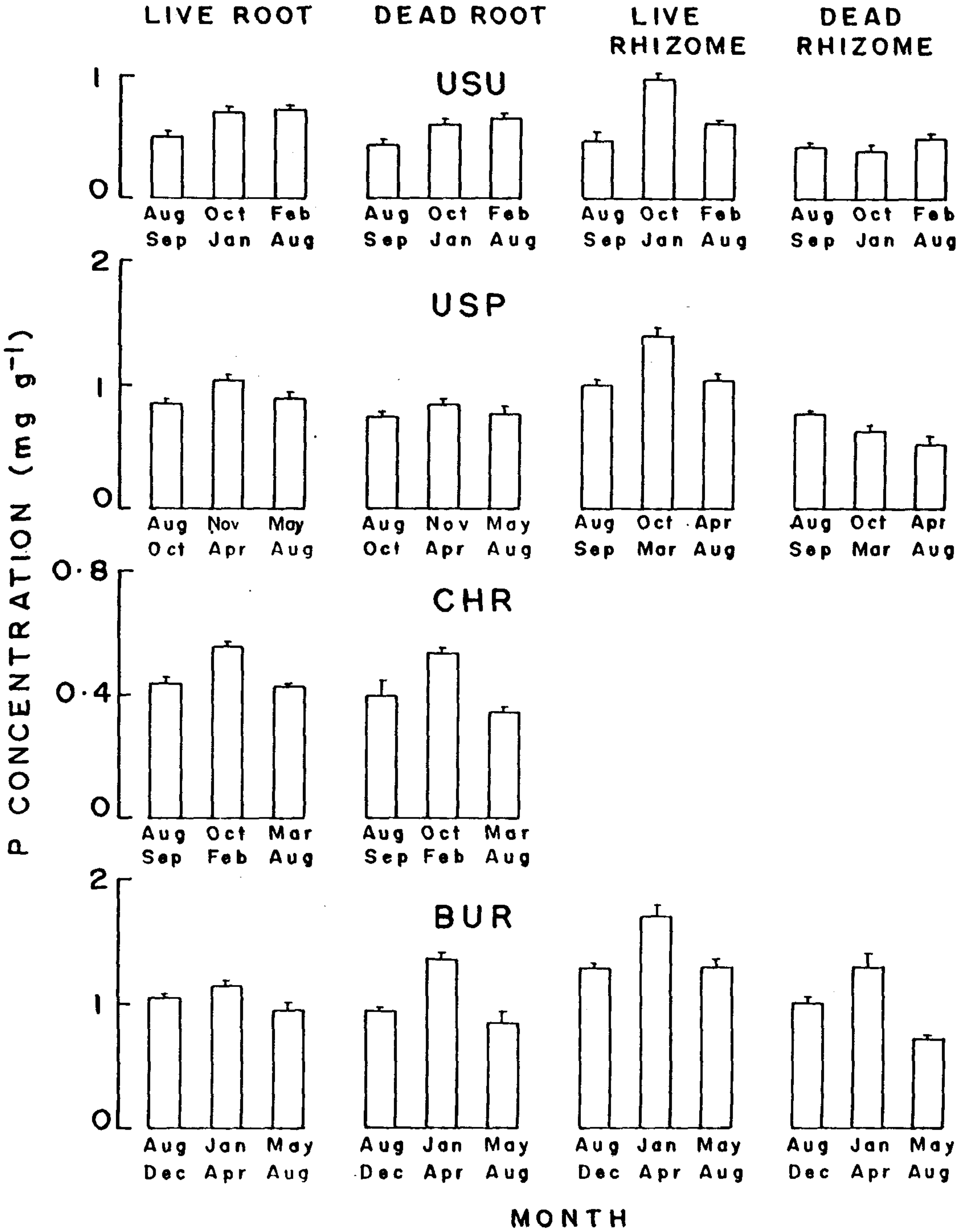


Fig. 7.2 Periodic fluctuation in phosphorus concentration (mg g^{-1}) in the belowground components of four grassland communities. Standard errors represented by vertical lines denote variability between months indicated below the histograms. The months which showed no significant difference ($p>0.01$) were pooled to calculate the periodic mean. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).

did not differ appreciably throughout the year, but in live rhizome, it was greater during October to March in the protected stand and October to January in the unprotected stand.

Table 7.3. Mean monthly concentration of P (mg g-1) in the belowground components of grassland communities at four sites.

	Root		Rhizome		
Site	Live	Dead	Live	Dead	LSD
Burnihat	1.05	1.05	1.39	0.92	**0.15**
Cherrapunji	0.48*	0.43*	--	--	**0.07**
Upper Shillong Protected	0.95	0.81	1.21	0.61	**0.09**
Unprotected	0.69	0.61	0.71	0.45	**0.09**
LSD	**0.07**	**0.10**	**0.14**	**0.12**	

LSD - Least Significant Difference at $p<0.05$
* includes rhizome also

Mean monthly values showed significant ($p<0.05$) differences between sites as well as between roots and rhizome (Table 7.3). At all the sites, concentration in live rhizome was higher than the other belowground components. Differences between live and dead roots were not significant, but dead rhizome exhibited significantly lower concentration than the live rhizome at all the sites. In all the belowground compartments phosphorus concentration was the highest at Burnihat and the lowest at Cherrapunji. Difference between protected and unprotected stands was highly significant ($p<0.001$) and the values were higher in the protected stand.

Aboveground parts:

The phosphorus concentration in live shoot fluctuated significantly ($p<0.01$) along months at all sites (Fig. 7.3) and showed higher values during early growth season. In the unprotected stand at Upper Shillong, it increased very rapidly after the burning, from February until April and then declined. In dead shoot, phosphorus concentration showed wide monthly variation but in the litter, it did not vary significantly except at Burnihat where the value was significantly lower in December than the other months.

Mean monthly values of phosphorus concentration also showed significant differences between compartments as well as between different sites (Table 7.4). The concentration was greater in live shoot than dead shoot and litter at all the sites. Except at Burnihat where litter showed higher phosphorus

Table 7.4. Mean monthly concentration of P (mg g-1) in live shoot, dead shoot and litter components of grassland communities at four sites.

Site	Live shoot	Dead shoot	Litter	LSD
Burnihat	0.80 ± 0.07	0.68 ± 0.07	0.98 ± 0.07	**0.17**
Cherrapunji	1.03 ± 0.05	0.49 ± 0.02	0.30 ± 0.02	**0.08**
Upper Shillong				
Protected	3.45 ± 0.15	1.90 ± 0.09	0.83 ± 0.03	**0.24**
Unprotected	2.45 ± 0.32	1.21 ± 0.10	0.59 ± 0.02	**0.47**
LSD	**0.44**	**0.18**	**0.10**	

± SE denotes variability through months
LSD - Least Significant Difference at $p<0.05$

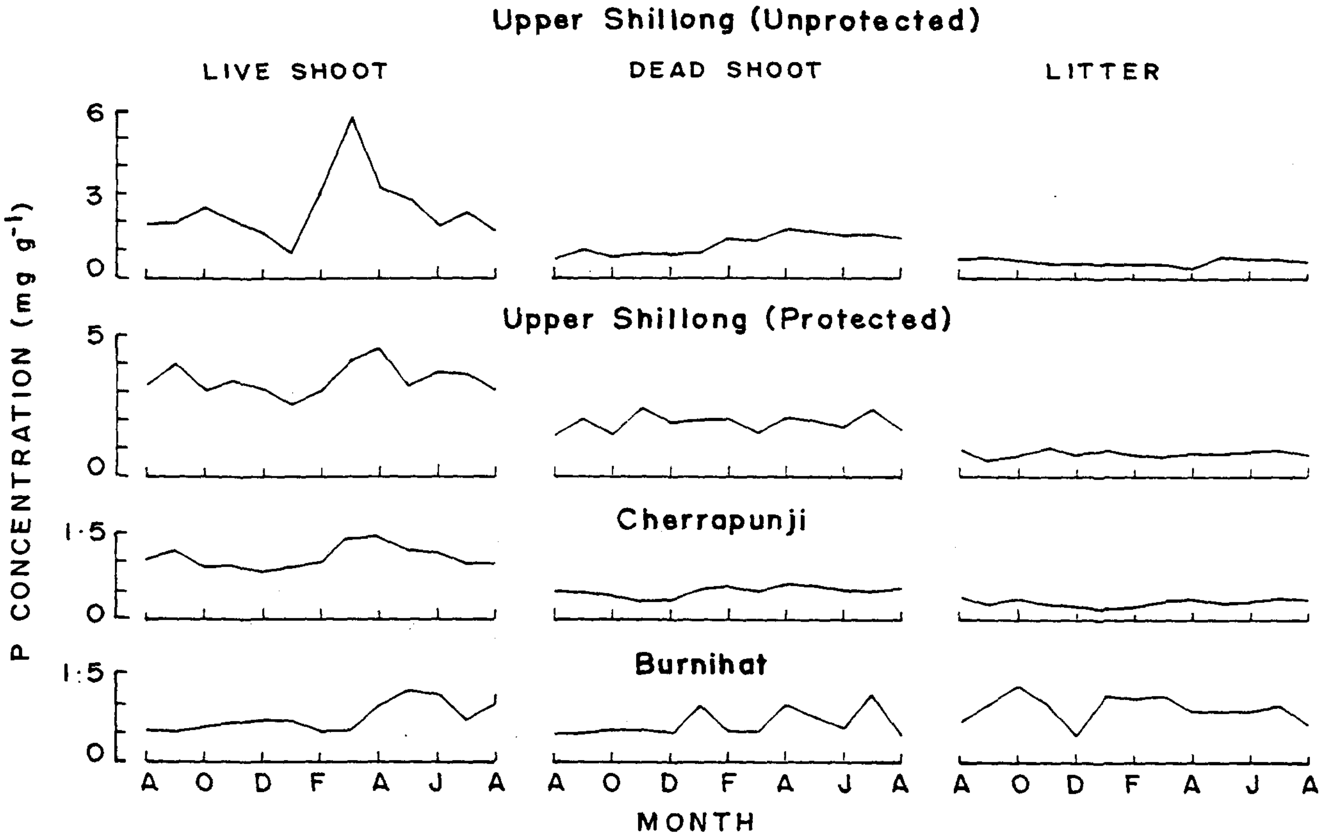


Fig. 7.3 *Monthly variation in phosphorus concentration (mg g^{-1}) in live shoot, dead shoot and litter mass in four grassland communities.*

concentration than dead shoot, it was greater in the dead shoot than the litter. The concentration in live shoot was highest at Upper Shillong followed by Cherrapunji and Burnihat, whereas in root it was maximum at Burnihat and minimum at Cherrapunji. For dead shoot and litter, the sites could be ordered as Upper Shillong> Burnihat>Cherrapunji. At Upper Shillong, phosphorus concentration in all the compartments was significantly ($p<0.05$) lower in the unprotected stand than in the protected one.

Accumulation of phosphorus in soil and vegetation compartments

Soil

Seasonal differences in extractable phosphorus content were insignificant ($p>0.05$) at all the sites (Table 7.5).

Table 7.5. Seasonal variation in extractable P capital in 0-30 cm soil layer at four study sites.

Season	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected	**LSD**
Late rainy (Aug-Oct)	4.3	8.8	4.5	6.2	**0.6**
Winter (Nov-Feb)	6.0	6.9	4.4	5.1	**NS**
Summer (Mar-May)	6.2	7.6	5.0	3.9	**0.8**
Early rainy (Jun-Aug)	5.4	9.3	4.5	4.7	**1.4**
LSD	**NS**	**1.8**	**NS**	**0.9**	
Mean	**5.1**	**7.5**	**4.2**	**4.6**	

LSD - Least Significant Difference at $p<0.05$
NS - Differences are not significant

However, the values at Cherrapunji were slightly higher than the other sites. On the basis of mean monthly values of standing state of extractable phosphorus in soil, which ranged between 4.2 to 7.5 Kg ha-1, communities could be arranged as protected> unprotected>Burnihat>Cherrapunji.

Vegetation

Belowground compartments:

Throughout the year, phosphorus storage in the live belowground phytomass was many-fold higher than that in the dead belowground compartment at all the sites (Fig. 7.4). At Burnihat, the seasonal values of live component revealed a summit during peak period of growth in September, after which it declined during winter and again increased rapidly. The dead belowground parts showed greater accumulation during late rainy months. At Cherrapunji, the live belowground compartment peaked in October followed by a decline until April afterwhich it again showed rapid increase. In the dead belowground compartment, accumulation was more during rainy season than the other months. In the protected stand at Upper Shillong, phosphorus accumulation in live belowground compartment showed peak in November and then decreased upto April. The values were almost constant from April to June and increased rapidly thereafter. The accumulation in dead belowground compartment at this site was maximum during August to October and minimum during November to December. In the unprotected stand, the seasonal trend was quite different from that in the protected stand. The peak value in live roots in September declined upto November, remained more or less constant

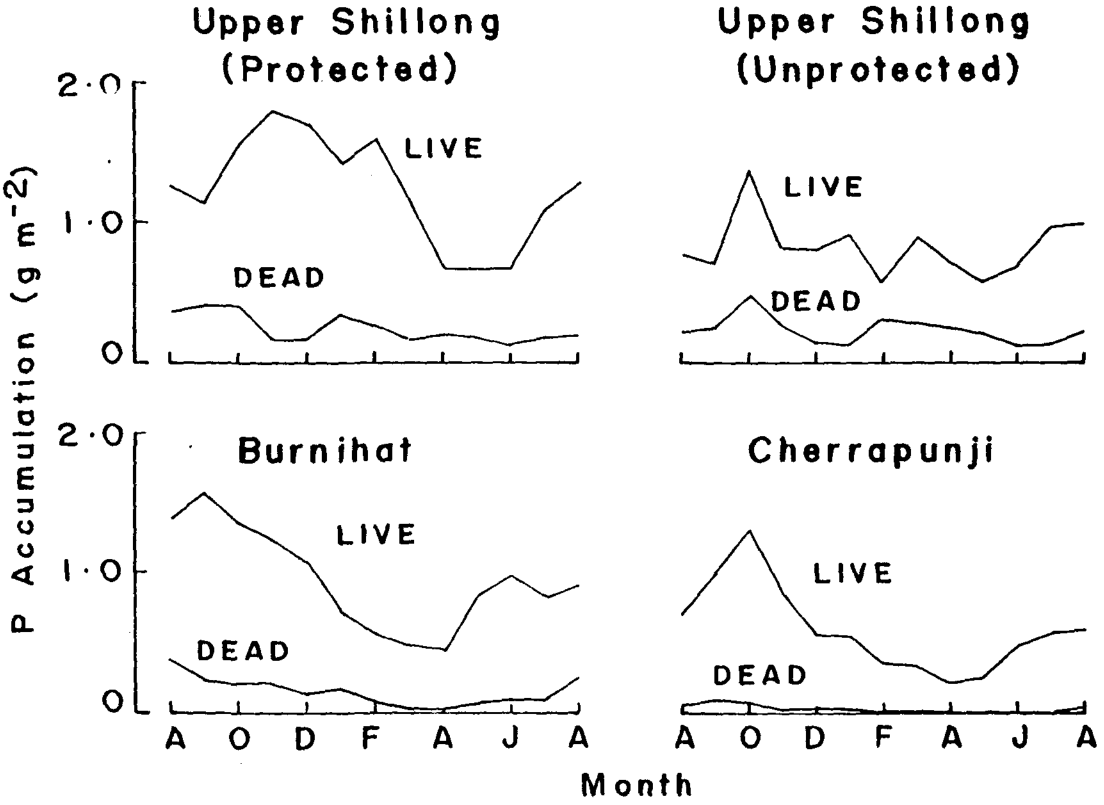


Fig. 7.4 *Monthly variation in standing state of phosphorus ($g\ m^{-2}$) in live and dead components of the belowground phytomass in four grassland communities.*

during November to January but declined rapidly in February. Seasonal dynamics in the dead belowground compartment was similar to the protected stand.

Seasonal values of phosphorus accumulation in belowground phytomass at three soil depths showed greater accumulation in 0-10 cm layer at all the sites (Fig. 7.5). Accumulation declined sharply in subsequent layers. At Burnihat, accumulation in middle and lower layers was slightly higher during summer season compared to other seasons. At Cherrapunji, similar seasonality was not well marked. In the protected stand at Upper Shillong, lower layers of soil showed relatively greater accumulation during early part of rainy season but in the unprotected stand accumulation was more during summer season, particularly in upper layer.

Proportional allocation of phosphorus to different fractions of belowground phytomass revealed greater accumulation in live compartment at all the sites and in all the seasons (Table 7.6). Storage in the dead phytomass was highest (about 20 %) in the unprotected stand at Upper Shillong and lowest (<5 %) at Cherrapunji. In this compartment relatively greater value was obtained during late rainy season at all the sites.

