COMMUNITY DYNAMICS AND EDAPHIC CHANGES IN RELATION TO COAL MINING IN JAINTIA HILLS, MEGHALAYA

By
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I certify that the thesis entitled "**Community dynamics and edaphic changes in relation to coal mining in Jaintia Hills, Meghalaya**" submitted by Miss Tariang Lyngdoh for the degree of **Doctor of Philosophy** of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by her under my supervision. She 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

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CHAPTER 1

GENERAL INTRODUCTION

The progress of mankind depends upon the judicious exploitation of natural resources. Utilization of these resources is of paramount importance in sustaining national development in both developed and developing countries. Historically, mining is second only to agriculture as the world's oldest and most important activity. Mining provides fuels for meeting energy requirements, metals for making engines and machines, ores for chemicals and fertilizers, clay for vases, rocks and stones for buildings, bridges and dams, and gold, diamonds and other precious stones for jewellery.

Though extraction of mineral resources is essential for development, unfortunately, mining particularly, surface mining causes severe environmental problems. The first consequence of any mining operation is the removal of vegetation and the degradation of land. Land, our most important natural resource, is destroyed by the extensive excavation and dumping of infertile overburden materials in the vicinity of these mines, which also result in air and water pollution. In the headlong rush to increase our standard of living, the pace of destruction to land by mining has increased dramatically during the last few decades. Hence, there is an urgent need to slow down the pace of destruction to land and to reclaim the already disturbed land, because if this pace of destruction is allowed to continue and no effort is made to restore disturbed lands then man's very survival on earth may be threatened. This has led many countries to develop and adopt laws, national programmes and specific policies for environmental protection. The basis of most laws applicable to mining industry and its effect on land seeks to control land degradation management, protect resources and regulate land reclamation and landscape restoration (CHADWICK *et al.* 1987).

Before developing any technique to reclaim these drastically disturbed lands, there is a need to understand their physical and chemical limitations because if these limitations are identified they can be treated effectively and economically. Consequently, a specific discipline of ecology called mining ecology has developed where ecologists devote in studying the physical, chemical and biological characteristics of lands degraded as a result of mining (WALI & KOLLMAN 1977). Knowledge of these aspects is a prerequisite to planning their future use.

Coal mining results in pit scarred landscape because of the extensive excavations and heaps of unwanted debris on the adjacent unmined land. These heaps of debris consist of consolidated and unconsolidated overburden materials overlying the coal seams which have been disturbed, and haphazardly mixed during the mining activity. They form a waste material known as **'overburden'** or **'mine spoil'** (WALI 1987, JHA & SINGH 1990). Coal mine spoil heaps are also known as 'tips', 'rucks', and 'banks' in England and Wales, as 'bings' in Scotland and as 'refuse banks' in North America (GLOVER 1975).

Coal mine spoils represent extremely degraded and disturbed ecosystem. Ecosystem disturbance has been defined by WALI (1987) as "an event or a series of events that results in altering the relationships of organisms and their habitat from their natural state both spatially and temporally". Disturbance may be classed as 'drastic' when they are created by natural causes such as volcanic eruptions and large scale earthquake activity. Surface mining for coal and other minerals is the example of man-made drastic disturbance.

The utilization of coal as an energy source, both by means of steam engine and in the form of coke was a major characteristic of the First Industrial Revolution. In fact it was on coal that nations built their industrial power in the nineteenth and early twentieth centuries. There was a slump in the demand of coal as an energy source after World War II due to the availability of oil. However, steep price rise of liquid hydrocarbon fuels, led to the increased use of coal (WORLD BANK 1979, WILSON 1980). Coal has now been established as a relatively attractive fuel in many industrial applications, but its overall prospects will depend on economic growth in the major industrialized regions of the world and its acceptability from a social and management point of view (CHADWICK *et al.* 1987).

Between 70% and 90% of the total quantity of coal is utilized for electricity generation. A substantial amount of coal has also been used in iron, steel, aluminium and cement industries. India is one of the nine largest coal producing countries in the world. The production was about 154.30 million tonnes in 1985-1986 and it is expected that the production level will reach 417 million tonnes by 2000 AD (COAL INDIA 1986).

Geological evidences indicate that coal seams were formed due to the decay of the terrestrial plants during the time beginning from the Carboniferous up to the Tertiary age under the influence of hydrostatic pressure and geothermal heat. In this period, forest trees grew in abundance in swampy areas, which had to suffer several phases of intermittent yet slow sinking. One phase gave rise to the formation of one coal bed and again the area was brought under sedimentation by river flow giving rise to shale and sand stone deposits, thus burying the coal bed formed earlier. Good amount of sediments deposited in the basin of swampy regions gave rise to luxuriant growth of trees which after dying out formed new seams of coal deposits. Several cycles of such formations are recorded in different parts of the world. Since all these took place under swampy anaerobic conditions relatively, high amount of pyrites (FeS_2) was also deposited.

But when coal is mined, neither the low grade carbonaceous material nor the inorganic rocks associated with the coal seams are wanted. These form the '**overburden**' or the '**spoil**'. The low carbonaceous material which is high in nitrogen, sodium and chlorine is slow to weather and produces very little in the way of nutrients for plant growth (BRADSHAW & CHADWICK 1980).