Table 7.6 further revealed that a major portion of phosphorus in the community was stored in roots at all the sites. The accumulation in rhizome was most prominent in the protected stand. At Cherrapunji, separation of root and rhizome could not be done and therefore, separate data for these compartments are not available for this site. At Burnihat the rhizome compartment was prominent during rainy season whereas at Upper Shillong it

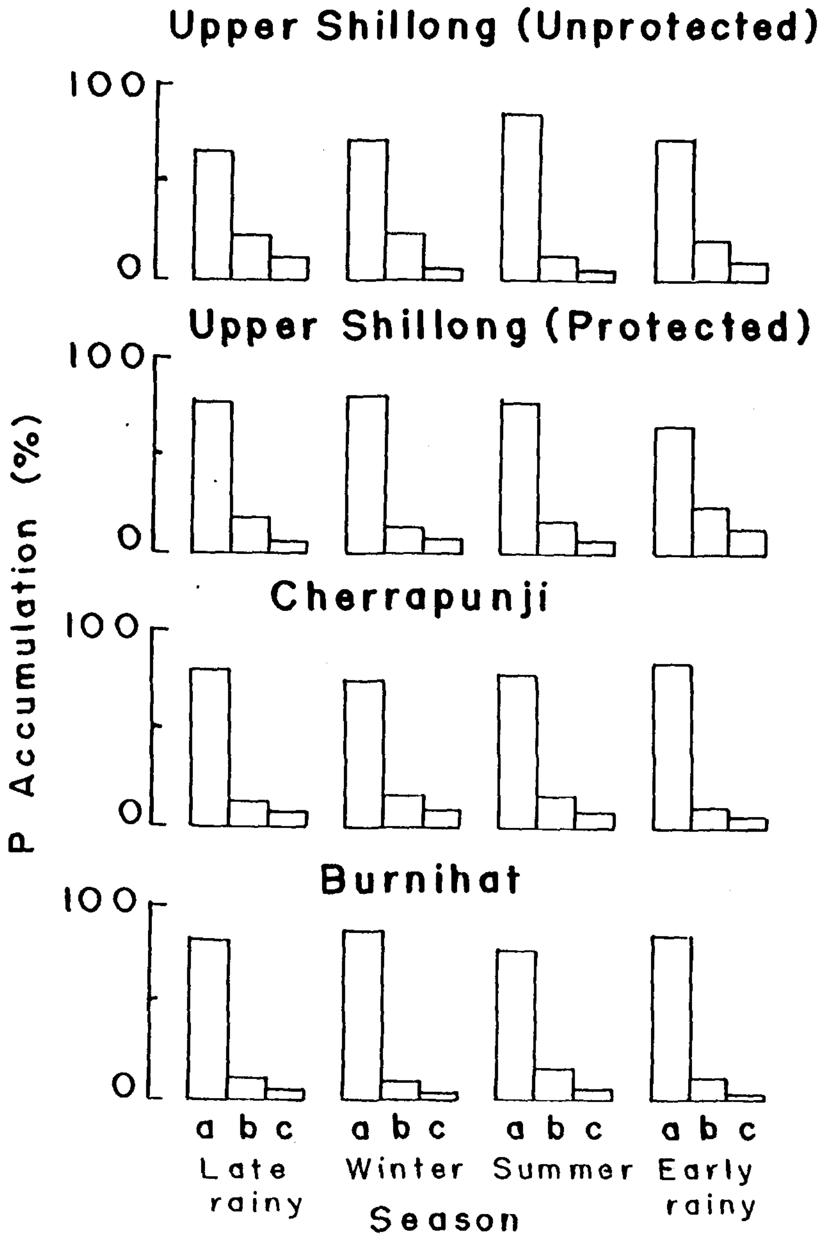


Fig. 7.5 *Seasonal variation in phosphorus accumulation in belowground phytomass at three soil depths; 0-10 (a), 10-20 (b) and 20-30 cm (c) in four grassland communities.*

Table 7.6. Seasonal variation in proportional allocation of P in different components of belowground phytomass in four grassland communities.

Belowground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Root	71.8	79.1	81.6	72.9
Rhizome	28.2	20.9	18.4	27.1
Live	84.1	86.0	92.5	86.8
Dead	15.9	14.0	7.5	13.2
		CHERRAPUNJI*		
Live	94.8	94.7	97.9	98.0
Dead	5.2	5.3	2.1	2.0
		UPPER SHILLONG (PROTECTED)		
Root	75.4	63.7	75.8	74.3
Rhizome	24.6	36.3	24.2	25.7
Live	77.2	88.2	82.9	85.6
Dead	22.8	11.8	17.1	14.4
		UPPER SHILLONG (UNPROTECTED)		
Root	87.2	81.0	88.8	84.0
Rhizome	12.8	19.0	11.2	16.0
Live	74.8	78.6	74.6	84.5
Dead	25.2	21.4	25.4	15.5

* Separate data for root and rhizome are not available

showed higher accumulation during winter season.

Aboveground compartments:

Monthly changes in phosphorus accumulation pattern in live shoot, dead shoot and litter compartments are shown in Fig. 7.6. Live shoot showed peak accumulation during August-September in all the communities. It decreased rapidly through September to November and then slowly during winter months, reaching its

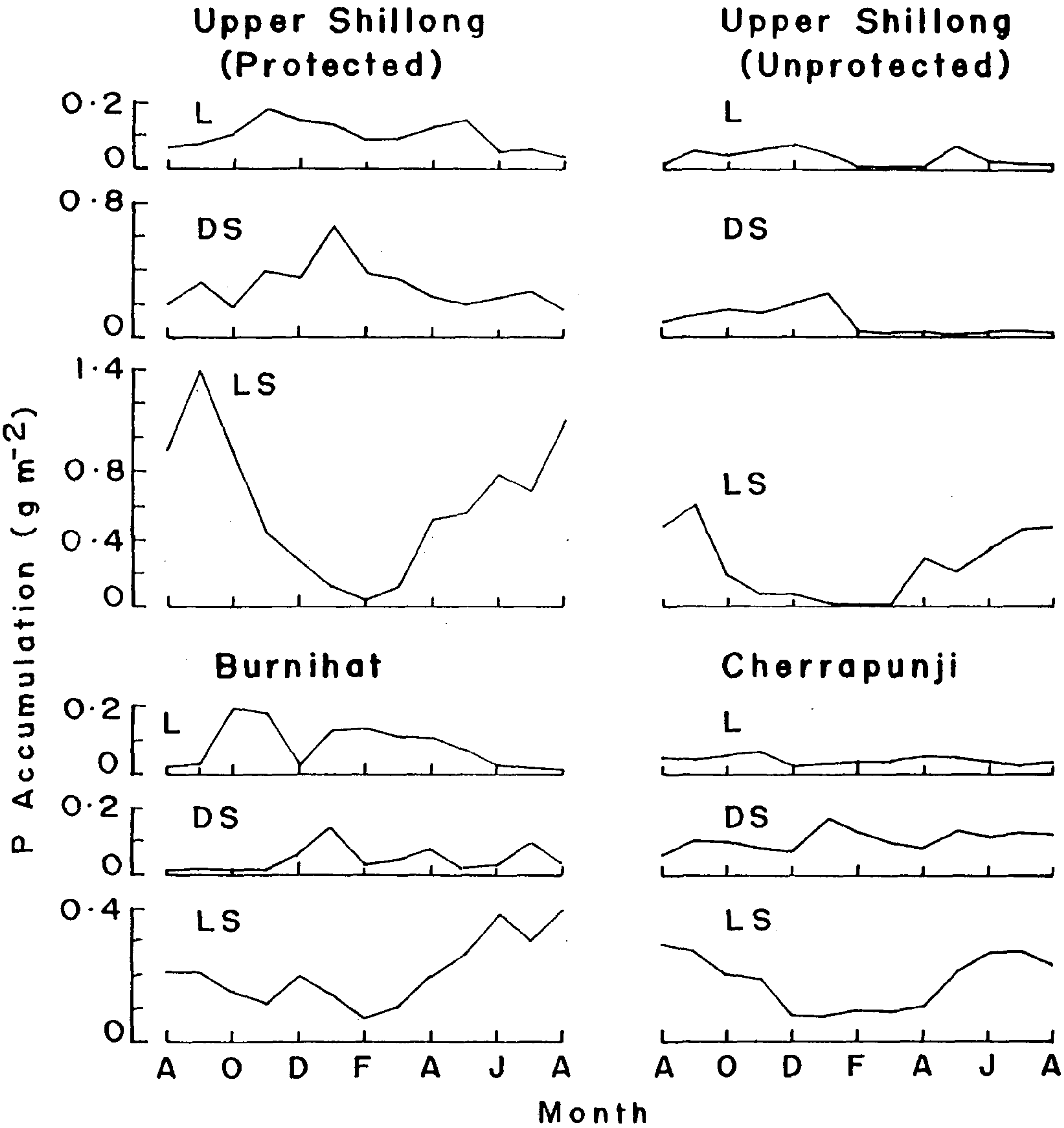


Fig. 7.6 Monthly variation in phosphorus accumulation (g m^{-2}) in live shoot (LS), dead shoot (DS) and litter (L) mass in four grassland communities.

minimum value at the end of winter season. With the onset of spring the vegetation grew rapidly and phosphorus content in live shoot also increased sharply.

The phosphorus content in dead shoot increased from August and attained its peak in January at all the sites. After January, phosphorus content in this compartment declined. The decline was faster in the unprotected stand due to fire in February which almost completely consumed the dead shoot and detritus in this stand. At Cherrapunji, standing state of phosphorus in this compartment was relatively constant throughout the year.

Phosphorus content in litter increased form August and attained peak in October/November at all the sites. At Burnihat and in the unprotected stand at Upper Shillong, it declined during winter season and this trend continued until early rainy season. However, due to burning of aboveground vegetation in unprotected stand at Upper Shillong, accumulation in this compartment significantly declined in February and remained so up to April. From April to May, there was a gain of phosphorus in this compartment, presumably due to early season litterfall. At Cherrapunji, it was more or less constant throughout the year.

When the monthly data of storage in aboveground compartments were pooled on seasonal basis, it showed a more distinct pattern was discernible (Table 7.7). At all the sites, accumulation in live shoot increased during summer and rainy seasons and decreased from late rainy to winter season. The dead shoot accumulated relatively higher proportion of phosphorus during winter season. On the contrary, litter compartment

Table 7.7. Seasonal variation in P accumulation (g m-2) and its proportional distribution (values in parentheses) in live shoot, dead shoot and litter in four grassland communities. ± SE denotes variability through months.

Aboveground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Live shoot	.189 ±.020 (64.3)	.137 ±.024 (42.4)	.189 ±.045 (58.5)	.358 ±.028 (81.9)
Dead shoot	.023 ±.002 (7.8)	.065 ±.028 (20.1)	.048 ±.015 (14.9)	.055 ±.023 (12.6)
Litter	.082 ±.057 (27.9)	.121 ±.032 (37.5)	.096 ±.011 (29.7)	.024 ±.004 (5.5)
		CHERRAPUNJI		
Live shoot	.253 ±.027 (64.9)	.112 ±.026 (41.8)	.135 ±.034 (47.5)	.255 ±.012 (61.9)
Dead shoot	.088 ±.012 (22.6)	.110 ±.023 (41.0)	.099 ±.015 (34.9)	.119 ±.003 (28.9)
Litter	.049 ±.005 (12.6)	.046 ±.008 (17.2)	.050 ±.004 (17.6)	.038 ±.004 (9.2)
		UPPER SHILLONG (PROTECTED)		
Live shoot	1.073 ±.161 (76.6)	.216 ±.089 (26.7)	.397 ±.141 (51.0)	.867 ±.133 (75.5)
Dead shoot	.241 ±.046 (17.2)	.454 ±.069 (56.2)	.257 ±.048 (33.0)	.227 ±.033 (19.8)
Litter	.087 ±.011 (6.2)	.138 ±.019 (17.1)	.124 ±.016 (15.9)	.054 ±.007 (4.7)
		UPPER SHILLONG (UNPROTECTED)		
Live shoot	.427 ±.124 (69.7)	.045 ±.018 (16.9)	.183 ±.086 (72.9)	.435 ±.040 (87.5)
Dead shoot	.140 ±.022 (22.8)	.168 ±.047 (63.2)	.034 ±.005 (13.5)	.036 ±.002 (7.2)
Litter	.046 ±.011 (7.5)	.053 ±.013 (19.9)	.034 ±.020 (13.5)	.026 ±.003 (5.2)

contained more phosphorus both in winter and ensuing summer seasons.

At Burnihat 42-82 per cent of the total aboveground was present in the live fraction (Table 7.7). This was followed by litter (6-38 %) and dead shoot (8-20 %). At Cherrapunji, the allocation pattern showed the following order:

Live shoot (42-65 %)>dead shoot (23-41 %)>litter (9-18 %).

Table 7.8. Monthly variation in P accumulation (g m-2) in belowground and aboveground compartments of the grassland community at Burnihat.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	1.76	0.23	0.25	1.99	2.01
Sep	1.80	0.24	0.27	2.04	2.07
Oct	1.57	0.17	0.37	1.74	1.94
Nov	1.45	0.15	0.33	1.60	1.78
Dec	1.23	0.26	0.29	1.49	1.52
Jan'89	0.87	0.29	0.42	1.16	1.29
Feb	0.62	0.11	0.25	0.73	0.87
Mar	0.51	0.15	0.26	0.66	0.77
Apr	0.48	0.28	0.39	0.76	0.87
May	0.88	0.29	0.36	1.17	1.24
Jun	1.05	0.41	0.44	1.46	1.49
Jul	0.91	0.40	0.42	1.31	1.33
Aug	1.17	0.42	0.44	1.59	1.61

LS - Live Shoot; DS - Dead Shoot; L - Litter

At Upper Shillong seasonality was more prominent than other sites. Here in the protected stand, accumulation in live shoot varied from 77 % in late rainy season to about 27 % in winter season. The corresponding values for the unprotected stand were 88 and 17 %. The range of variation in dead shoot was 17-56 % in the protected stand and 7-63 % in the unprotected stand. Seasonal variation in litter ranged from 4-10 % and it was

Table 7.9. Monthly variation in P accumulation (g m-2) in belowground and aboveground compartments of the grassland community at Cherrapunji.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	0.73	0.35	0.40	1.08	1.13
Sep	1.07	0.38	0.42	1.45	1.49
Oct	1.36	0.30	0.35	1.66	1.71
Nov	0.90	0.27	0.34	1.17	1.24
Dec	0.57	0.15	0.18	0.72	0.75
Jan'89	0.58	0.25	0.29	0.83	0.87
Feb	0.38	0.22	0.26	0.60	0.64
Mar	0.33	0.18	0.22	0.51	0.55
Apr	0.23	0.19	0.25	0.42	0.48
May	0.26	0.33	0.38	0.59	0.64
Jun	0.49	0.38	0.42	0.87	0.91
Jul	0.57	0.39	0.42	0.96	0.99
Aug	0.64	0.35	0.39	0.99	1.03

LS - Live Shoot; DS - Dead Shoot; L - Litter

Table 7.10. Monthly variation in P accumulation (g m-2) in below-ground and aboveground compartments in the protected grassland community at Upper shillong.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	1.62	1.12	1.20	2.74	2.82
Sep	1.53	1.73	1.81	3.26	3.34
Oct	1.98	1.09	1.20	3.07	3.18
Nov	1.95	0.84	1.02	2.79	2.97
Dec	1.85	0.65	0.80	2.50	2.65
Jan'89	1.74	0.77	0.91	2.51	2.65
Feb	1.83	0.42	0.51	2.25	2.34
Mar	1.29	0.47	0.56	1.76	1.85
Apr	0.87	0.75	0.88	1.62	1.75
May	0.83	0.74	0.89	1.57	1.72
Jun	0.79	1.01	1.07	1.80	1.86
Jul	1.28	0.98	1.04	2.26	2.32
Aug	1.50	1.30	1.34	2.80	2.84

LS - Live Shoot; DS - Dead Shoot; L - Litter

similar in both the stands.

Throughout the year phosphorus accumulation in total belowground phytomass was greater than the aboveground parts at all the sites (Tables 7.8 to 7.11). Standing state of phosphorus in belowground parts at Cherrapunji was significantly ($p<0.01$) lower than the other sites (Table 7.12). Burnihat was comparable to the unprotected stand, but it showed lower value than the protected stand. At Upper Shillong, however, it was more in the

Table 7.11. Monthly variation in P accumulation (g m-2) in belowground and aboveground compartments in the unprotected grassland community at Upper shillong.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	1.01	0.58	0.61	1.59	1.62
Sep	0.99	0.75	0.82	1.74	1.81
Oct	1.87	0.37	0.41	2.24	2.28
Nov	1.07	0.23	0.29	1.30	1.36
Dec	0.96	0.29	0.36	1.25	1.32
Jan'89	1.05	0.29	0.35	1.34	1.40
Feb	0.90	0.05	0.06	0.95	0.96
Mar	1.18	0.06	0.07	1.24	1.25
Apr	0.95	0.35	0.37	1.30	1.32
May	0.78	0.24	0.31	1.02	1.09
Jun	0.81	0.40	0.43	1.21	1.24
Jul	1.10	0.50	0.52	1.60	1.62
Aug	1.24	0.52	0.54	1.76	1.78

LS - Live Shoot; DS - Dead Shoot; L - Litter

protected stand than in the unprotected stand. The trend of phosphorus accumulation in shoot (live+dead) was, however, different. The protected stand at Upper Shillong accumulated about 3 times more phosphorus than the unprotected stand and Burnihat and Cherrapunji communities. The accumulation pattern did not change when phosphorus content in litter was added to the values of shoot. Total (aboveground +belowground) phosphorus accumulation in the community was minimum at Cherrapunji and maximum in the protected stand at Upper Shillong; Burnihat and the unprotected stand having similar values occupied the intermediate position.

Belowground/aboveground ratio

This ratio was more than unity throughout the year at all the sites (Fig. 7.7), thereby indicating relatively greater phosphorus accumulation in the belowground compartment in all the four grassland communities. Seasonal trend was similar at Burnihat and Cherrapunji where it increased from August onwards and showed peak in October/November and then declined. At Upper Shillong, the peak was recorded during February-March. The mean monthly ratio was 4.23, 2.13, 1.62 and 2.97 at Burnihat, Cherrapunji, and in the protected and unprotected stand at Upper Shillong, respectively.

Table 7.12. Mean monthly accumulation of P (gm-2) in total belowground and aboveground compartments of four grassland communities.

Site	Belowground	Aboveground		Total	
		LS+DS	LS+DS+L		
	(a)	(b)	(c)	(a+b)	(a+c)
Burnihat	1.10 ± 0.12	0.26 ± 0.03	0.35 ± 0.02	1.36 ± 0.13	1.45 ± 0.12
Cherrapunji	0.62 ± 0.09	0.29 ± 0.02	0.33 ± 0.02	0.91 ± 0.10	0.96 ± 0.10
Upper Shillong protected	1.47 ± 0.12	0.91 ± 0.10	1.02 ± 0.09	2.38 ± 0.15	2.48 ± 0.15
unprotected	1.07 ± 0.08	0.36 ± 0.06	0.40 ± 0.06	1.43 ± 0.10	1.47 ± 0.10
LSD	0.25	0.14	0.14	0.29	0.29

LS - Live Shoot; DS - Dead Shoot; L - Litter ± SE denotes variability through months
LSD - Least Significant Difference at $p<0.05$

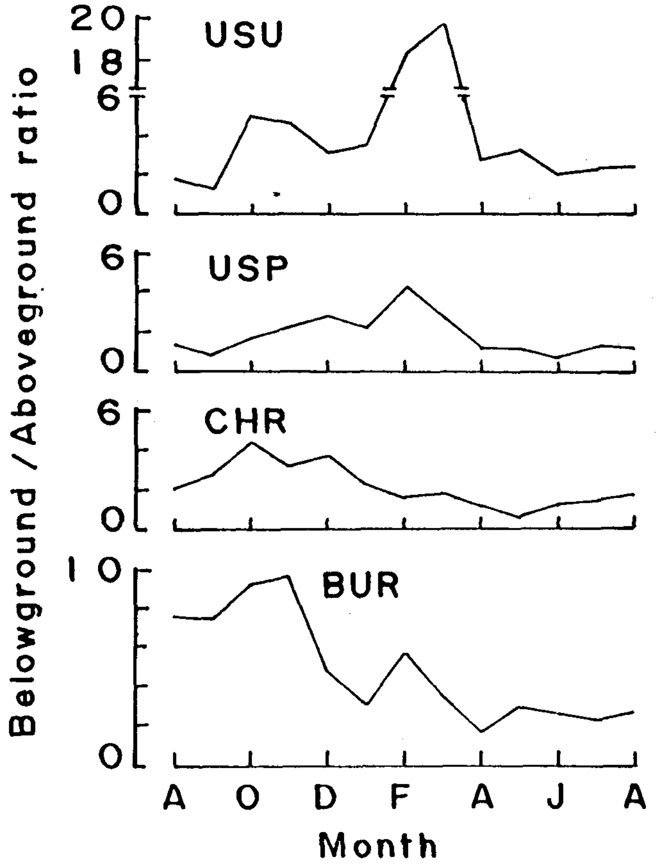


Fig. 7.7 *Monthly variation in the ratio of phosphorus accumulation in belowground and aboveground compartments of four grassland communities. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

Proportional distribution of phosphorus in soil and vegetation components

Of the total amount of the phosphorus present in the plant and soil (only extractable P), 56-85 % participated in biological circulation and rest was present in the soil (Table 7.13). A major portion of phosphorus locked in the community biomass was reflected in the belowground phytomass, particularly in the live fraction (root + rhizome). Differences in the distribution pattern of phosphorus in the compartments (as per cent of total in each compartment) was analysed through a two-way factorial multivariate analysis of variance. The analysis was run with all six compartments, viz., live shoot, dead shoot,

Table 7.13. Proportional distribution of P in plant/soil system of four grassland communities. Values are based on means across the months (Aug'88 to Aug'89).

Component	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected
Aboveground vegetation	13.36	16.88	31.45	18.43
Live	10.85	10.73	20.87	13.24
Dead	2.51	6.15	10.58	5.19
Litter	4.30	2.70	3.58	2.13
Belowground vegetation	56.24	36.46	50.50	55.56
Live	48.57	34.88	42.37	43.35
Dead	7.68	1.58	8.13	12.20
Total vegetation	73.90	56.04	85.53	76.12
Soil*	26.10	43.96	14.47	23.88

* Extractable phosphorus

litter, live belowground, dead belowground and soil. The results showed that the distribution pattern of phosphorus was significantly influenced by site ($p<0.01$) and compartment ($p<0.01$). Interactive influence of site and compartment was also significant ($p<0.05$).

Table 7.14. Annual* uptake, transfers and release of P (Kg ha-1) in four grassland communities.

Flow	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected
Uptake in ANP	6.14	3.58	18.21	8.10
Uptake in BNP	10.17	10.70	15.57	18.37
Total uptake	16.58	14.28	33.78	26.47
Transfer from live to dead shoot	4.55	4.13	16.07	8.07
Transfer from dead shoot to litter	4.42	3.57	16.50	8.74
Transfer from live to dead root	14.82	11.57	15.22	16.16
Release from litter	4.43	3.64	16.82	8.78
Release from dead root	16.07	11.58	16.74	16.12
Total release	20.50	15.22	35.56	24.90
% Recycle (Total release x 100/Total uptake)	123.6	106.6	99.4	94.1

* No. of days: Burnihat-382; Cherrapunji-379; Upper Shillong-406
ANP -Aboveground Net Production; BNP -Belowground Net Production

Uptake, transfers and release of phosphorus

Total annual phosphorus uptake varied from 14.3 at Cherrapunji to 26.5 Kg ha-1 at Upper Shillong (protected stand). Aboveground uptake varied more widely than the belowground uptake over the four communities (Table 7.14). At Burnihat, Cherrapunji and in the protected stand, the belowground uptake exceeded aboveground uptake. In the protected stand, however, the aboveground uptake was more than belowground uptake.

At Burnihat, 75 % of the total uptake by shoot was transferred to the dead shoot. Transfer from dead shoot to litter and then release from the litter were almost equal to the inputs to the respective compartments. In the belowground parts transfer from live to dead compartment was 46 % more than the belowground uptake. The release from the dead was slightly more than the input to this compartment.

At Cherrapunji, annually 15 % more phosphorus was transferred from live shoot to dead shoot than the uptake by shoot. Transfer from dead shoot to litter was, however, less than the input but release from litter was equal to the input to this compartment. Thus the net release from the aboveground compartment equals the input through uptake. In the belowground parts, input was more than the transfer from live to dead compartment, but the release from dead was equal to the input to this compartment. In this way net loss of phosphorus from the total system was negligible (Table 7.15).

In the protected stand at Upper Shillong, uptake by shoot was more than its transfer from live to dead shoot, However, the transfer from dead shoot to litter and its

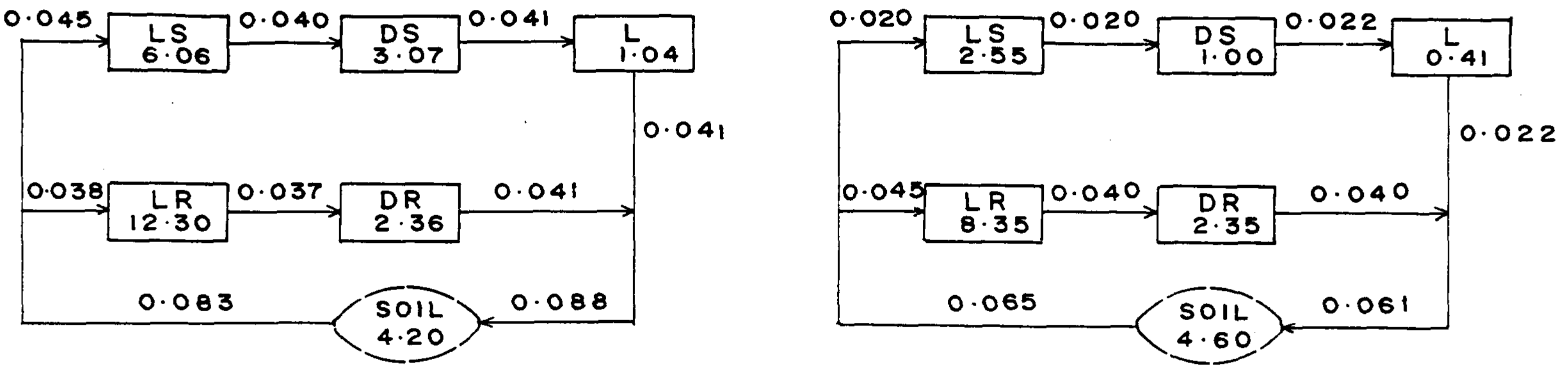
Table 7.15. Uptake, release and retention calculated as per cent of total uptake.

	Uptake in		Release from		Retention in	
Site	AG	BG	AG	BG	AG	BG
Burnihat	38	62	27	99	11	-37
Cherrapunji	25	75	25	81	0	-6
Upper Shillong protected	54	46	50	50	4	-4
unprotected	31	69	33	61	-2	8

AG - Aboveground; BG - Belowground

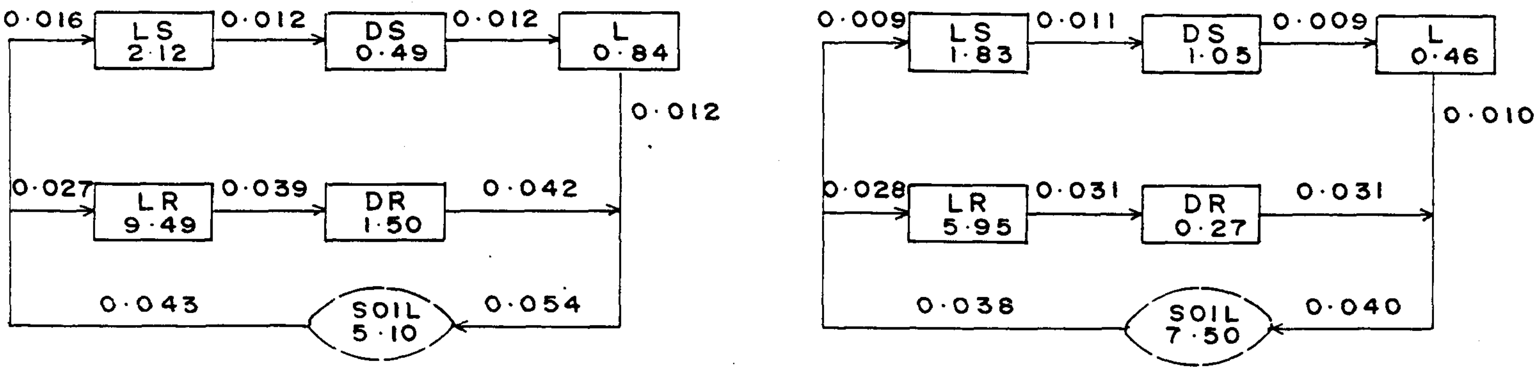
subsequent release was more or less equal to the input into respective compartments. Finally, about 8 % of the total uptake was retained in shoot during the study period. In the unprotected stand, almost all uptake was transferred from live shoot to litter through dead shoot compartment and the net release from the litter was almost equal to the aboveground uptake.

The transfer of phosphorus from live to dead belowground parts was equal to the uptake in the protected stand at Upper Shillong. The release from the dead belowground compartment was, however, slightly greater than the input to this compartment. In the unprotected stand, on the other hand, transfer from live to dead belowground compartment was about 12 % less than the uptake. The release from the dead compartment was, however, equal to the input to this compartment. Total input and output of phosphorus showed a net gain of 8 % in the belowground compartment and 2 % loss from the aboveground parts during the same period (Table 7.15).



Upper Shillong (Protected)

Upper Shillong (Unprotected)



Burnihat

Cherrapunji

Fig. 7.8 Mean standing state of phosphorus in vegetation, litter and soil compartments and net flux rates in four grassland communities of Meghalaya. Values within boxes are mean standing state (Kg ha^{-1}) and those on arrows are net flux rates (mg m^{-2} d^{-1}). (LR - Live root; DR - Dead root; LS - Live shoot; DS - Dead shoot and L - Litter).

Phosphorus turnover and cycling

The turnover rate (k) of phosphorus was highest in the aboveground compartment (0.92-1.08) and lowest (0.57-0.98) in belowground parts (Table 7.16). In the unprotected stand, however, phosphorus turnover rate in litter was quite fast (0.88-1.66) and was followed by aboveground compartment. The phosphorus turnover rate in the community gradually increased from 0.79 at Burnihat to 1.1 at Upper Shillong. Protection enhanced phosphorus turnover rate in the community.

Table 7.16. Phosphorus turnover rates for aboveground and belowground vegetation and litter compartments in the four grassland communities.

	Turnover rate (k)			
Site	Belowground	Aboveground	Litter	Total
Burnihat	0.57	1.46	1.42	0.79
Cherrapunji	0.79	0.92	0.88	0.84
Upper shillong protected	0.79	1.05	0.93	1.01
unprotected	0.98	1.08	1.66	1.16

DISCUSSION

Behaviour of phosphorus in all the communities was in many respects similar to nitrogen cycle discussed in the preceding chapter. Therefore, only the distinguishing features of phosphorus cycling are highlighted here.

The first important feature is the extremely low level of phosphorus in soils of all the communities. The concentration of available phosphorus or Bray's P_2 extractable phosphorus in these soils is below 2 ppm, whereas a value of 10 ppm is considered critical for plant growth requirement (Murphey *et al.* 1973). These levels are thus insufficient to meet the growth needs of vegetation. The most probable reason for this characteristic of grassland soils of Meghalaya is the abundance of iron and aluminium ions. Soils in humid tropics are usually rich in free iron and aluminium hydroxides and sesquioxides. They tend to have high phosphorus-fixing capacities rendering phosphorus very immobile and often unavailable for uptake by plants (Laverdiere 1982; Wood *et al.* 1984).

Secondly, the phosphorus concentration in various vegetation compartments differed from that of nitrogen. Unlike nitrogen, difference in phosphorus concentration between rhizome and root was not prominent. The overall trend of phosphorus concentration in aboveground vegetation compartments was live shoot>dead shoot>litter. Greater concentration in dead shoot than litter was in sharp contrast to nitrogen, which showed higher concentration in litter. It seems that phosphorus immobilization is not much and its concentration decreases progressively during the course of senescence of green shoot and then conversion to litter. This trend corroborates the results of other studies carried out at Ratlam (Billore & Mall 1976), Ujjain (Billore & Mall 1985) and Champhi (Chaturvedi *et al.* 1988). Although soil at Cherrapunji had higher concentration of available phosphorus than the other sites, the belowground parts contained considerably less phosphorus compared to other sites. Conversely, protected grassland community at Upper Shillong had greater phosphorus concentration in various belowground compartments than that in the unprotected community, but the phosphorus level in the two soils did not vary significantly. This trend differed from nitrogen which did not show significant intersite variation in belowground compartments. The aboveground vegetation compartments at Cherrapunji had lower nitrogen concentration than Burnihat and Upper Shillong communities. Minimum phosphorus at Burnihat and maximum at Upper Shillong is apparently related to phosphorus level in the soil. Higher nutrient availability due to better soil conditions such as pH, soil texture, soil moisture and/or greater nutrient acquisition capacity (inherent characteristic) of the constituent species in the community could be the probable reasons of higher phosphorus concentration at Upper Shillong.

The third interesting feature is that the total reserves of available phosphorus in soil upto rooting zone (30 cm) was less than the uptake by vegetation in all the grassland communities. Such a situation indicates the need of rapid replenishment of phosphorus in available soil pool in order to maintain its proper and continuous supply for plant uptake since phosphorus input through outside sources such as precipitation, fertilizer and animal supplemental feed seems to be relatively unimportant. In these grasslands, internal cycling of phosphorus wherein plant detritus serves as the chief source of phosphorus input is more important. The data suggest that nearly all the phosphorus absorbed by plants is returned to the soil pool through litter and belowground detritus. Rapid rate of turnover of phosphorus in belowground and litter compartments was responsible for quick recycling of phosphorus within the ecosystem. Generally, phosphorus turnover rates in these communities were nearly twice as fast as recorded in the semiarid grassland at Ujjain (Billore & Mall 1985). Higher turnover rate is obviously related to the climatic conditions of this region, which not only favours luxuriant plant growth, but also accelerates decomposition rate of dead plant material. Apart from climatic conditions, grazing and burning also accelerated phosphorus turnover rates, as is evident from higher values in the unprotected stand.

It is hypothesized that mineralization of dead organic matter in the form of litter and belowground phytomass is the chief source of phosphorus replenishment to soil pool. Every year the total phosphorus input to soil through these sources is almost fully utilized by the growth of vegetation. This leaves the nutrient pool in soil in a state of equilibrium.

Fourth major difference was in the effect of offered protection on phosphorus cycling. Both phosphorus flux rates between different compartments and percentage recycling in aboveground vegetation increased markedly as a consequence of protection of the community against burning and cattle grazing at Upper Shillong. This is in contrast to the nitrogen cycling in which protection increased only flux rates between various compartments but did not affect the relative proportions of nitrogen circulating through above- and belowground vegetation. This effect is explainable and is attributed to the concentration of phosphorus in the above- and belowground compartments. Due to more concentration of phosphorus in both above- and belowground compartments in the protected community than in the unprotected community, flux rates are higher in the former. Since phosphorus concentration in aboveground vegetation is relatively much higher in the protected community than in the unprotected one, it enhanced the proportion of phosphorus cycling through aboveground vegetation.

Other properties like seasonal dynamics of concentration and standing state of phosphorus in above- and belowground parts and its proportional allocation were similar to those observed for nitrogen.