Though mining and use of minerals in India date back to the Indus Valley Civilization, coal mining was first taken up in India in 1774 by SUMNER and HEATLY in Raniganj coal field (TANDON 1990). Till the year 1830 several coal mines came up in the Raniganj coal field area. In the north east, coal mining was initiated by LA TOUCH (1882, 1883, 1884, 1889, and 1890). This was followed by the preliminary works of FOX (1935-38) in Garo Hills and detailed works of AROGYASWAMI and DESIKACHARI (1949-

1950) in southern Khasi Hills. Coal occurrence in Jaintia Hills were examined by shallow drilling in 1962-63 by J. P. DIAS and others (BULLETIN OF GEOLOGICAL SURVEY OF INDIA, 1969).

The State of Meghalaya is rich in mineral resources, of which the principal ones are coal, limestone, and sillimanite. These minerals are haphazardly mined because of individual ownership of lands. The ownership of land barring a few areas largely lies with the people. Coal deposits occur as thin seams which range in thickness from 30 cm to 1.5 m in the sedimentary rocks, sandstones and shale of the Eocene age (GUHA ROY 1991). These deposits usually occur along the southern fringe of the Shillong plateau extending over a length of 400 Km. In the hills of Meghalaya, the coal bearing sedimentary formations are sub-horizontal to gently dipping in nature. Important coal fields of Meghalaya are Laitryngew, Cherrapunjee, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, East Darrangiri, Pynursla and Lyngkyrdem, Mawlong-Shella-Ishamati in the Khasi Hills, West Darrangiri , Siju, Pyndengru-Balphakram; Salsella Block in the Garo Hills, and Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioksi in the Jaintia Hills.

Coal mining in Meghalaya is carried out by private operators and is done manually by **'Rat-Hole method'** which is very crude, uneconomical and unscientific (Plate 1.1 a&b). In this method pits ranging from 5 to 100 m^2 are excavated into the soil till the seam of coal is reached. The depth at which this seam occurs ranges from 2 to 10 metres. Coal is then removed from this pit. Tunnels are then made into the seam sideways and coal is brought into the pit by wheel-barrows. From the pit coal is taken outside by carrying in conical baskets. Here and there columns of coal are left intact to serve as pillars for supporting the soil above. Subsequently, these pillars are also cut down, as a result of which, the soil covering the coal seams sinks down forming large cracks on top. While digging the pits, the soil and rocks above the coal seams are thrown haphazardly outside the pit and thus cause large destruction to the surrounding land and vegetations (Plate 1.2 a&b, Plate 1.3).

Coal mine spoils when freshly tipped have a great range of particle size ranging from large pieces of shale to silt and clay (MOLYNEUX 1963). At first the shale is relatively bright blue or grey, but as weathering proceeds the colour becomes somewhat subdued. Much of the shale disintegrates into clay, a feature of this process being the breaking down of the shale along its laminations so that the fragments become slate like in shape. The pieces of mudstone and sandstone occasionally found within the spoil become much more noticeable as weathering continues. An important feature of the clay is its impermeability which leads to considerable surface run-off (MOLYNEUX 1963).

Coal mine spoils present very rigorous conditions for plant growth. Colonization, establishment and maintenance of vegetation on these spoils are extremely difficult. There are various factors which limit plant growth on these spoils. The principal factor is always extreme acidity caused due to the oxidation of iron pyrites (FeS_2) (CHADWICK 1973, CARUCCIO 1975). So, colonization of spoils is only by those species which have the ability to evolve tolerance (Plate 1.4 a&b). The number of species colonizing them increases with the increase in pH of the substratum (BRADSHAW & CHADWICK 1980). Continued acidification for many years may lead to die back of well established vegetation (COSTIGAN *et al.* 1981). Besides, acidic coal mine spoils contain toxic levels of soluble elements such as Fe, Al, Mn and Cu. The physical factors which limit plant establishment and survival include high surface temperature, moisture stress (RICHARDSON 1975), soil particle size (DOWN 1974), surface instability leading to erosion (BRIERLEY 1956, DOWN 1975) and compaction (HALL 1957, RICHARDSON 1975).

Soil fertility is also the major factor which regulates plant growth. Nitrogen and phosphorus are the two limiting nutrients on coal mine spoils (WILLIAMS 1975, WITTWER *et al.* 1981). IVERSON & WALI (1982) reported phosphorus as the limiting nutrient during colonization and early successional process on surface-mined lands in North Dakota. When nitrogen and phosphorus are inadequate, plant growth is adversely affected. Besides, organic matter is also deficient. This is due to the absence of litter. SCHAFER *et al.* (1980) reported that even in 53 year old spoil the organic matter is present only in the upper few centimetres.

Mining ecology has been extensively studied in different parts of the world. BANERJEE (1981), SINGH & JHA (1987), JHA (1989, 1990, 1992),) and JHA & SINGH (1990, 1992) have contributed much to our knowledge of the ecology of Indian mine spoils in dry tropical region. With the exception of few publications (LYNGDOH *et al.* 1992, UMA SHANKAR *et al.* 1993), there is no serious ecological studies on coal mine spoils of this region.

Considering the aforesaid facts, the present study on "**Community dynamics and edaphic changes in relation to coal mining in Jaintia Hills, Meghalaya**", was conducted in Jarain area of Jaintia Hills district to cover the following aspects.

1. Edaphic changes in coal mine spoils undergoing natural recovery.
2. Community dynamics on the spoils of different ages.
3. Biomass dynamics and net primary productivity in relation to age of the mine spoils.
4. Nutrient compartmentation in mine spoils of different ages.
5. Growth of a few selected species (e.g. *Eriosema chinense*, *Axonopus compressus*, and *Eragrostiella leioptera*) on soils from the unmined site and the mine spoils of two ages.