A comparison of uptake, release and recycle of phosphorus in the grassland communities studied, with those from other ecoclimatic regions of India reveals that unlike semiarid and Himalayan grasslands, more than 50 % of the annual uptake is diverted to belowground parts in humid grasslands of Meghalaya. Lamotte & Bourliere (1983) found that, on an average, the annual plant uptake of phosphorus from soil rages from 4.9 Kg ha-1 Yr-1 in semiarid grasslands to 49.6 Kg ha-1 Yr-1 in dry subhumid grasslands of the IBP (International Biological Programme) and MAB (Man and Biosphere) sites in India. The values presented in Table 7.18 indicate that the plant uptake of phosphorus at Champhi, Kumaun Himalaya is very low compared to the reported range. The values at Ratlam are close to the lower limit, whereas at Ujjain it is near the higher limit of the IBP and MAB sites. In the present study it ranged between 14-34 Kg ha-1 Yr-1 which is well within the limits reported by Lamotte & Bourliere (1983).

The amount of phosphorus that returns to the soil each year ranges from 3.2 Kg ha-1 Yr-1 to 30.3 Kg ha-1 Yr-1 on the IBP and MAB sites. In humid grasslands of Meghalaya, the amount of

Table 7.17. Phosphorus uptake, release (Kg ha-1 Yr-1) and recycling (%) in Indian grasslands.

Grassland type	Uptake			Release			Recycle			Author(s)
	AG	BG	Total	AG	BG	Total	AG	BG	Total	
Semiarid grasslands										
Ratlam	7.9	7.9	16.0	2.5	4.7	7.2	31.6	59.5	45.0	Billore & Mall (1976)
Ujjain										Billore & Mall (1985)
Zero grazed	59.7	17.5	77.2	8.8	14.1	22.9	14.7	80.6	29.7	
Light grazed	36.9	9.7	46.6	2.1	11.6	13.7	5.7	119.6	29.4	
Moderate grazed	25.4	16.4	41.8	3.2	8.9	12.1	12.6	54.3	28.9	
Heavy grazed	17.2	29.8	47.0	4.4	10.3	14.7	25.6	34.6	31.3	
Himalayan grasslands										
Champhi (Nainital)	2.2	0.7	2.9	1.7	0.5	2.2	77.3	71.4	75.9	Chaturvedi *et al.* (1988)
Humid grasslands										
Burnihat	6.1	10.2	16.3	4.4	16.1	20.5	72.1	157.8	125.6	*This study*
Cherrapunji	3.6	10.7	14.3	3.6	11.6	15.2	100.0	108.4	106.6	--do--
Upper Shillong										
protected	18.2	15.6	33.8	16.8	16.7	35.6	92.3	107.1	99.4	--do--
unprotected	8.1	18.4	26.5	8.8	16.1	24.9	108.6	87.5	94.1	--do--

phosphorus release through plant detritus (15.2 to 20.5 Kg ha-1 Yr-1) is more or less equal to uptake. In this respect these grasslands differ from their counterparts in other parts of the country wherein annual uptake is 2.4 fold higher than the release. The only exception was Himalayan grassland at Champhi which showed a trend similar to the humid grasslands of Meghalaya.

Chapter 8

Potassium cycling

Chapter 8

POTASSIUM CYCLING

INTRODUCTION

Potassium differs from nitrogen and phosphorus in its mode of release from vegetation. It is primarily returned to soil nutrient pool by leaching (Long *et al.* 1956). Leaching of nutrients is of great importance in the mineral economy of plants and is defined as the removal of substances from plants by the action of aqueous solutions associated with rain, dew, mist and fog (Tukey 1970).

The importance of leaching of potassium as a way of return to the soil is well-documented in the studies carried out in forest ecosystem by Likens *et al.*(1967), Lewis (1974), Johnson & Risser (1974), Whittaker *et al.* (1979) and Gholz *et al.* (1985). This kind of information is very much limited in the tropical grasslands. A few researches have been undertaken in India on this aspect in the grassland communities at Ratlam (Billore & Mall 1976), Ujjain (Billore & Mall 1985) and Champhi (Chaturvedi *et al.* 1988). The data available from the MAB research sites have been presented by Misra (1983).

In this chapter, potassium cycling has been described in three grassland types of Meghalaya. The data were collected on i) accumulation and distribution of potassium in different vegetation components and soil, ii) potassium uptake by vegetation, its transfer to various aboveground and belowground compartments, and finally iii) its release to soil through litter and belowground dead phytomass. Apart from this, effect of protection against burning and grazing on accumulation and cycling of potassium at a high altitude site has also been evaluated.

RESULTS

Potassium concentration in soil and vegetation

Soil

The time series data on exchangeable potassium concentration (meq 100g-1) in soils of three study sites are given in Table 8.1. Three-factorial multivariate analysis of variance showed significant difference in potassium concentration ($p<0.01$) due to month, site and depth (Table 6.2). The effects of site and depth were much stronger than the variation through months. During the study period, potassium concentration ranged from 0.104 to 0.232, 0.061 to 0.100 and 0.056 to 0.102 at Burnihat; 0.092 to 0.128, 0.058 to 0.085 and 0.021 to 0.049 at Cherrapunji; 0.209 to 0.328, 0.158 to 0.195 and 0.147 to 0.192 in the protected and 0.185 to 0.237, 0.111 to 0.148 and 0.099 to 0.135 in the unprotected stand at Upper Shillong in 0-10, 10-20 and 20-30 cm soil layers, respectively.

Mean concentration of exchangeable potassium was highest at Upper Shillong followed by Burnihat and Cherrapunji (Fig. 8.1). At Upper Shillong, the protected stand had significantly higher value ($p<0.01$) than the unprotected stand. At all the sites, potassium concentration decreased with increasing depth. The decrease from upper to middle soil layer was, however, more marked. Difference between middle and lower layers was

Table 8.1. Monthly variation in exchangeable K concentration (meq 100g-1) in three soil layers of four grassland communities.

	Burnihat			Cherrapunji			Upper Shillong					
							protected			unprotected		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
MONTH	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30	00-10	10-20	20-30
AUG'88	.118	.071	.094	.097	.068	.046	.209	.158	.147	.185	.148	.132
SEP	.192	.091	.075	.092	.060	.030	.225	.180	.163	.192	.148	.127
OCT	.151	.086	.073	.102	.070	.033	.293	.192	.168	.196	.142	.126
NOV	.143	.080	.066	.109	.063	.032	.296	.195	.175	.216	.141	.130
DEC	.130	.061	.056	.113	.062	.030	.297	.188	.192	.202	.140	.130
JAN'89	.145	.091	.085	.097	.068	.047	.258	.172	.180	.175	.127	.114
FEB	.112	.082	.070	.094	.067	.036	.259	.169	.188	.188	.123	.103
MAR	.104	.078	.073	.107	.058	.029	.231	.171	.179	.203	.120	.112
APR	.121	.099	.086	.121	.059	.049	.234	.176	.183	.202	.119	.108
MAY	.148	.076	.066	.120	.084	.046	.293	.172	.176	.232	.111	.125
JUN	.232	.100	.087	.128	.078	.048	.328	.184	.172	.237	.146	.135
JUL	.208	.098	.093	.121	.077	.041	.277	.184	.182	.219	.118	.112
AUG	.138	.082	.102	.115	.085	.047	.243	.174	.164	.198	.117	.099

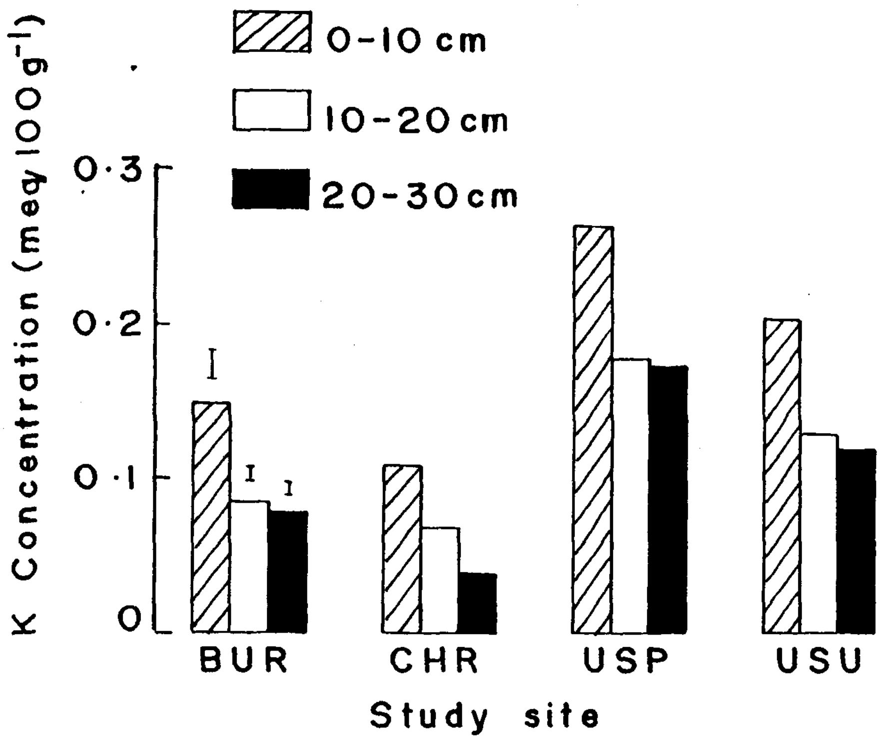


Fig. 8.1 *Mean monthly concentration (meq $100g^{-1}$) of exchangeable potassium in three soil layers of four grassland communities. LSD (5%) is shown by vertical line. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

not significant, except at Cherrapunji (Fig. 8.1).

Table 8.2. Results of three-factorial (replicated) analysis of variance (fixed effects model) to test null hypothesis (Ho) for variations in soil potassium concentration along months, sites, depths and their interactions.

Variation	d.f.	SS	MS	F
General mean	1	0.012741	0.012741	...
Month	12	0.000058	0.000005	236.38**
Site	3	0.001810	0.000603	29746.18**
Depth	2	0.000851	0.000426	20986.29**
Month x Site	36	0.000066	0.000002	89.75**
Month x depth	24	0.000054	0.000002	111.89**
Site x Depth	6	0.000038	0.000006	311.25**
Mon x Site x Dep	72	0.000057	0.000001	39.10**
Residual	312	0.000006	0.000000	...
TOTAL	468	0.015682	0.000034	...

** = Significant at $p<0.01$

Vegetation

Belowground parts:

Potassium concentration in belowground parts showed monthly fluctuation with some distinctive patterns (Fig. 8.2). In order to further clarify the pattern of variation through sampling dates, the means were calculated for live root and rhizome for those months along which concentration did not vary significantly ($p>0.01$). The corresponding months were also taken for calculating means for dead root and rhizome. At Burnihat, potassium concentration was slightly greater during December to May in live root and October to May in live rhizome than during rest part of the year. Similarly, both live root and rhizome showed lower value during August to November and August to September, respectively. At Cherrapunji, the periodic changes in

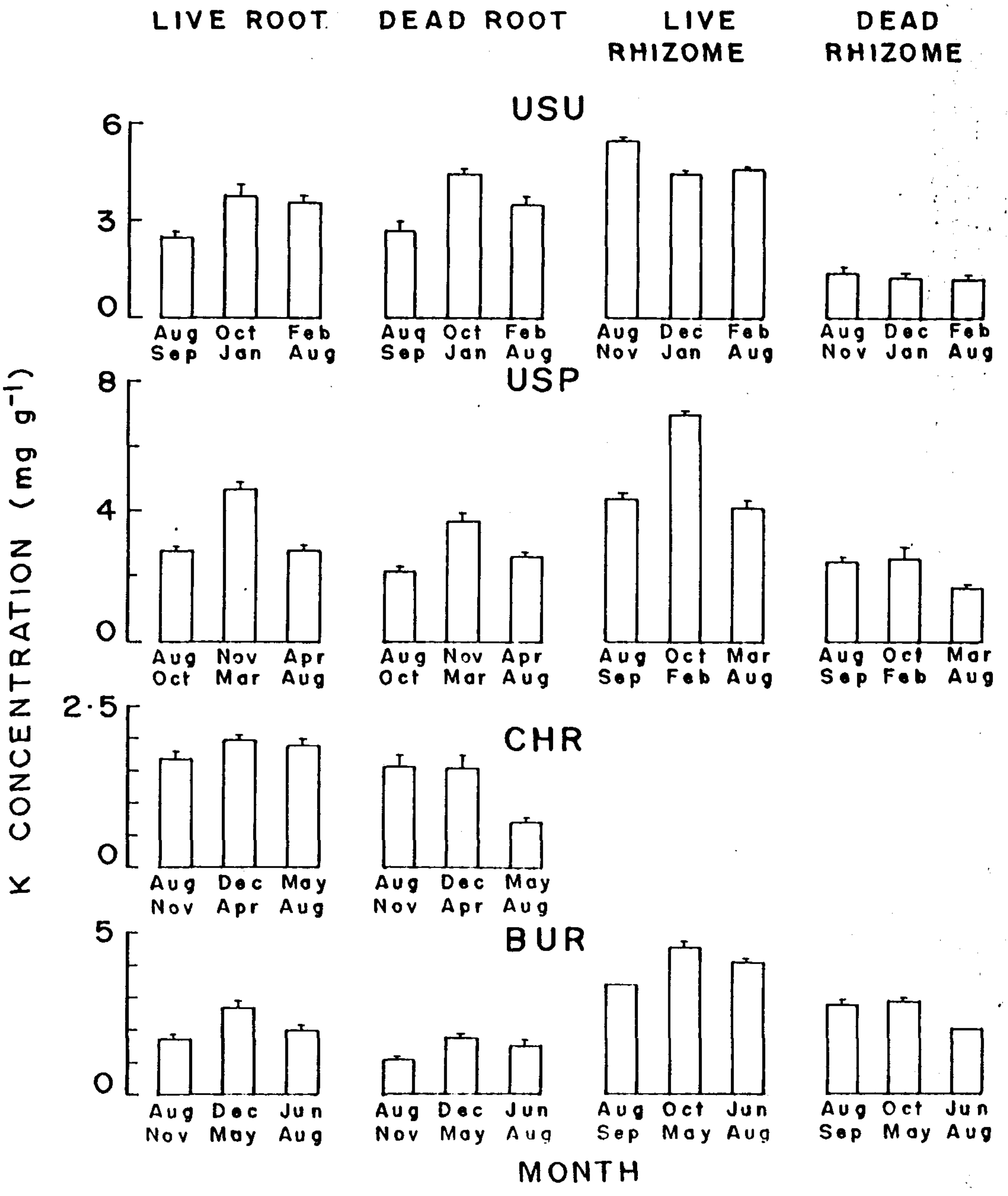


Fig. 8.2 *Periodic fluctuation in potassium concentration (mg g^{-1}) in the belowground components of four grassland communities. Standard errors represented by vertical lines denote variability between months indicated below the histograms. The months which showed no significant difference ($p>0.01$) were pooled to calculate the periodic mean. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

concentration were not prominent. It may be recalled that the live root at this site included rhizome fraction also. In the protected stand at Upper Shillong, potassium concentration in live root and live rhizome was 1.6-1.7 times greater during November to March and October to February, respectively as compared to the remaining months in the year. In the unprotected stand, however, potassium concentration in live root was slightly lower during August to September and in the live rhizome it was more or less constant throughout the year.

Table 8.3. Mean monthly concentration of K (mg g-1) in the belowground components of grassland communities at four sites.

	Root		Rhizome		
Site	Live	Dead	Live	Dead	**LSD**
Burnihat	2.26	1.53	4.28	2.67	**0.36**
Cherrapunji	1.80*	1.30*	--	--	**0.29**
Upper Shillong Protected	3.56	3.04	5.32	2.13	**0.73**
Unprotected	3.45	3.68	4.59	1.25	**0.45**
LSD	**0.46**	**0.45**	**0.70**	**0.42**	

LSD - Least Significant Difference at $p<0.05$
* includes rhizome also

Mean monthly potassium concentration was significantly different between live and dead root and rhizome compartment as well as between different sites (Table 8.3). At all the sites, live rhizome showed higher concentration than dead rhizome and live and dead roots. Live root had significantly greater concentration than dead root at Burnihat and Cherrapunji but not at Upper Shillong. The potassium concentration in all the compartments was significantly greater at Upper Shillong in comparison to other two sites. At Upper Shillong, the protected stand had higher values than the unprotected stand. The difference between live root and live as well as dead rhizomes were highly significant whereas the difference between live and dead roots was weakly significant.

Aboveground parts:

Potassium concentration in live shoot showed significant ($p<0.01$) monthly fluctuation in all the communities (Fig. 8.3). At all the sites, concentration was more during spring (summer) season and peaked in April/May. In dead shoot, monthly variation was indistinct at all the sites except in the unprotected stand at Upper Shillong in which the concentration

Table 8.4. Mean monthly concentration of K (mg g-1) in live shoot, dead shoot and litter components of grassland communities at four sites.

Site	Live shoot	Dead shoot	Litter	**LSD**
Burnihat	8.99 ± 0.48	5.87 ± 0.24	3.57 ± 0.30	**0.85**
Cherrapunji	7.62 ± 0.46	1.54 ± 0.13	1.25 ± 0.10	**0.68**
Upper Shillong Protected	9.54 ± 0.93	2.60 ± 0.19	2.84 ± 0.17	**1.33**
Unprotected	8.33 ± 0.69	3.05 ± 0.44	2.28 ± 0.19	**1.16**
LSD	**NS**	**0.67**	**0.49**	

± SE denotes variability through months
LSD - Least Significant Difference at $p<0.05$
NS - Difference is not significant

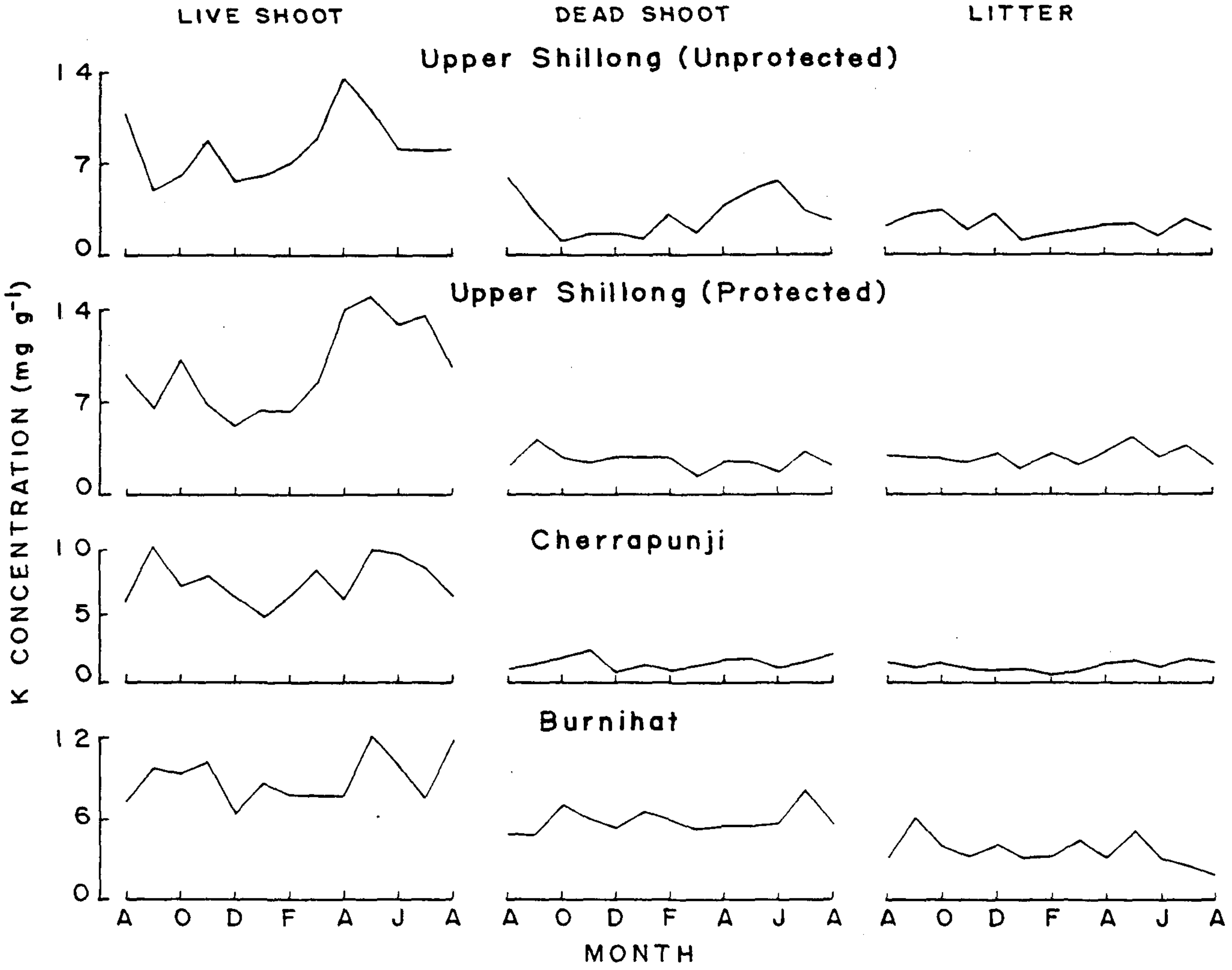


Fig. 8.3 *Monthly variation in potassium concentration (mg g^{-1}) in live shoot, dead shoot and litter mass in four grassland communities.*

was greater during spring (summer) season. Potassium concentration in litter, though fluctuated throughout the year, did not show any definite trend.

Mean monthly values were much greater in live shoot than in dead shoot and litter at all the sites (Table 8.4). The difference between dead shoot and litter did not vary significantly at all the sites except Burnihat. Intersite variations in live shoot were not significant. The general trend in dead shoot and litter was Burnihat>Upper Shillong>Cherrapunji. The live shoot had 2.5 to 3.5 times greater concentration as compared to live root.

Table 8.5. Seasonal variation in exchangeable K capital in 0-30 cm soil layer at four study sites.

Season	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected	**LSD**
Late rainy (Aug'88-Oct)	247.6	156.1	452.4	363.7	**48.1**
Winter (Nov-Feb)	219.5	160.0	502.2	349.6	**55.8**
Summer (Mar-May)	330.7	241.3	651.5	482.5	**32.2**
Early rainy (Jun-Aug'89)	269.6	183.7	480.1	343.0	**53.8**
LSD	**43.4**	**19.0**	**56.0**	**40.6**	
Mean	**244.4**	**170.2**	**482.9**	**354.7**	

LSD - Least Significant Difference at $p<0.05$

Accumulation of potassium in soil and vegetation compartments

Soil

There were significant ($p<0.05$) seasonal differences in soil potassium capital at all the sites (Table 8.5). The value was significantly higher during summer season, but in other seasons it did not vary much. The intersite variations were highly significant ($p<0.001$) in all the seasons. On the basis of mean monthly values, sites could be arranged in the following order: protected stand (483 Kg ha-1)>unprotected stand (355 Kg ha-1)>Burnihat (244 Kg ha-1)>Cherrapunji (170 Kg ha-1).

Vegetation

Belowground compartments:

Throughout the year potassium storage in dead phytomass was many times less than that in the live phytomass at all the sites (Fig. 8.4). At Burnihat, peak in live fraction was noticed in October, which declined upto April and then increased rapidly with the onset of rainy season. The dead parts showed greater accumulation during later part of the rainy season. At Cherrapunji, the peak in the live compartment was seen in September followed by a decline from September to May and then a rapid increase through rainy season. In the protected stand at Upper Shillong, accumulation in live compartment showed peak in November, after which it was more or less constant until February and then it declined upto April. From April to June it was again constant but increased sharply in subsequent months. The accumulation in dead belowground compartment at this site was maximum during September-October and minimum during April-June. In rest of the months, however, it was more or less constant. In

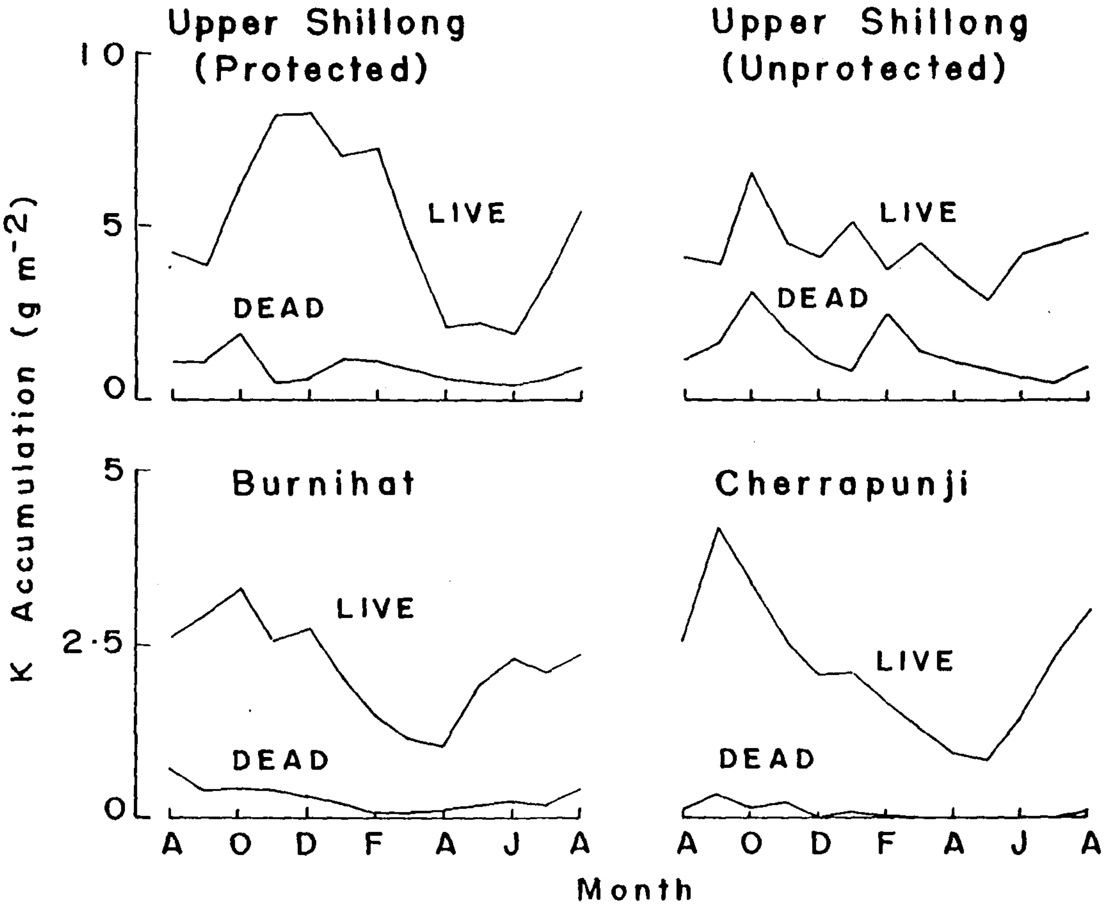


Fig. 8.4 Monthly variation in standing state of potassium (g m^{-2}) in live and dead components of the below-ground phytomass in four grassland communities.

the unprotected stand, it showed a multimodal curve. In live root it decreased from October to December and then increased during January. In the month of February when aboveground vegetation was burned, the value declined slightly, however, a corresponding increase took place in the dead compartment. Seasonal dynamics of potassium stored in the dead compartment was similar to that observed in the protected stand, except that the decline was more rapid from February to July.

Seasonal values of stratified distribution of potassium in belowground phytomass showed greater accumulation in upper soil layer (0-10 cm) at all the sites (Fig. 8.5). Accumulation of potassium declined sharply at lower depths. At Burnihat, the middle and lower layers showed slightly higher values during summer season. The middle and lower depths showed slightly less accumulation during early rainy season at Cherrapunji and during summer season in the unprotected stand at Upper Shillong. In the protected stand greater accumulation in the middle and lower depths was found during early rainy season.

Proportional allocation of potassium in total root and rhizome and total live and dead fractions of belowground phytomass revealed that at all the sites and in all the seasons, a major portion of potassium was present in the live compartment (Table 8.6). Highest (about 24 %) storage in dead compartment was in the unprotected stand at Upper Shillong and lowest (<5%) at Cherrapunji. Despite the fact that seasonality was not well marked, the values were greater during late rainy season at all the sites. Results further revealed that root stored a major portion of potassium at all the sites (Table 8.6). The

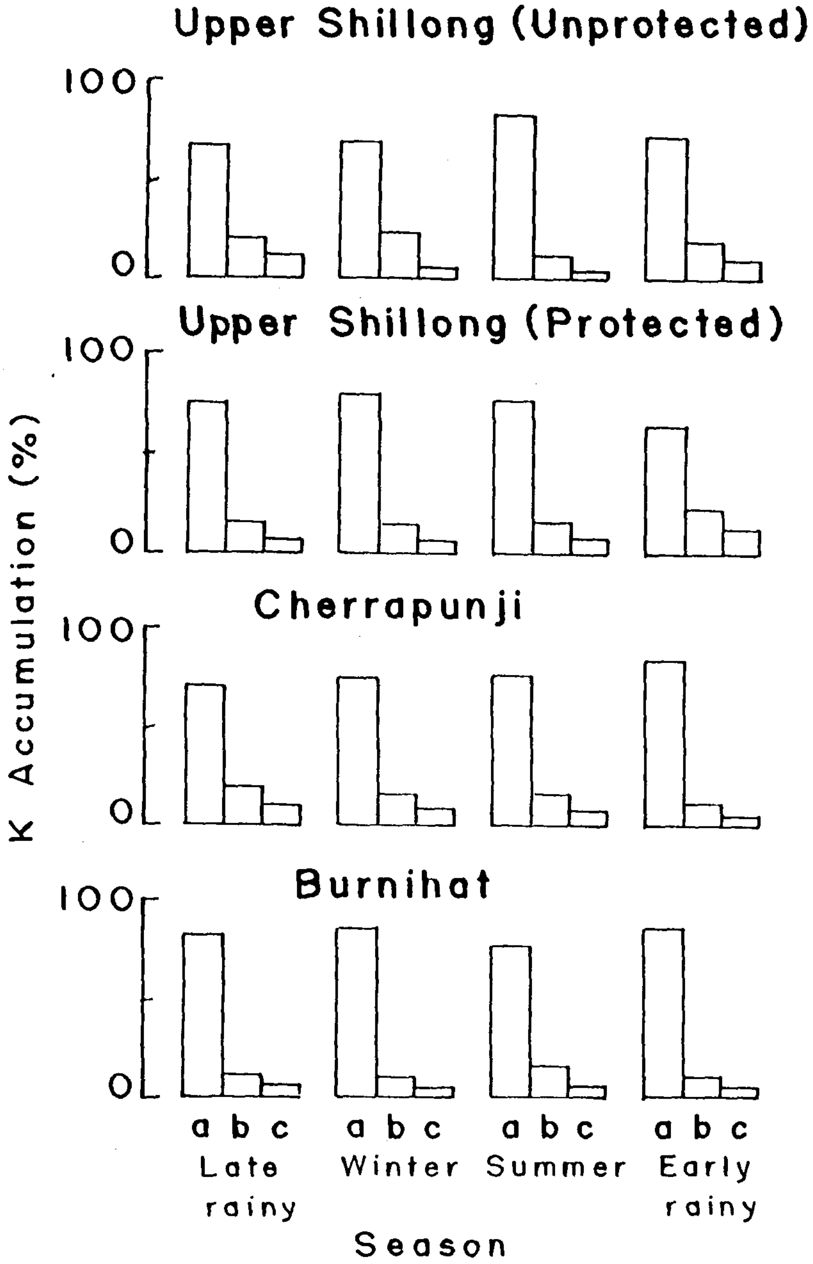


Fig. 8.5 Seasonal variation in potassium accumulation in below-ground phytomass at three soil depths; 0-10 (a), 10-20 (b) and 20-30 cm (c) in four grassland communities.

Table 8.6. Seasonal variation in proportional allocation of K in different components of belowground phytomass in four grassland communities.

Belowground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Root	56.6	75.7	74.1	64.4
Rhizome	43.4	24.3	25.9	35.6
Live	86.2	89.4	91.2	88.3
Dead	13.8	10.6	8.8	11.7
		CHERRAPUNJI*		
Live	94.5	95.5	98.2	98.8
Dead	5.5	4.5	1.8	1.2
		UPPER SHILLONG (PROTECTED)		
Root	67.1	62.5	77.0	69.2
Rhizome	32.9	37.5	23.0	30.8
Live	77.9	90.1	81.8	83.9
Dead	22.1	9.9	18.2	16.1
		UPPER SHILLONG (UNPROTECTED)		
Root	84.4	62.8	84.9	76.7
Rhizome	15.6	37.2	15.1	23.3
Live	70.9	72.8	75.6	85.5
Dead	29.1	27.2	24.4	14.5

* Separate data for root and rhizome are not available

accumulation in rhizome was highest in the protected stand. At Cherrapunji, separation of root and rhizome could not be done, therefore, separate data for these compartments are not available. At Burnihat, rhizome compartment was prominent during rainy season, whereas in the protected and unprotected stands at Upper Shillong it showed higher accumulation during winter season.

Aboveground compartments:

Monthly changes in the standing state of potassium in live shoot, dead shoot and litter compartments are shown in Fig. 8.6. Accumulation in live shoot decreased from September onwards, attaining the minimum value during winter season. After winter when vegetation showed rapid growth during wet summer, the potassium content in live shoot again increased sharply.

Potassium content in dead shoot increased from August onwards and showed peak in November at Cherrapunji and in January at other sites. Following the peak, it declined and reached at its minimum in May/June. In the unprotected stand, a sudden drop was observed during February on account of burning of vegetation.

Potassium content in litter increased from August and attained peak in November at Burnihat and Cherrapunji and in December at Upper Shillong, after which it declined slightly and remained nearly constant throughout the winter season. Further, it showed some increase in May and then again decreased rapidly.

Data presented on seasonal basis (Table 8.7) reveal that potassium accumulation in live shoot declined from rainy to the next summer season at Burnihat, whereas at Cherrapunji and Upper Shillong, the decrease continued until winter. Thereafter it increased rapidly at all the sites. The dead shoot accumulated relatively higher proportion of potassium during winter season at Cherrapunji and Upper Shillong. Seasonal trend was less clear at Burnihat.