The experimental data on the above mentioned aspects have been presented in Chapters 4-8. These Chapters are preceded by chapters 1-3. The **General Introduction'** (present chapter) sets out the objectives of the study. The literature pertaining to various relevant aspects such as plant succession, biomass and productivity, edaphic properties and reclamation of coal mine spoils have been briefly reviewed in Chapter 2 (**Review of Literature**). A brief description of climate, soil and vegetation of the study area and morphology and distribution of a few plant species such as *Axonopus compressus*, *Eragrostiella leioptera* and *Eriosema chinense* are given in Chapter 3. The results presented in Chapters 4-8 have been critically discussed in the corresponding chapter. An attempt has also been made to integrate the major findings of the entire work under '**General Discussion**' (Chapter 9).

Plate 1.1a - Pit formed as a result of 'rat hole' method of mining on the plain surface

Plate 1.1b - Pit formed on the hill slope. Note the presence of the coal seam

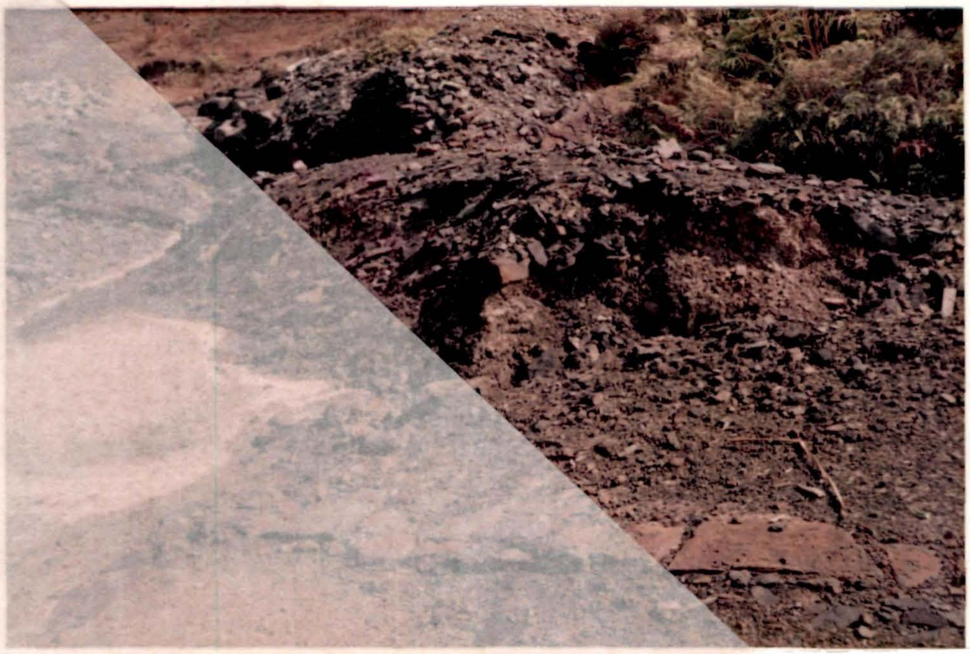


Plate 1.2a - Heaps of debris consisting of haphazardly mixed materials

Plate 1.2b - Heaps of debris consisting mostly of slates

Plate 1.3 - Unmined land destroyed by mine seepage

Plate 1.4a - Portion of the heap colonized by *Axonopus compressus*

CHAPTER 2

REVIEW OF LITERATURE

Destruction of land for the basic processes of living has gone on since the beginning of civilization. But the pace of this destruction has depended on the pace of development. Early civilization has damaged only small areas of land and left very little trace of this damage to the present day. With the advent of the Industrial Revolution the damage has increased and become widespread. As man harnessed water, steam, electricity and other sources of power, both the demand for resources and the scale on which they could be exploited increased dramatically.

Mining of minerals causes considerable damage to the ecosystem because of the excavations and dumping of the waste materials thrown on the adjacent site which form the 'spoil'. These spoils present a special habitat where conditions are extremely unfavourable for plant growth and establishment.

Ecology of these spoils has been intensively studied in different parts of the world. Ecosystem development on china clay wastes was studied by DANCER *et al.* (1977), MARRS & BRADSHAW (1980), and MARRS *et al.* (1980, 1981). Studies on reclamation of china clay wastes were carried out by MARRS & BRADSHAW (1982). Establishment of vegetation on asbestos wastes was studied by MOORE & ZIMMERMANN (1977). Iron mine tailings were studied by LEISMAN (1957), SHETRON & DUFFEK (1970) and MARTINIK (1977), and bentomite mine spoils were studied by SCHUMAN *et al.* (1987). Floristic diversity of lead mining wastes was studied by CLARK &

CLARK (1981), lead and zinc by KIMMERER (1984) and copper mining wastes by GOODMAN & GEMMELL (1978), and VEERANJANEYULU & DHANARAJU (1990). Gold mine dumps were studied by JAMES (1966), CLAUSEN (1973) and CRESSWELL (1973). SCHMELH & MCCASLIN (1973), HARBERT & BERG (1978), HAMON & KRUSPE (1981) and HOWER *et al.* (1992) studied the vegetative stabilization and properties of spent oil shale. YOUNGE & MOOMAW (1960), MORGAN (1971), PRASAD & PANDEY (1985) and LAL (1993) studied the ecology of bauxite mined lands. Rock phosphate and limestone quarries were studied by HUMPHRIES (1977), RICHARDSON & EVANS (1986), SONI *et al.* (1989), DADHWAL & SINGH (1993) and others.