Proportional allocation showed that at Burnihat 63-88 % of the total standing state of potassium in shoot was present in live fraction (Table 8.7). This was followed by dead shoot in

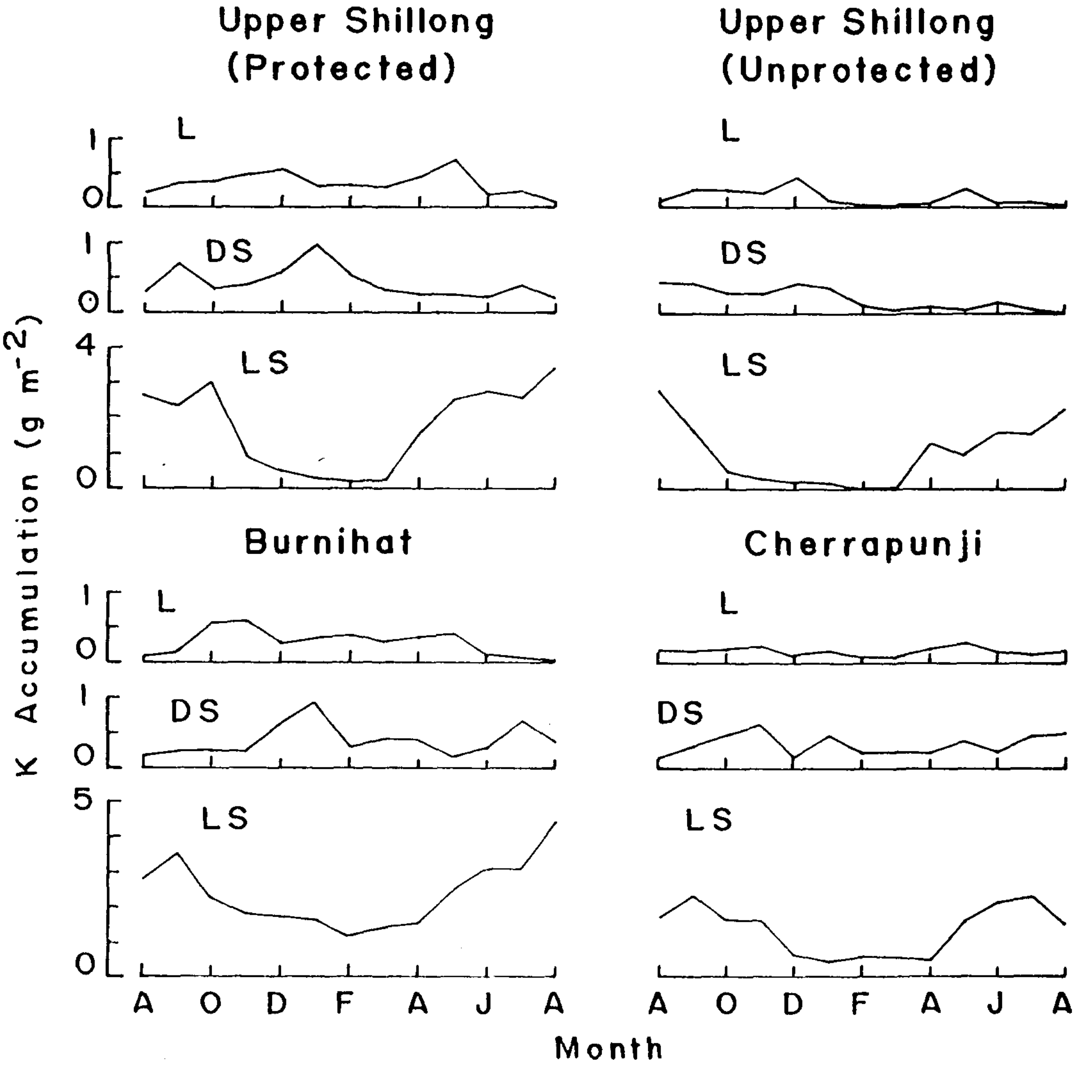


Fig. 8.6 *Monthly variation in potassium accumulation ($g\ m^{-2}$) in live shoot (LS), dead shoot (DS) and litter (L) mass in four grassland communities.*

Table 8.7. Seasonal variation in K accumulation (g m-2) and its proportional distribution (values in parentheses) in live shoot, dead shoot and litter in four grassland communities. ± SE denotes variability through months.

Aboveground component	Late rainy (Aug-Oct)	Winter (Nov-Feb)	Summer (Mar-May)	Early rainy (Jun-Aug)
		BURNIHAT		
Live shoot	2.86 ±0.38 (84.4)	1.59 ±0.15 (62.8)	1.82 ±0.35 (72.2)	3.57 ±0.46 (87.5)
Dead shoot	0.25 ±0.03 (7.4)	0.54 ±0.16 (21.3)	0.33 ±0.08 (13.1)	0.44 ±0.11 (10.8)
Litter	0.28 ±0.15 (8.3)	0.40 ±0.07 (15.8)	0.37 ±0.02 (14.7)	0.07 ±0.02 (1.7)
		CHERRAPUNJI		
Live shoot	1.86 ±0.22 (78.5)	0.81 ±0.26 (60.4)	0.88 ±0.37 (64.2)	2.02 ±0.25 (78.0)
Dead shoot	0.31 ±0.09 (13.1)	0.35 ±0.11 (26.1)	0.28 ±0.05 (20.4)	0.40 ±0.07 (15.4)
Litter	0.20 ±0.01 (8.4)	0.18 ±0.04 (13.4)	0.21 ±0.05 (15.3)	0.17 ±0.02 (6.6)
		UPPER SHILLONG (PROTECTED)		
Live shoot	2.65 ±0.22 (77.0)	0.42 ±0.16 (28.8)	1.47 ±0.67 (65.9)	2.94 ±0.28 (86.5)
Dead shoot	0.46 ±0.12 (13.4)	0.62 ±0.13 (42.5)	0.28 ±0.03 (12.6)	0.28 ±0.05 (8.2)
Litter	0.33 ±0.05 (9.6)	0.42 ±0.06 (28.8)	0.48 ±0.11 (21.5)	0.18 ±0.04 (5.3)
		UPPER SHILLONG (UNPROTECTED)		
Live shoot	1.60 ±0.67 (73.4)	0.19 ±0.07 (27.5)	0.75 ±0.38 (78.9)	1.83 ±0.23 (64.0)
Dead shoot	0.38 ±0.06 (17.4)	0.29 ±0.07 (42.0)	0.07 ±0.01 (7.4)	0.94 ±0.03 (32.9)
Litter	0.20 ±0.05 (9.2)	0.21 ±0.09 (30.4)	0.13 ±0.06 (13.7)	0.09 ±0.01 (3.1)

which the values ranged between 7 and 21 %. In litter, it ranged from 2-16 %. At Cherrapunji the corresponding ranges were 60-79 %, 15-26 % and 7-15 %. At Upper Shillong, seasonal differences were quite prominent. In both the stands relative accumulation in live shoot declined from about 73-77 % in the late rainy season to 28 % in the winter season. Simultaneously, the accumulation in dead shoot and litter increased indicating rapid transfer of

Table 8.8. Monthly variation in K accumulation (g m-2) in belowground and aboveground compartments of the grassland community at Burnihat.

Month	Belowground	Aboveground		Total	
	(a)	LS+DS (b)	LS+DS+L (c)	(a+b)	(a+c)
Aug '88	3.26	2.96	3.06	6.22	6.32
Sep	3.29	3.83	4.00	7.12	7.29
Oct	3.70	2.52	3.10	6.22	6.80
Nov	2.94	2.08	2.66	5.02	5.60
Dec	3.01	2.36	2.64	5.37	5.65
Jan '89	2.24	2.60	2.95	4.84	5.19
Feb	1.54	1.48	1.89	3.02	3.43
Mar	1.19	1.83	2.15	3.02	3.34
Apr	1.13	1.94	2.30	3.07	3.43
May	2.10	2.69	3.10	4.79	5.20
Jun	2.57	3.41	3.51	5.98	6.08
Jul	2.34	3.77	3.81	6.11	6.15
Aug	2.85	4.86	4.91	7.71	7.76

LS - Live Shoot; DS - Dead Shoot; L - Litter

potassium from live to dead and from dead to litter compartments. In general, the trend of potassium allocation was live shoot>dead shoot>litter.

Total accumulation in aerial parts was nearly equal to the belowground parts at Burnihat (Table 8.8) but less at Cherrapunji (Table 8.9). However, it was much greater in belowground phytomass in both the stands at Upper Shillong

Table 8.9. Monthly variation in K accumulation (g m-2) in belowground and aboveground compartments of the grassland community at Cherrapunji.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	2.63	1.83	2.03	4.46	4.66
Sep	4.48	2.60	2.78	7.08	7.26
Oct	3.54	2.06	2.29	5.60	5.83
Nov	2.77	2.18	2.46	4.95	5.23
Dec	2.03	0.75	0.87	2.78	2.90
Jan'89	2.21	0.91	1.10	3.12	3.31
Feb	1.74	0.82	0.93	2.56	2.67
Mar	1.35	0.77	0.89	2.12	2.24
Apr	0.96	0.71	0.94	1.67	1.90
May	0.87	2.00	2.28	2.87	3.15
Jun	1.42	2.45	2.61	3.87	4.03
Jul	2.32	2.78	2.92	5.10	5.24
Aug	3.02	2.02	2.22	5.04	5.24

LS - Live Shoot; DS - Dead Shoot; L - Litter

Table 8.10. Monthly variation in K accumulation (g m-2) in belowground and aboveground compartments in the protected grassland community at Upper shillong.

Month	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Aug'88	5.32	2.91	3.14	8.23	8.46
Sep	4.92	2.99	3.35	7.91	8.27
Oct	8.11	3.42	3.82	11.53	11.93
Nov	8.62	1.25	1.72	9.87	10.34
Dec	8.78	1.02	1.57	9.80	10.35
Jan'89	8.15	1.26	1.57	9.41	9.72
Feb	8.30	0.61	0.95	8.91	9.25
Mar	5.22	0.56	0.87	5.78	6.09
Apr	2.69	1.89	2.33	4.58	5.02
May	2.70	2.79	3.48	5.49	6.18
Jun	2.44	2.97	3.16	5.41	5.60
Jul	4.07	2.97	3.22	7.04	7.29
Aug	6.44	3.70	3.82	10.14	10.26

LS - Live Shoot; DS - Dead Shoot; L - Litter

(Tables 8.10 to 8.11). Generally both the compartments showed lower accumulation from February to April. Mean monthly value in belowground parts was significantly lower at Burnihat and Cherrapunji than Upper Shillong ($p<0.05$), but neither the difference between Burnihat and Cherrapunji nor between protected and unprotected stands at Upper Shillong was significant (Table 8.12).

The trend of potassium accumulation in shoot (live +

Table 8.11. Monthly variation in K accumulation (g m-2) in belowground and aboveground compartments in the unprotected grassland community at Upper shillong.

Month	Belowground (a)	Aboveground LS+DS (b)	Aboveground LS+DS+L (c)	Total (a+b)	Total (a+c)
Aug'88	5.27	3.21	3.31	8.48	8.58
Sep	5.55	1.98	2.24	7.53	7.79
Oct	9.61	0.72	0.98	10.33	10.59
Nov	6.50	0.58	0.79	7.08	7.29
Dec	5.21	0.69	1.14	5.90	6.35
Jan'89	5.97	0.55	0.68	6.52	6.65
Feb	6.33	0.10	0.14	6.43	6.47
Mar	5.94	0.08	0.14	6.02	6.08
Apr	4.70	1.43	1.51	6.13	6.21
May	3.83	0.97	1.21	4.80	5.04
Jun	4.92	1.77	1.85	6.69	6.77
Jul	5.11	1.64	1.74	6.75	6.85
Aug	5.83	2.35	2.43	8.18	8.26

LS - Live Shoot; DS - Dead Shoot; L - Litter

dead) was different. At Cherrapunji, the value was less than those at Burnihat and Upper Shillong protected stand but it did not differ significantly with the unprotected stand. In this stand, accumulation in shoot was significantly lower than the protected stand. If the potassium content of litter was added to the values of shoot, the accumulation pattern at different sites did not change. On the basis of mean standing state (aboveground+belowground), the sites could be arranged in the following order:

Upper Shillong protected stand>unprotected stand>Burnihat>Cherrapunji.

Table 8.12. Mean monthly accumulation of K (g m-2) in total belowground and aboveground compartments of four grassland communities.

Site	Belowground (a)	Aboveground LS+DS (b)	 LS+DS+L (c)	Total (a+b)	 (a+c)
Burnihat	2.47 ± 0.23	2.79 ± 0.26	3.08 ± 0.23	5.27 ± 0.42	5.56 ± 0.40
Cherrapunji	2.26 ± 0.29	1.68 ± 0.22	1.87 ± 0.22	3.94 ± 0.44	4.13 ± 0.44
Upper Shillong protected	5.83 ± 0.67	2.18 ± 0.31	2.54 ± 0.30	8.01 ± 0.61	8.37 ± 0.60
unprotected	5.75 ± 0.38	1.24 ± 0.26	1.40 ± 0.25	6.99 ± 0.39	7.15 ± 0.39
LSD	1.01	0.63	0.60	1.12	1.11

LS - Live Shoot; DS - Dead Shoot; L - Litter   ± SE denotes variability through months
LSD - Least Significant Difference at $p<0.05$

Belowground/aboveground ratio

This ratio was less than unity at Burnihat and more than unity at Cherrapunji and Upper Shillong (Fig. 8.7). At Burnihat and Cherrapunji, the ratio was more during September to October and declined thereafter upto April. In the protected stand at Upper Shillong, it increased from August to February and then declined rapidly in March and thereafter remained stable. In the unprotected stand, the seasonal trend differed from that of the protected stand. In this stand, the ratio increased rapidly from August to October and then declined sharply till December. After December, it again increased rapidly and peaked in February. The mean monthly ratio was 0.89, 1.35, 2.67 and 4.64 at

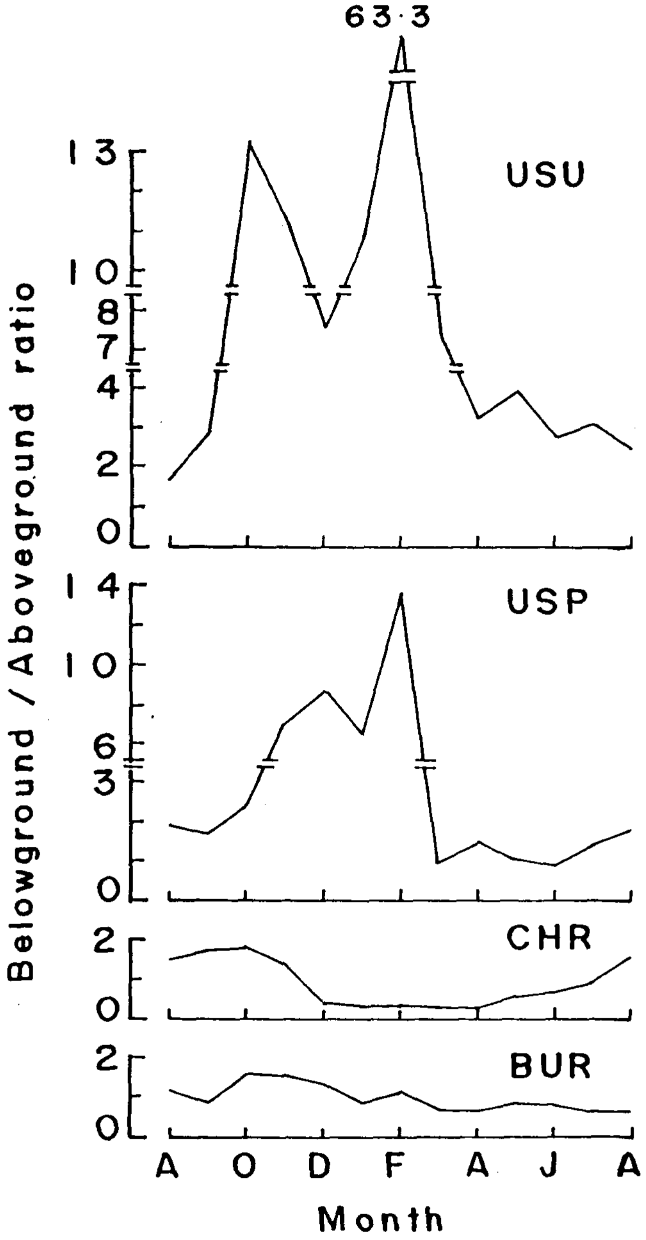


Fig. 8.7 *Monthly variation in the ratio of potassium accumulation in belowground and aboveground compartments of four grassland communities. (BUR - Burnihat; CHR - Cherrapunji; USP - Upper Shillong protected and USU - Upper Shillong unprotected).*

Burnihat, Cherrapunji, and in protected and unprotected stands at Upper Shillong, respectively.

Proportional distribution of potassium in soil and vegetation components

Of the total potassium present in the plant-soil system of the grassland communities, more than 80 % was in soil and only 15 to 20 % participated in biological circulation (Table 8.13). A major portion of potassium locked in the community biomass was reflected in the belowground compartments, particularly in live fraction (root + rhizome) at Cherrapunji and in the protected and unprotected stands at Upper Shillong. Unlike these communities,

Table 8.13. Proportional distribution of K in plant/soil system of four grassland communities. Values are based on means across the months (Aug'88 to Aug'89).

Component	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected
Aboveground vegetation	9.31	7.95	3.85	2.91
Live	7.97	6.37	3.10	2.41
Dead	1.34	1.58	0.75	0.50
Litter	0.97	0.88	0.63	0.38
Belowground vegetation	8.24	10.67	10.29	13.55
Live	7.27	10.27	8.74	10.23
Dead	0.97	0.41	1.55	3.32
Total vegetation	18.52	19.51	14.77	16.46
Soil*	81.48	80.49	85.23	83.54

* Exchangeable potassium

at Burnihat, aerial parts accumulated slightly more than the belowground parts. Differences in the distribution pattern of potassium in the soil and vegetation compartments (as per cent of total in each compartment) was analysed through a two-way factorial multivariate analysis of variance. The analysis was run with all six compartments, viz., live shoot, dead shoot, litter, live belowground, dead belowground and soil. The results showed that the distribution pattern of potassium was significantly influenced by site ($p<0.05$) and compartment ($p<0.01$) and so was the effect of interaction between site and compartment ($p<0.05$). Since this analysis may prohibit a fair conclusion (Bokhari & Singh 1975), soil was excluded in the second analysis, but the results remain unchanged.

Uptake, transfers and release of potassium

Total annual potassium uptake varied from 74 to 139 Kg ha-1 among the four sites (Table 8.14). At Burnihat, about 61 % uptake was in aboveground net production. On the other sites, however, the value ranged between 43 % (Cherrapunji) and 27 % (unprotected stand at Upper Shillong).