Several studies have been done on colliery wastes by a number of workers, *viz.*, BRIERLEY (1956), CORNWELL & STONE (1968), BARNHISEL & MASSEY (1969), DOUBLEDAY (1971), DOWN (1973, 1974, 1975a, 1975b), WILLIAMS (1975), WILLIAMS & CHADWICK (1977), DENNINGTON & CHADWICK (1978), GAME *et al.* (1982), FYLES *et al.* (1985), SINGH & JHA (1987), JHA & SINGH (1990a, 1990b, 1992), and others. These studies were mainly related to the floristic composition as well as the physical and chemical properties of colliery spoils in different parts of the world.

Studies pertaining to techniques of reclaiming these spoils and floristic composition and physico-chemical properties of the reclaimed spoils were made by various workers viz, GEMMELL (1973, 1977), FITTER *et al.* (1974), GLOVER (1975), POWER *et al.* (1978b), POWELL *et al.* (1980), JOHNSON & BRADSHAW (1979), BLOOMFIELD *et al.* (1981), RIMMER (1982), BRADSHAW (1983, 1984, 1987), BRENNER (1984), PALMER & CHADWICK (1985), BRENNER & STEINER (1987), BRENNER *et al.* (1994), LAL (1994) and others.

The important studies on various aspects of mining ecology undertaken so far, are reviewed in the following pages.

Physico-chemical Properties

Coal mine spoils represent such habitat where conditions are extremely unfavourable for plant growth. Various factors that are responsible for rendering the spoils unsuitable for plant growth, are briefly discussed here.

Soil Structure and Texture - Particle size of soil derived from coal mine wastes plays an important role in the colonization by plant species (BYRNES & MILLER 1973, DOWN 1974). When the clay content is high, soils tend to become water-logged and when the silt content is high, soils often become compact forming crusts which restrict seedling growth and entry of water and air in the soil system (RICHARDSON *et al.* 1971). POWER *et al.* (1978a) reported the bulk density of spoils of Northern Great Plain to be 10-30% lower than the original soil and PEDERSON *et al.* (1980) found that spoils having high bulk density and low porosity had low infiltration rates. Several researchers reported lower clay content, lack of structure , no difference in bulk density, low water holding capacity and poor physical conditions of mine spoils even after several years of revegetation (RICHARDSON 1975, SCHAFER & NIELSEN 1979, RIMMER 1982, RUSSEL & LAROI 1986).

Stability - Coal mine spoils are unstable. This problem can be ascribed to spoil topography because a lot of materials is dumped to produce steep topography with a natural angle of rest of over 30° (JOHNSON & BRADSHAW 1979). Inevitably, these are liable to erosion. The steep sloped bare spoils erode severely and in many instances increase the silting and acidity of the nearby streams (CURTIS 1973). Downslope displacement or slumping of surface soil can occur on unvegetated areas (WINSTEAD 1962). The amount of surface soil lost during soil erosion can be as high as 8.4 g^{-min} in the barren spoil compared to only 0.25 g^{-min} in the colonized spoil (RICHARDSON 1975). This rate of erosion is very high and it can still remain high even in spoils (32-36° slope) which are as old as 178 years (DOWN 1975). ARCHIBOLD (1980) observed that slope washed due to rain easily moves seeds to the base of the slope. Besides, fine clay particles are also carried along through run-off water (JHA & SINGH 1990).

Water Supply - The coal mine spoil with an extremely coarse texture has a low moisture holding capacity and effective water retention becomes possible only when the substrate becomes dominated by particles of sand, silt and clay. The coarse sandy soils have poorer moisture-retaining properties than do heavy clays. However, plant-available water, defined as the difference in the volume of water held per unit of soil at field capacity and at permanent wilting point is somewhat less dependent on texture. Thus a light loam may hold more available water than a heavy clay and a uniform fine sand mine tailings more than the silty-clay overburden (LUDEKE 1973). The effectiveness of available water storage is also related to supply in terms of precipitation and its distribution throughout the year. In spite of the availability of precipitation throughout the year, coarse texture of coal mine spoils makes them poor in water retention capacity or their compacted structure results in poor infiltration (MEYER 1973). Both these conditions lead to poor water availability. Besides, loss of water as run-off and evaporation of soil water as a result of high temperature are responsible for the poor water storage in the soil.

Water availability is a serious problem at the soil surface. But its effect on plants varies from species to species depending on their tolerance to moisture stress (BELL & UNGAR 1981). Seed germination of many species is greatly reduced at soil moisture tensions which approximate the permanent wilting point (WRIGHT *et al.* 1978).

Acidity - pH is a major factor controlling plant growth on all soils particularly derelict land. Extreme acidity imposes direct and indirect constraints on sward development, continuity and persistence (JOHNSON & BRADSHAW 1979). On coal mine spoils high acidity is of overriding importance. The extent of acidity problems in coal mine spoils differs considerably from one coalfield to another and the pH value ranges from 1.5 to 8.0; the commonest range being 3-5. This variation derives partly from differences in the duration of exposure, the abundance of minerals with neutralizing properties and the factor of combustion (GEMMELL 1977). Coal mine spoils when freshly formed show neutral or slightly alkaline pH (BRADSHAW & CHADWICK 1980). Exposure and weathering of iron pyrites (FeS_2) cause dramatic increase in acidity and a progressive decline in the pH of the spoil. A series of oxidation and hydrolysis reactions, proceeding concurrently and assisted by ferrous ion oxidizing bacteria eg *Thiobacillus ferro-oxidans* (JOHNSON & BRADSHAW 1979) cause pyritic dissolution and acid regeneration in coal mine shales. Extreme acidity inhibits root growth, reduces nutrient availability and adversely affects soil structure (JOHNSON & BRADSHAW 1979, IVERSON & WALI 1982, MARSCHNER 1991). The weathering process is complex (CARUCCIO 1975, CHADWICK 1975), but can be summarized by the following equation:

$$4FeS_2 + 15O_2 + 14H_2O = 4Fe(OH)_3 + 8H_2SO_4$$

If the acidification continues for many years it will ultimately lead to die back of well-established vegetation (NIELSON & PETERSON 1972, COSTIGAN *et al.* 1981). Associated with the high acidity is a high availability of ferous, copper, zinc, aluminium and manganese (BARNHISEL & MASSEY 1969, MASSEY & BARNHISEL 1972) and a low supply of magnesium, calcium, potassium, nitrogen and phosphorus (BLACK 1968, BARNHISEL & MASSEY 1969, RILEY 1973, HAVILL *et al.* 1974). Tolerance to acidity varies from species to species (BANNISTER 1976, BRADSHAW & CHADWICK 1980). Only those species which have the ability to tolerate extreme acidity can colonize the mine spoils (BRADSHAW & CHADWICK 1980).

Temperature - A fundamental characteristic of continuous ground vegetation is that it reduces diurnal and seasonal fluctuations in soil temperature. Consequently, in the absence of a plant cover and its radiation absorptive properties, substrates behave very differently. On a strip mine spoil of Pennsylvania which has a low thermal conductivity even under conditions of intense solar radiation, high air temperatures and low soil moisture status, temperatures approaching 70°C have been recorded and sustained (DEELY & BORDEN 1973). On black shale pit heaps in Durham England, values as high as 57°C have been recorded (RICHARDSON 1958). Soil and surface temperatures have an important role in the establishment of vegetation. Temperatures are associated with high evaporation rates of soil water thus causing poor water availability in coal mine spoils (BLACK 1968). When the surface temperature exceeds 50°C even for short periods it can lead to high seedling mortality (DAY 1963).

Toxicity - Metal toxicity is another problem encountered on coal mine spoils. KIMBER *et al.* (1978) working on coal mine spoils of Scotland reported the presence of a number of metals at levels which could be toxic to plants. The content of aluminium and iron is particularly high. The toxic levels of Fe, Al and Mn (BERG & VOGEL 1973) and Cu, Ni and Zn (MASSEY & BARNHISEL 1972) may be found in coal mine spoils. WALI & FREEMAN (1973) working on coal mine spoils of North Dakota found that Bo, Cu, Fe, Li, Sr and Zn contents were much greater in spoils compared to unmined sites. Toxicity can still be a problem even in case of reclaimed mine sites (RIMMER 1982). However, some coal mine spoils which are generic in nature (BARTH & MARTIN 1984) can also be a non-toxic medium for plant growth. These spoils can easily be revegetated, eg. Jhingurda coal mine spoils of India. (SINGH & JHA 1987, JHA & SINGH 1990, 1992).

Organic matter and nutrients - Deficiencies of essential plant nutrients are almost universal feature of all degraded land and probably the single most important constraint on vegetation establishment. Totally inadequate reserves of nitrogen and phosphorus are the most common limitations, though deficiency of potassium, calcium and magnesium also occurs (JOHNSON & BRADSHAW 1979).

In coal mine spoils, there is a great loss of nutrients in the system because of the disruption of the ecosystems (LIKENS *et al.* 1970, STARK 1977, O'NIELL *et al.* 1977). Litter layer which is an exchange site for nutrients is also lost from the system during soil and wind erosion. Thus nutrient holding capacity of coal mine spoils is drastically reduced. Therefore, a major disadvantage of the surface mined land sites is the low fertility of the spoil material (JHA & SINGH 1990, 1992). In coal mine spoils, soil is just a skeleton and soil forming processes are confined to the few centimeters even in older spoils (DOWN 1975, ANDERSON 1977, SCHAFER *et al.*, 1980, RIMMER 1982). SCHAFER *et al.* (1980) found that organic matter was present only in the upper few centimeters of a 53 year old spoil. DOWN (1975) found 0.79, 1.52 and 1.81% organic matter on sites of age 0, 5 and 12 years, respectively in mine spoils at Somerset coal field. ANDERSON (1977) reported a large amount of accumulation of carbon and nitrogen in Saskatchewan mine spoils where the 28-year old spoil and the native soil have similar humus content. He assumed that equilibrium in organic matter content could be attained in 250-350 yrs in Saskatchewan mine spoils. But TOY & SHAY (1987) found no significant difference in organic matter between the top layer of mine spoil and natural spills in Northern Great Plains.