At Burnihat, 62 % of the aboveground uptake was transferred from live shoot to dead shoot. Rate of transfer from dead shoot to litter and release of potassium from litter was almost equal to the inputs to the respective compartments (Fig. 8.8). In the belowground parts, transfer of potassium from live to dead compartment was 7 % more than their uptake. Similarly, the release from the dead compartment was about 7 % greater than the input to this compartment. There was a net loss of 5 % from the belowground compartment compared to the total potassium

Table 8.14. Annual uptake, transfers and release of K (Kg ha-1) in four grassland communities.*

Flow	Burnihat	Cherrapunji	Upper Shillong protected	Upper Shillong unprotected
Uptake in ANP	45.13	31.61	43.12	29.32
Uptake in BNP	28.75	41.95	95.61	81.07
Total uptake	73.88	73.56	138.73	110.39
Transfer from live to dead shoot	27.95	33.06	34.29	34.22
Transfer from dead shoot to litter	26.16	29.72	35.19	37.98
Transfer from live to dead root	30.73	37.64	83.65	73.42
Release from litter	26.56	29.65	36.28	38.12
Release from dead root	32.91	38.00	84.37	75.46
Total release	59.47	67.65	120.65	113.58
% Recycle (Total release x 100/Total uptake)	80.5	92.0	87.0	102.9

* No. of days: Burnihat-382; Cherrapunji-379; Upper Shillong-406
ANP -Aboveground Net Production; BNP -Belowground Net Production

uptake (Table 8.15).

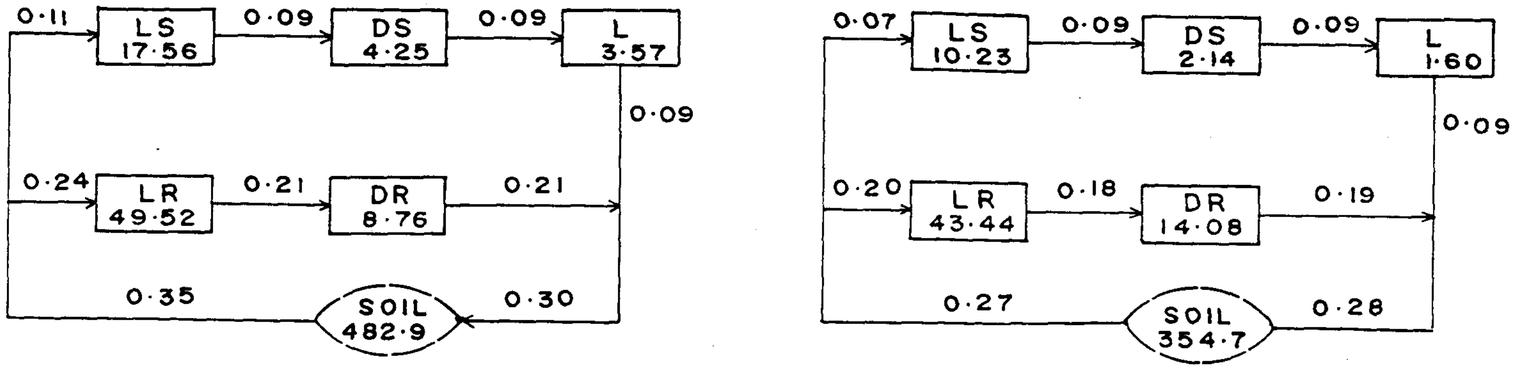
At Cherrapunji, potassium transfer from live shoot to dead shoot was about 5 % more than the uptake, but the transfer from dead shoot to litter was 10 % less than the input to the former compartment. Almost all of the potassium transferred to litter was released from the litter. Finally, about 3 % of total annual uptake was retained in the aboveground vegetation during the study period (Table 8.15). In the belowground parts retention was about 5 % of the total annual uptake; most of which was locked-up in the live component.

Table 8.15. Uptake, release and retention calculated as per cent of total uptake.

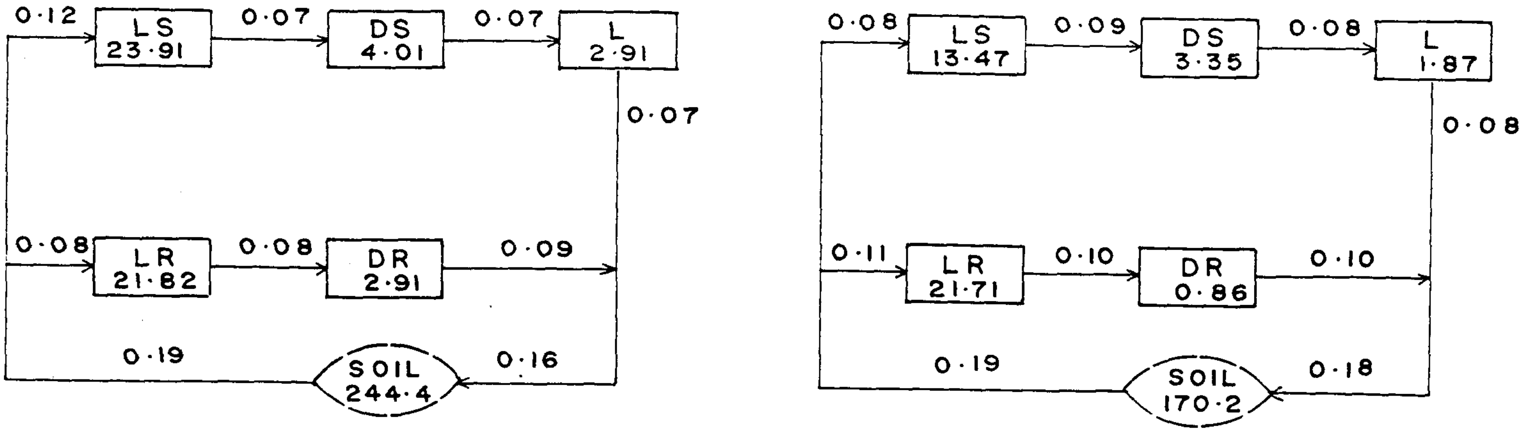
	Uptake in		Release from		Retention in	
Site	AG	BG	AG	BG	AG	BG
Burnihat	61	39	36	44	25	-5
Cherrapunji	43	57	40	52	3	5
Upper Shillong protected	31	69	26	61	5	8
unprotected	27	73	35	68	-8	5

AG - Aboveground; BG - Belowground

In the protected stand at Upper Shillong, potassium uptake by shoot exceeded (26 %) than its transfer from live to dead shoot compartment. However, the transfer from dead shoot to litter and then its release from the litter was slightly higher than the input into respective compartments. Thus, about 5 % of total annual potassium uptake was retained in shoot during the study period. Contrary to this, in the unprotected stand, transfer from live shoot to dead shoot exceeded (16 %) the uptake by shoot. The release from litter was also slightly greater than the input to this compartment. Consequently, there was a net loss of about 8 % of the total uptake from the aboveground system.



Upper Shillong (Protected) Upper Shillong (Unprotected)



Burnihat Cherrapunji

Fig. 8.8 *Mean standing state of potassium in vegetation, litter and soil compartments and net flux rates in four grassland communities of Meghalaya. Values within boxes are mean standing state (Kg ha^{-1}) and those on arrows are net flux rates (mg m^{-2} d^{-1}). (LR - Live root; DR - Dead root; LS - Live shoot; DS - Dead shoot and L - Litter).*

The transfer of potassium from live to dead belowground compartment was 13 % less than the uptake in the protected stand at Upper Shillong. The release from the dead belowground compartment was almost equal to the input to this compartment. Total input and output of potassium in belowground compartment showed a net retention of 8 %, a major portion of which was present in the live compartment. In the unprotected stand, transfer from live to dead compartment was 10 % less than the uptake. The release from the dead compartment was, however, slightly more than the input. Total input and output (both from above- and belowground compartments of the community) showed a net loss of 3 % during the study period (Table 8.15).

Potassium turnover and cycling

Potassium turnover rate in litter compartment was greater than the aboveground and belowground compartments at all the sites (Table 8.16). Further, it was faster in the aboveground parts than in the belowground compartment. In both the stands at

Table 8.16. Potassium turnover rates for aboveground and belowground vegetation and litter compartments in four grassland communities.

	Turnover rate (k)			
Site	Belowground	Aboveground	Litter	Total
Burnihat	0.78	0.93	1.20	0.95
Cherrapunji	0.94	1.14	1.39	1.01
Upper Shillong protected	1.09	1.17	1.15	1.16
unprotected	0.84	0.91	1.39	1.04

Upper Shillong, potassium turnover rate was higher in the aboveground compartment. Protected stand, however, had higher rates than the unprotected stand for the two compartments. In case of litter, this trend was reversed. At community level, potassium turnover rate was highest in the protected stand at Upper Shillong and lowest at Burnihat. Between Cherrapunji and the unprotected stands at Upper Shillong, the turnover rate did not differ markedly.

The daily flux rates of potassium between the compartments varied widely at different sites (Fig. 8.8). The rate of potassium uptake and release was maximum in the protected stand at Upper Shillong followed by the unprotected stand. Difference between Burnihat and Cherrapunji was not much. In the protected stand at Upper Shillong, both uptake and release rates were greater than that in the unprotected stand. Except at Burnihat, flux rates through belowground compartments were higher than those through aboveground compartments. At Burnihat, the reverse was true.

DISCUSSION

Behaviour of potassium is similar to nitrogen and phosphorus in some respects, but at the same time it has its own characteristics which are different from both of them.

The intersite variations in mean potassium concentration in soil were similar to nitrogen and on this basis the sites could be arranged as: protected>unprotected>Burnihat> Cherrapunji. This is apparently related to the percentage of finer particles (clay + silt) in the soil; the site having higher percentage of fine particles showed greater concentration of exchangeable potassium and vice versa. The depthwise variation was, however, different from nitrogen and phosphorus. A sharp fall in potassium concentration from surface to subsurface layers could be related to the distribution of belowground biomass at different depths which also showed a similar trend. Relatively greater amount of belowground biomass in upper soil layer together with inputs from aerial parts in the form of leachate and litter might have contributed to higher exchangeable potassium in upper layer at all the sites. But its relatively lower amount at a high rainfall area indicates a strong possibility of loss of potassium from the system through rain water.

Among the system compartments, the highest potassium concentration was found in live shoot at all the sites. This may be due to its greater concentration in mesophyll cells. Potassium promotes the translocation of photosynthate from leaves, and thus it may indirectly determine the rate of photosynthesis. Epstein (1972) reported that the photosynthetic rate is slowed down when assimilates accumulate in the leaf. A rapid export of photosynthate from the leaf could be important for maintenance of a high net photosynthetic rate (Neales & Incoll 1968). Hartt (1969) has presented evidence that potassium accelerates the movement of assimilates from leaves of sugar cane, *Saccharum officinarum*. Potassium also plays a very important role in opening and closing of stomates in green shoot (Fujino 1967) and thereby its concentration is expected to be higher in live shoot than in other plant parts.

In dead shoot potassium concentration was much lower than live shoot but the differences between dead shoot and litter were not significant. This could be the effect of retranslocation of potassium from live shoot during senescence and leaching losses from aerial parts. However, on the basis of data presented here, it is rather difficult to emphasize the relative importance of these two processes in decline in potassium concentration in shoot from live to dead stage. It is thus presumed that both withdrawal and leaching together might have contributed to the significant loss of potassium from the live shoot during senescence. Epstein (1972) emphasized that the potassium utilization in plant parts is efficient in the sense that it is readily redistributed from older leaves to young growing organs. Wallace (1930) reported that loss of potassium from Nearly equal levels of potassium in dead shoot and litter suggests that the leaching losses from dead shoot and litter are not prominent. It seems that by the time live shoot is converted to dead shoot, a substantial loss of soluble potassium has already occurred either through leaching or retranslocation and there remains only those forms which are not prone to leaching or are inescapable.

The intersite variations in live shoot were insignificant, but the differences between dead shoot and litter were quite distinct. In both these compartments, the values were highest at Burnihat and lowest at Cherrapunji and were related to the mean annual precipitation of the area.

A close examination of flow diagram reveals that most of the potassium absorbed by plants is returned to the soil through litter and belowground detritus (Fig. 8.8). Perhaps, there is no indirect method for calculating nutrient release, which separates the nutrient losses through leaching from those occurring through decay of litter and belowground detritus. Therefore, direct measurements of leaching losses by rainfall interception are required to enrich the knowledge of potassium cycling.

Another salient feature of the potassium cycling was that the relative proportions of potassium recycled through above- and belowground compartments differed markedly from nitrogen and phosphorus. Unlike nitrogen and phosphorus, the daily flux rates of uptake, transfers and release through aboveground compartments were greater than those of the belowground compartments at Burnihat. At other sites also, the belowground compartment was relatively less important than aboveground compartment in this respect. This may be ascribed to the greater concentration of potassium in shoot than in the belowground parts.

Like phosphorus, both flux rates of potassium between the compartments and percentage recycling in aboveground vegetation increased markedly as a consequence of protection of the community against burning and cattle grazing at Upper Shillong. This is in contrast to the nitrogen cycling in which protection increased only flux rates between various compartments but did not affect the relative proportions circulating through above- and belowground compartments.

Seasonal dynamics of concentration and standing state of potassium in above- and belowground parts and its proportional allocation was similar to nitrogen and phosphorus.

A comparison of uptake, release and recycling of potassium in the grassland communities with those from other ecoclimatic regions of India reveals that the grassland community at Burnihat resembles the one at Ujjain where as reported by Billore & Mall (1985), more than one-half of annual potassium uptake is found in aboveground parts. Lamotte & Bourliere (1983) found that, on an average, the annual plant uptake of potassium from soil ranges from 86 to 180 Kg ha-1 on the MAB research sites in India. The values presented in Table 8.17 indicate that the plant uptake of potassium at Cherrapunji and Upper Shillong is well within the limits reported by Lamotte & Bourliere (1983).

Table 8.17. Potassium uptake, release (Kg ha-1 Yr-1) and recycling (%) in Indian grasslands.

	Uptake			Release			Recycle			
Grassland type	AG	BG	Total	AG	BG	Total	AG	BG	Total	Author(s)
				Semiarid grasslands						
Ratlam	9.1	9.2	18.3	2.0	4.2	6.2	22.0	45.7	33.9	Billore & Mall (1976)
Ujjain										Billore & Mall (1985)
Zero grazed	74.1	25.7	99.8	11.8	20.7	32.5	15.9	80.5	32.6	
Light grazed	42.0	15.0	57.0	3.7	17.9	21.6	8.8	119.3	37.9	
Moderate grazed	30.6	25.2	55.8	3.6	13.7	17.3	11.8	54.4	31.0	
Heavy grazed	22.1	25.6	47.7	4.4	8.8	13.2	19.9	34.4	27.7	
				Himalayan grasslands						
Champhi (Nainital)	7.7	16.2	23.9	6.5	2.9	9.4	84.4	17.9	39.3	Chaturvedi *et al.* (1988)
				Humid grasslands						
Burnihat	45.1	28.8	73.9	26.6	32.9	59.5	59.0	114.2	80.5	This study
Cherrapunji	31.6	42.0	73.6	29.7	38.0	67.7	94.0	90.5	92.0	--do--
Upper Shillong										
protected	43.1	95.6	138.7	36.3	84.4	120.7	84.2	88.3	87.0	--do--
unprotected	29.3	81.1	110.4	38.1	75.5	113.6	130.0	93.1	102.9	--do--

In semiarid grasslands at Ratlam (Billore & Mall 1976) and Ujjain (Billore & Mall 1985) and in a Himalayan grassland at Champhi (Chaturvedi *et al.* 1988) about 30-40 % of annual uptake (9.4 to 32.5 Kg ha-1) returns to the soil each year. In the grasslands of Meghalaya this value goes upto 80 % of annual uptake (120.7 kg ha-1). In this way these grasslands differ from their counterparts in the other bioclimatic zones of the country in having faster recycling rate, probably due to low level of exchangeable cations, including potassium in the acidic soil of Meghalaya.

Chapter 9

General Discussion

Chapter 9

GENERAL DISCUSSION

The grasslands in Meghalaya represent the most degraded stage of forest vegetation. Like other grasslands of the country, they also owe their origin to repeated human interventions with natural vegetation in the form of shifting agriculture, burning and cattle grazing. Results presented in the foregoing chapters show that the grassland communities found at three different altitudes differ markedly from one another in species composition and relative proportion of species in various life forms. At lower altitude the community is dominated by therophytes while those at higher altitudes have chamaephytes as the dominant life-form. This is unlike other grasslands communities of the country where therophytes constitute the dominant life-form (Yadava & Singh 1977). Importance of altitude in influencing the composition of grassland communities of the state is, thus, clearly evident. Increase in the proportion of chamaephyte, in the community with increase in altitude has also been reported by Raunkiaer (1918), Allan (1937) and Gelting (1934). Apart from altitudinal variation, community composition was also affected by annual burning and mild cattle grazing throughout the year as is evident from a decrease in overall species diversity of the community, decline in dominance of *Imperata cylindrica* from protected to unprotected stand and an increase in the dominance of *Osbeckia crinita*, *Pteridium aquilinum* and *Arundinella nepalensis* in the unprotected stand at Upper Shillong. Hadley

(1970) and Kucera & Koelling (1964) have also reported a shift in species dominance due to fire.

Unlike tropical grasslands where coexistence of grasses, sedges and legumes is a normal feature (Medina 1985), all the communities studied, showed poor representation of legumes. Unfavourable soil conditions, particularly low extractable phosphorus and high acidity which are common features of all the sites seem to be responsible for poor growth of legumes in these communities.