Nitrogen deficiency is a major factor limiting the growth of plants on spoils (DAVISON & JEFFRIES 1966, FITTER & BRADSHAW 1974, HANDLEY *et al.* 1978, BRADSHAW & CHADWICK 1980). Although the establishment of a stable, self sustaining ecosystem depends on the effective cycling of several major elements, the accumulation of nitrogen and the formation of effective cycling is particularly important. Nitrogen deficiency in coal mine spoils could be due to its great susceptibility to leaching losses (RICHARDSON & DICKER 1972, GEMMELL 1973) and it could also be due to its non-availability even though there are considerable amounts of nitrogen unavailable to plants in the coal and carbonaceous shales of coal mine spoils (CORNWELL & STONE 1968, 1973, PALMER *et al.* 1985). WITTWER *et al.* (1981) found nitrogen and phosphorus as limiting growth factors in south eastern Kentucky mine spoils. The acidity and pyritic content of coal mine spoils influence their availability to plants (GEMMELL 1977). IVERSON & WALI (1982) observed phosphorus as a major limiting nutrient during the colonization and early succession process on surface mined land in North Dakota. Phosphorus deficiency leads to stunted plant growth (SAFAYA & WALI 1979). Phosphorus is universally deficient in U. S. mine spoils (BAUER *et al.* 1977, POWER *et al.* 1978a). Potassium status is normally higher. This could be because the leaching lossess of potassium are usually less critical than that of nitrogen and moreover, when structural deterioration and clay mineral breakdown occurs, for example, due to regeneration of acidity, rapid release of potassium may result (GEMMELL 1977). However, SCHAFER & NIELSEN (1979) working on mine spoils at Colstrip, Montana reported potassium, calcium and magnesium to be concentrated relative to sodium in the upper soil layer. JOHNSON *et al.* (1982) reported that most sites had adequate levels of nutrients for good plant growth after 10-70 years disturbance at Oklahoma, where concentrations of nitrogen, phosphorus, potassium and calcium were twice as high as that of forest soils.

WALI (1987) reported that rates of accumulations for organic matter was 13.1 g m^{-2} yr^{-1}, nitrogen 2.5 g m^{-2} yr^{-1}, phosphorus 0.01 g m^{-2} yr^{-1} and potassium 0.49 g m^{-2} yr^{-1}. C:N ratio, indicator of both soil fertility and productivity, showed the widest range for 1 year old sites (5-40) but values comparable to the unmined mixed grass prairie sites were found in approximately 50 years.

Natural succession on mine spoils

Ecological succession, one of the central concepts in ecology, implies interlinked and concommitant changes in habitat properties, vegetation and associated biota over time (WALI 1987). Succession begins with the invasion of plant disseminules and seeds from neighbouring areas on the harsh environments of surface materials newly excavated in the process of mining. Succession is considered 'primary' when it is initiated on new land surfaces never before inhabited, as for example, on bare rocks, and after volcanic activity. Abandoned mined land succession belongs to this category. 'Secondary' succession on the other hand, commences with the natural plant establishment on habitats that were earlier inhabited by plants, for example ploughed field that have been left fallow after the crop harvest.

Floristic composition is considered to be one of the major distinguishing characters of any community and its knowledge is important in understanding the ecosystem functions. Similarly, in drastically disturbed ecosystems, for example the mine spoils, this knowledge helps in understanding natural succession on these spoils. Natural succession on mine spoils is a subject of both practical and ecological interest. WALI & FREEMAN (1973) and IMES & WALI (1977, 1978) pointed out that an adequate understanding of natural succession processes should be included in all efforts to reclaim degraded land, because without this knowledge no desired plant cover will be possible.

Factors which control vegetation development on mine spoils are microclimate, spoil properties, surrounding flora, nutrient holding capacity (RUSSEL & LAROI 1986, SZAFONI *et al.* 1988), and dissemination efficiency of propagules (LEISMAN 1957, GIBSON *et al.* 1985,). Various studies have been conducted to analyse the vegetation which occurs naturally on coal mine spoils (BRIERLEY 1956, HALL 1957, CORNWELL 1971, BELL & UNGAR 1981, BRENNER 1984, RUSSEL & LAROI 1986, JHA & SINGH 1990, 1992). RUSSEL & LAROI (1986) found low plant cover, usually less than 10% and very low species richness in rocky spoils. The species richness increased substantially in finer textured spoils, with higher water and nutrient holding capacities. Asteraceae and poaceae members were the most predominant species on coal mine spoils (BRIERLEY 1956, WALI & FREEMAN 1973, ALVAREZ *et al.* 1974, GLENN-LEVIN 1979, JONESCU 1979, RUSSEL 1985, PRASAD & PANDEY 1985). Poaceae members possess a fibrous root system and such species are better able to adapt for erosion control than tap rooted species (BRENNER 1984), while Asteraceae members are able to reach the mine spoils in large quantity since they are easily dispersed by wind. This could be the reason behind their predominance in coal mine spoils.

DOWN (1973) working on an age series of Somerset coal fields reported that hemicryptophytes comprised between 68 to 79% of the total number of species in each spoil age. Of these, the rosette hemicryptophytes comprised 31.8% of the species on the 12- year old spoil and 11.8% on the 98- year old spoil. DOWN (1973) suggested that artificial planting of rosette hemicryptophytes may be beneficial in reclamation schemes.

GIBSON *et al.* (1985) studied species composition of 49 reclaimed coal strip mines ranging in age from 10 to 70 years and reported that structural characteristics of the vegetation were similar to mature upland forests on the older and favourable sites. JOHNSON *et al.* (1982) found that the average mine spoils had 80% and 55% trees as compared to upland and flood plain forests respectively. In some cases stagnation of succession may take place as reported by SCHAFER & NIELSEN (1979) for a 50-year old spoil. Stagnated half shrub/annual grass seral stage occurred due to sandy texture

In some spoils even after several years of abandonment, species diversity, abundance and density were very low, vegetations were sparse and scattered and in some cases vegetation dvelopment did not occur altogether (GLENN-LEVIN 1979, WALI & FREEMAN 1973). In North Dakota, abandoned mine spoils ranging in age from 1-50 years revealed a slow progression of both species colonizatiion and soil development (WALI & FREEMAN 1973, WALI & PEMBLE 1982). Species diversity in abandoned mined areas in Western Dakota showed that even after 50 years of abandonment, the species diversity (numerical prevalence) was only half that of neighbouring unmined sites (WALI & FREEMAN 1973). However, WALI & PEMBLE (1982) found that relatively rapid changes in the habitats occurred in the first 17 years after mining. Sophisticated analysis of stand data (ordination) revealed that site age was the most important factor in species diversity and composition.

Biomass and Productivity

Green plants assimilate and transform light energy into potential chemical energy stored in the organic molecules of plants. Plants use a part of this potential energy during respiration and whatsover is left behind into the plants adds to the biomass. Biomass is a manifestation of net production. Knowledge of biomass and production rate of any ecosystem helps in understanding the ecosystem function.

JOHNSON *et al.* (1982) found that older sites which contain high calcium and nitrogen had higher biomass, but on sites with less favourable conditions biomass remained low for several years. VAIL & WITTWER (1982) observed 47.7 tonnes ha^{-1} production in a 10-year old cotton wood plantation in eastern Kentucky mine spoils. Total annual productivity was reported to be 14 g m^{-2} and 222 g m^{-2} respectively for 1-10 and 41-50 year old spoils in central and western Missouri coal mines (CARREL *et al.* 1979).

Biomass and productivity of the vegetation growing naturally on coal mine spoils depend on the age of the spoil. Shoot biomass on different microsites *viz.*, slope, coal patch, undulating surface and flat surface having age 5-20 years ranged from 100-251, 60-270, 54-301 and 91-350 g m^{-2}, respectively (JHA 1990). The biomass of dominant species-*Xanthium strumarium* decreased with the increasing age of the spoils at Jhingurda while that of the other species increased with the age of the spoil (JHA 1990).

WYATT *et al.* (1980) found three times higher root biomass in old spoils than in new spoils or undisturbed spoils, which was related to the presence of the tap rooted plant species. Species composition and time have been reported to be the major factors for root biomass distribution. HOLECHECK (1982) observed higher root biomass in fertilized spoils than unfertilized naturally revegetated spoils and suggested that in mine spoils at Colstrip, soil development will have reached native range condition after 10 years if spoils are levelled and a seed source is available. FYLES *et al.* (1985) and FYLES & MCGILL (1987) found higher root biomass values in fertilized mine spoils than in naturally revegetated spoils. JHA (1989) found that 65% to 85% of the total root biomass was observed in the upper 0-15 cm of spoil depth. He also found an increase in root biomass with increase in age of coal mine spoils.

Restoration, Reclamation and Rehabilitation

Land that has suffered from man's industrial activities may be described as '**spoiled**' or '**degraded**', '**disturbed**' or '**devastated**', '**derelict**' or '**damaged**' (BRADSHAW & CHADWICK 1980). Several terms such as restoration, reclamation, ecosystem reconstruction, rehabilitation etc., have been used to describe the efforts to rebuild such lands. **Restoration** implies that the conditions of the site at the time of disturbance will be restored after a development activity (BOX 1978). The use of this term is widespread for the restoration of monuments, paintings, buildings and refers to a return to the original as closely as possible. In ecological studies there are several examples where restoration has been achieved (WALI 1975a, GLENN-LEVIN & LANDERS 1978, CLAMBEY & PEMBLE 1986 and others). However, restoration on a grand scale is expensive and time consuming. It needs a thorough base of knowledge to answer the fundamental ecological question, why do species grow where they do ?. In addition, the paucity of land and water resources in many countries is such that few can afford to restore degraded ecosystems to their original state.

Reclamation implies that the site is habitable to organisms that were originally present or to others that approximate the original inhabitants (BOX 1978). This term has traditionally been used by soil scientists for many years in reclaiming salt affected soils for agriculture. Its most recent and frequent use has been in reclaiming surface mined ecosystems (WALI 1975b, SCHALLER & SUTTON 1978, REITH & POTTER 1986, HOSSNER 1988, BABU *et al.* 1990).

Ecosystem Reconstuction appears to be a suitable term (BRADSHAW 1983). MITSCH & JORGENSEN (1989) used the terms **Ecological Engineering** and **Ecotechnology** defining them as 'the design of human society with its natural environment for the benefit of both'.

Rehabilitation implies that the land will be returned to the form and productivity in conformity with an approved land use plan, ensuring that the system will remain in a stable ecological state, it does not contribute substantially to environmental deterioration and is consistent with the surrounding aesthetic values (BOX 1978).

Since mining of coal without damaging the ecosystem is impossible, therefore, an attempt should always be made to return the degraded ecosystem to its original form or to aesthetically pleasing condition (Jordan *et al.* 1988). The method of reclamation and species grown during reclamation would determine the rate and type of vegetation development (BRENNER 1979).