Shannon diversity index was negatively correlated with dominance at all the sites and this agrees with the trend reported by earlier workers (McNaughton 1967; Singh & Misra 1969). In spite of low species diversity and high dominance, the Cherrapunji community seems to be quite stable. Dabadghao & Shankarnarayan (1973) and Ramakrishnan *et al.* (1981) have also expressed similar views. Thus the generally held view that species diversity leads to stability (Margalef 1963; McNaughton 1967) does not seem to hold good for this community. Based on their studies on communities Bazzaz (1975) and Bormann & Likens (1979) have demonstrated that a high species diversity may not necessarily bring greater stability in the community. On the contrary, Odum (1983) has emphasized that compared to structural complexity, functional diversity seems to contribute more to the community stability. At Cherrapunji, unfavourable soil conditions such as highly disturbed thin soil profile and low moisture content, CEC, and extractable phosphorus, high acidity and regular burning appear to have acted as the major stresses for the last several decades and have arrested the development of the community in this exceptionally high rainfall area.

Seasonality in species composition and growth is another characteristic feature of the tropical grasslands. Ample amount of data available from semiarid, dry and moist subhumid ecoclimatic zones of the country (Singh 1967; Singh & Yadava 1974); Billore & Mall 1985) suggests that such a seasonality is correlated with strong seasonal variation in temperature and rainfall. Similar seasonal changes are not prominent in the grasslands of Meghalaya, particularly the one which is located at lower altitude because neither the summer season is too much unfavourable for plant growth nor the winter as is the case in other parts of the country. Nevertheless, severe and relatively long and dry winter at higher altitudes almost completely suppresses the shoot growth, thereby causing a decline in species richness and stand density at Cherrapunji and Upper Shillong sites which are located at higher elevation.

Nutrient storage in soil in the grassland communities varied from one site to another. Total nitrogen content down to 30 cm depth tended to increase with altitude. Extractable phosphorus and exchangeable potassium did not follow this trend, but the amount of the latter was highest at Upper Shillong and lowest at Cherrapunji. This showed some relationship with the relative proportion of fine particles (silt + clay) in the soil. At Upper Shillong, this fraction was 40 % while at Cherrapunji it constituted only 19 % of the soil. Soils of all the grasslands under study are extremely poor in extractable phosphorus content whose value never exceeded 0.8 g m-2. It is interesting to note that its highest value was obtained at Cherrapunji where soil seems to be highly degraded both physically and chemically. Abundance of inseparable very fine roots in soil might have contributed to the relatively higher amount of extractable phosphorus at Cherrapunji.

Depthwise distribution of these nutrients was similar for all the three mineral elements, i.e., all of them showed greater accumulation in the top 10 cm soil layer and decreased accumulation in deeper layers.

Concentration of all the nutrients was generally higher in the aerial parts. And on the basis of mean concentration, nutrients could be arranged in the following order: N>K>P. In the aerial parts their concentrations were higher in the live shoot followed in descending order by dead shoot at all the sites. Difference between dead shoot and litter varied from one element to another. Nitrogen concentration was less in the dead shoot than litter; phosphorus being higher in litter and potassium almost equal in both dead shoot and litter. Lower concentration of all the three mineral elements in dead shoot than live fraction could be due to their retranslocation, during senescence and leaching to the more active regions in the plants. Other workers (Billore & Mall 1976,1985; Chaturvedi *et al.* 1988) who observed similar result, have also expressed the possibility of withdrawal of nutrients from senescing plant parts. Difference in potassium concentration between live and dead shoots is more prominent than is the case with nitrogen and phosphorus. Since leaching is the important route of potassium loss from the system (Long *et al.* 1956; Tukey 1970), decline in potassium concentration from live to dead shoot could be attributed to this process. Greater concentration of N in litter than dead shoot might be due to microbial immobilization as suggested by Swift (1979) and Melillo *et al.* (1982). The trend that litter contains less phosphorus than dead shoot corroborates the findings of Billore & Mall (1976, 1985) and Chaturvedi *et al.* (1988). In the belowground parts also, live root showed higher concentration than the dead part. Such a difference could also be ascribed to retranslocation as discussed by Chaturvedi *et al.* (1988).

As far as the total accumulation of nutrients in vegetation is concerned, more than 50 % was in the belowground parts. The amount of different nutrients, however, varied widely from one another. The amount of nitrogen was maximum followed by potassium and phosphorus at all the sites (Table 9.1). Sitewise difference was not prominent in case of nitrogen. However, accumulation of other two elements at Upper Shillong was nearly two times more than at Cherrapunji. Wide variation in phosphorus and potassium accumulation in vegetation at these two sites seems to be related mainly to the differences in soil and climatic conditions that influenced growth and abundance of constituent plant species. At Cherrapunji, thin, coarse-textured, acidic soil with less WHC & moisture content and severe winter and wind of high velocity during March-April are not congenial for the growth of large number of plant species. Consequently total nutrient accumulation was also less compared to Upper Shillong where soil profile is relatively thick and well developed and texture, moisture, pH, CEC provide much better substrata for plant growth in spite of severe winter.

A comparison of the protected and unprotected stands at

Upper Shillong clearly indicates the deleterious effect of grazing and burning on accumulation of mineral elements, particularly phosphorus. In both the stands accumulation in belowground phytomass was greater than in the aboveground parts. Disturbances in the form of mild grazing and annual winter burning marginally increased their accumulation in the belowground compartment.

Accumulation pattern of mineral elements in the humid grassland communities of Meghalaya is different from other grassland communities found in elsewhere in the country where greater accumulation has been reported in the aboveground compartment by several workers (Mishra 1979; Yadava 1980; Billore & Mall 1985; Agrawal & Tiwari 1987; Chaturvedi *et al.* 1988). Greater allocation of biomass and nutrients to the belowground parts indicates a relatively more important role of belowground parts in the overall energy flow and nutrient cycling in the humid grassland ecosystem. The results suggest that behaviour of all the nutrients was not similar so far as their relative allocation in above and belowground compartments of the vegetation is concerned. This is clearly evident in case of nitrogen which showed greater accumulation in belowground parts in those communities which have developed at higher altitude and face more severe climatic and/or edaphic conditions. Phosphorus and potassium allocation did not vary much. Thus on an overall basis it may be concluded that the humid grasslands of India differ from the semiarid and subhumid grasslands in showing greater accumulation of mineral elements in the belowground parts of the vegetation component.

Table 9.1. Mean storage of N, P and K in system compartments (g m-2), their uptake by vegetation and release from li and belowground detritus (g m-2 Yr-1) in the grassland communities of Meghalaya.

	Burnihat			Cherrapunji			Upper Shillong protected			Upper Shillong unprotected		
	N	P	K	N	P	K	N	P	K	N	P	K
Nutrient storage												
Soil	748.8	0.5	24.4	884.7	0.8	17.0	1467.9	0.4	48.3	1166.1	0.5	35.
Vegetation												
Belowground	7.4	1.1	2.5	9.5	0.6	2.3	9.3	1.5	5.8	10.1	1.1	5.
Aboveground	3.6	0.4	3.1	3.3	0.3	1.9	3.9	1.0	2.5	2.5	0.4	1.
Total	11.0	1.5	5.6	12.8	0.9	4.2	13.2	2.5	8.3	12.6	1.5	7.
Annual uptake	13.1	1.6	7.1	22.3	1.4	7.1	18.5	3.0	12.5	13.3	2.4	9.
Annual release	14.7	2.0	5.7	21.2	1.5	6.5	14.5	3.2	10.8	14.0	2.2	10.
Turnover rate	0.90	0.79	0.95	0.99	0.84	1.01	0.97	1.01	1.16	0.93	1.16	1.
Release/uptake ratio	1.12	1.25	0.80	0.95	1.07	0.92	0.78	1.07	0.87	1.05	0.92	1.

Total uptake of nitrogen, phosphorus and potassium in the four grassland communities did not show any relationship with their respective levels in the soil (Table 9.1). Altitudinal variation and climatic variables also could not be correlated with the uptake. Thus factors which control nutrient uptake remain undetectable and this calls for further investigation. Generally, a greater portion of nutrient uptake was reflected in belowground production. Behaviour of potassium at Burnihat and phosphorus in the protected stand at Upper Shillong was different, since aboveground uptake was more than the belowground uptake. The amounts of different nutrients varied at different sites, but the overall uptake pattern (N>P>K) was similar at all the sites. The pattern of uptake of different nutrients observed in the present study conforms with the findings of Billore & Mall (1985) and could well be linked with the relative requirements of these mineral elements in the plant body (Epstein 1972).

As a result of protection of the community against burning and grazing, an increase of 39, 25 and 26 per cent was noticed in nitrogen, phosphorus and potassium uptake, respectively. Higher uptake of nitrogen, phosphorus and potassium in the zero grazed stand than those under varying grazing intensities has also been reported from a semiarid grassland at Ujjain by Billore & Mall (1985). Mishra (1979) also reported similar influence of disturbance in a dry subhumid grassland at Kanpur.

The amount of annual nitrogen uptake at the lower elevation site in Meghalaya is closer to the average reported for the tropical grassland by Yadava & Singh (1979), but the values obtained for the higher altitude sites are higher than the average reported by these workers. Conversely, phosphorus uptake at Burnihat and Cherrapunji is less and at Upper Shillong it is more than the mean reported by Singh & Yadava (1979) for tropical grasslands. Potassium uptake is 3-4 times more in humid grasslands of Meghalaya as compared to a Himalayan grassland at Champhi (Chaturvedi *et al.* 1988) and a semiarid grassland at Ratlam (Billore & Mall 1976), but it is close to the value reported for the grassland community at Ujjain (Billore & Mall 1985).

The pattern for nutrient release was similar to that of uptake (Table 9.1). Almost entire amount is returned annually to the soil through litter and belowground detritus in the grasslands under investigation. This trend is different from other grasslands of the country where a substantial portion of uptake is retained in various above and belowground vegetation compartments. In other words, recycling rate is faster in the humid grasslands of Meghalaya compared to the grasslands of semiarid and subhumid bioclimatic zones of the country. Faster nutrient turnover rate may be attributed to the climatic conditions of Meghalaya which are conducive not only for plant growth but also for fast decay of the dead remains.

Summary

SUMMARY

This study deals with the community composition, storage of N, P and K in different vegetation compartments and soil and their cycling between plant-soil system of the degraded plant communities represented by grasslands in Meghalaya. The study emphasizes the effects of altitude, climate, soil and protection against mild cattle grazing and annual burning on the various aspects mentioned above.

The experimental sites are located at Burnihat, Cherrapunji and Upper Shillong having an altitude of 100, 1300 and 1900 m, respectively in the East Khasi Hills district of Meghalaya. The data were collected during August 1988 to August 1989. The mean values of climatic variables were: maximum and minimum temperatures 26.0 and 22.4°C, respectively and annual rainfall 2871 mm at Burnihat; maximum and minimum temperatures 19.7 and 16.6°C, respectively and annual rainfall 16247 mm at Cherrapunji; and maximum and minimum temperatures 18.5 and 17.0°C, respectively and annual rainfall 3268 mm at Upper Shillong.

The soil at Burnihat and Upper Shillong is sandy loam whereas at Cherrapunji it is highly stony; three-fourth of the total substratum being gravel or stone. Water holding capacity, pH, cation exchange capacity and total exchangeable bases are considerably low at Cherrapunji compared to the other sites. Organic carbon content increased significantly with altitude and ranges between 1.72 % at Burnihat and 3.5 % at Upper Shillong (protected stand). The mean values of total nitrogen content are

7488, 8847, 16679 and 11661 Kg ha-1 at Burnihat, Cherrapunji, and in the protected and unprotected stands at Upper Shillong, respectively. The extractable phosphorus is very low at all the sites and does not exceed 7.5 Kg ha-1. Exchangeable potassium ranges between 170 Kg ha-1 at Cherrapunji and 483 Kg ha-1 in the protected stand Upper Shillong.

Species content varied from 15 at Cherrapunji to 32 in the protected stand at Upper Shillong. The community at Burnihat was dominated by *Setaria glauca* whereas *Arundinella khaseana* and *Arundinella nepalensis* were dominants at Cherrapunji and Upper Shillong, respectively. Proportion of perennial species and chamaephytes in the community increased significantly with elevation. Legumes were poorly represented in all the grassland communities. forbs were most prominent at Upper Shillong, whereas the Cherrapunji grassland community was composed almost entirely of grasses. At Cherrapunji, species diversity was low and dominance was high compared to those at Burnihat and Upper Shillong. The grassland communities at various elevations were quite dissimilar. However, at Upper Shillong, there was about 80% similarity between the protected and unprotected stands.

Protection of community at Upper Shillong against annual winter burning and mild cattle grazing increased species content, density, cover and diversity. Dominance of *Osbeckia crinita* and *Arundinella nepalensis* declined following protection while that of *Imperata cylindrica* increased.

Nitrogen reserve in soil at Upper Shillong was approximately twice that of Burnihat and Cherrapunji. Of the total nitrogen in the soil-plant system, more than 98 % was present in soil and only 1 to 1.5 % participated in biological circulation. Difference in the standing state of nitrogen in vegetation was insignificant among the four communities and the mean value ranged between 10.2 g m-2 at Burnihat and 12.2 g m-2 at Upper Shillong (protected stand). In all the communities, belowground parts accumulated more N than aerial parts. Annual uptake was maximum (232 Kg ha-1) in the Cherrapunji community. At Burnihat and in the unprotected stand at Upper Shillong, annual uptake was about 40 % less than the uptake at Cherrapunji. In the protected stand at Upper Shillong, uptake (206 Kg ha-1) was less than Cherrapunji but more than other sites. About two-third of the total uptake was diverted to belowground parts at Burnihat and Upper Shillong, whereas at Cherrapunji, it was much higher (*ca.* 88 %). The annual release through litter and belowground detritus was more than the uptake at Burnihat and in the unprotected stand at Upper Shillong. At Cherrapunji and in the protected stand at Upper Shillong, release was less than the uptake. The annual budget showed a net loss of about 13 % of the total uptake at Burnihat and 6 % in the unprotected stand at Upper Shillong. On the other hand, there was a net retention of about 5 % at Cherrapunji and 21 % in the protected stand at Upper Shillong. In all the communities, turnover rate was near unity indicating almost complete recycling within a year.

The amount of extractable phosphorus in soil ranged between 4.2 Kg ha-1 at Upper Shillong and 7.5 kg ha-1 at Cherrapunji. Its mean accumulation in vegetation was maximum in the protected stand at Upper Shillong (2.48 g m-2) and minimum at Cherrapunji (0.96 g m-2). The grassland communities at Burnihat and Cherrapunji exhibited more or less equal value but the unprotected stand had lower value than the protected stand. In all the communities, accumulation was 2-3 times more in the belowground parts than in the aboveground parts. Of the total available phosphorus content in soil and that stored in plant system, about 56 % was in vegetation at Cherrapunji, 86 % in the protected stand, *ca.* 25 % at Burnihat and in the unprotected stand at Upper Shillong. The accumulation in belowground parts was relatively less (36 %) at Cherrapunji than the other sites (51-56 %). In all the communities, the annual uptake was more than the amount of extractable phosphorus in soil. The annual uptake was maximum (34 Kg ha-1) in the protected stand at Upper Shillong, and it is nearly two times that of Burnihat and Cherrapunji. In the unprotected stand, it was 26 Kg ha-1. About two-third of the total uptake was transferred to the belowground parts at Burnihat and in the unprotected stand. In the protected stand, it was more than the unprotected stand. At Cherrapunji, the proportion of belowground uptake was 75 %. The release was more than the uptake at Burnihat, Cherrapunji and in the protected stand. In the unprotected stand, however, it was slightly less than the uptake. The annual budget showed a net loss of about 26 and 6 % of the total phosphorus uptake at Burnihat and Cherrapunji. Interestingly, the unprotected stand retained 6 % in belowground vegetation. In all the communities, turnover rate was quite fast and the value ranged between 0.8 and 1.2; the minimum being at Burnihat and maximum in the unprotected stand.

The exchangeable potassium in the soil was related to the percentage of fine particles (clay + silt) and its amount was maximum in the protected stand (483 Kg ha-1) and minimum at Cherrapunji (170 Kg ha-1). At Burnihat, the reserve of exchangeable potassium in soil was about 50 % of that present in the protected stand at Upper Shillong, whereas in the unprotected community this was about twice that at Cherrapunji. Potassium content in the vegetation was maximum in the protected stand (8.37 g m-2) and minimum at cherrapunji (4.13 g m-2). It was 7.15 g m-2 in the unprotected stand and 5.56 g m-2 at Burnihat. Except at Burnihat, accumulation was more in the belowground than in the aboveground parts. The reverse was true at Burnihat. About 15-19% of the total labile potassium in soil and that stored in plant system participated in biological circulation. The annual uptake was maximum in the protected stand (139 Kg ha-1). A higher proportion of uptake was channelized to the belowground parts in all the communities except Burnihat where aboveground compartment was more prominent. The annual release through dead plant parts was less than uptake at all the sites except in the unprotected stand at Upper Shillong where the output and input were more or less equal. The annual budget showed a net gain of 20 % at Burnihat, 8 % at Cherrapunji and 13 % in the protected stand. Potassium turnover rate ranged between 0.95 and 1.16.

Protection of the community at Upper Shillong for about 7 months increased the accumulation of N, P and K in soil and vegetation compartments of the community. The uptake and release and daily flux rates between the compartments also increased. There was a build up of nitrogen and potassium mainly in the belowground phytomass of the community after protection.

A comparison of nutrient cycling in these grassland communities with those from other ecoclimatic zones of the country shows that in humid grasslands of Meghalaya, belowground parts play more important role in accumulation and cycling of nutrients than the aerial parts which have been reported to be of greater significance in other ecoclimatic regions of the country. The turnover of N, P and K is much faster in these grasslands compared to the subhumid, semiarid and Himalayan grasslands. The high turnover rate also depict the recycling of almost all the uptake of these elements annually in the grasslands of Meghalaya.

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