It is increasingly recognized that the supply of nutrients is usually the major factor limiting plant growth in a variety of types of derelict land (BRADSHAW & CHADWICK 1980). As with the agricultural crops, the limiting nutrient in the degraded lands is frequently nitrogen (WILSON 1965, DAVISON & JEFFRIES 1966, WILLIAMS 1975, BRADSHAW & CHADWICK 1980). When derelict land is artificially revegetated a source of nitrogen has to be provided, either as a fertilizer or as a nitrogen fixing plant such as legumes (SKEFFINGTON & BRADSHAW 1980). Growing legumes for the purpose of fixing nitrogen is an attractive proposition. The energy cost of using legumes to maintain sward has been estimated as being considerably less than using fertilizer (LAIDLAW & WRIGHT 1980) and a legume in whose roots nitrogen is actively fixed should supply nitrogen to the root zone of a sward continuously in a way that no fertilizer can. This is an important consideration on derelict land where there is often little or no mineral nitrogen supply from organic matter (WILLIAM & COOPER 1976).

The use of legumes in reclamation, as a means of accumulating nitrogen, has been described on china clay wastes (DANCER *et al.* 1977, LANNING & WILLIAMS 1980). The effectiveness of various legume and non legume associations in fixing nitrogen on the same substrate has been reported by SKEFFINGTON & BRADSHAW (1980). Legumes (usually white clover) have been a component of seed mixtures for reclamation purposes on colliery spoil for some years and the factors affecting establishment and growth of legumes on deep and open cast mines have been described by FITTER & BRADSHAW (1974), SZABO *et al.* (1974), FAIL & WOCHOK (1977), BENNET *et al.* (1978), JEFFRIES *et al.* 1981, POWELL *et al.* (1882, 1983). It has been shown that legumes eg *Lupinus arboreus* can accumulate as much as 180 kg N ha^{-1} yr^{-1} on an ameliorated mica waste (PALANIAPAN *et al.* 1979), and *Trifolium repens* can accumulate 100 kg N ha^{-1} yr^{-1} (DANCER *et al.* 1977).

Grasses have also been used for reclamation of mined lands (FITTER & BRADSHAW 1974, SKEFFINGTON & BRADSHAW 1980, RIES & DEPUIT 1984). The fibrous root system of grasses can bind the soil particles and thus prevents erosion. Legumes when grown together with grasses can supply nitrogen to the grasses as shown by JEFFRIES *et al.* (1981) who reported a higher nitrogen concentration in *Agrostis castellana* grown on white clover on colliery spoil and china clay waste compared to those in *A. castellana* in monoculture.

In India, studies on restoration of mine lands are very meagre (PRADIP & SRIVASTAVA 1982, PRASAD & SHUKLA 1985, JHA & SINGH 1990). PRADIP & SRIVASTAVA (1982) found that *Acacia auriculiformes* and *Adina cordifolia* were successful on Girdi-C colliery spoils. PRASAD & SHUKLA (1985) found that certain plant species *viz.*, *Acacia auriculiformis*, *A. nilotica*, *Albizia lebbeck*, *A. procera*, *Dalbergia sisoo* and *Eucalyptus camaldulensis* showed better growth on the spoils. JHA and SINGH (1990) reported that *Stylosanthes hamata*, a legume species was very effective in controlling soil erosion on coal mine slopes.

CHAPTER 3

STUDY SITES: SOIL, CLIMATE AND VEGETATION

LOCATION

The study sites are located in Jarain (Latitude 25° 19'N, Longitude 92° 8'E, altitude 1250 m asl) in Jaintia Hills District which is approximately 88 Km south east of Shillong, the capital of Meghalaya, India (Fig.3.1). This area has a striking landscape with round topped hillocks and undulating topography. Three coal mine spoils which are about 2 years, 5 years and 10 years of age were selected for the study (Plate 3.1-3.3). Under each age group three heaps measuring approximately 400 m^2 in area, 10-15 m in height and having about 45-65° slope were selected. In addition to these, an adjacent unmined grassland measuring approximately 1.3 ha was also chosen to serve as a control for comparison (Plate 3.4 a & b). The whole area prior to mining had a savanna type of vegetation (grassland interspersed with forest patches).

A basic assumption of research on ecological development using the chronosequence approach is that members of the sequence were originally identical and of the factors which influence development, only time varies. For this reason, study sites were deliberately selected to be as similar as possible in terms of ecologically significant parameters. All the study sites were located within 500 m horizontal distance from each other.

GEOLOGY

The plateau region of Jaintia Hills is the continuation of the Shillong plateau of the Khasi Hills. The plateau region (Jowai) is predominantly composed of metamorphic rocks and consists of thick series of quartzites and schists with intrusions of granites, dolerites and perodites and thin embedded bands of argillites. The southern slope (Jarain) composed of Jaintia series consists of Pre-tertiary and tertiary rocks of limestones lying almost horizontally.

SOIL

In the central plateau, the soils are mainly lateritic with an assortment of red and brown soils on high lands and black and yellowish soils in the valleys. In the southern region of Jaintia Hills where the rainfall is generally heavier, the soils are mostly sandy, reddish brown in colour, acidic in nature, having low moisture content, low cation exchange capacity and very poor in organic matter and nutrients.

CLIMATE

The climate of the region (Fig.3.2 a & b) is mild with neither too cold winter nor too hot summer. The mean annual maximum and minimum temperatures recorded during the study was 23°c and 16°c respectively (Fig.3.2). The rainfall is rather heavy (yearly average of about 5000 mm). The year can be divided into three seasons: (i)Spring (March to mid-May), (ii)Rainy (mid-May to October, (iii)Winter (November to February). The spring season is characterised by occasional showers and gradual increase in temperature over the preceding winter months. During February to March a strong wind blows over this region. Spring is followed by the rainy season during which more than 75% of the annual rainfall is received. July-August are the typical monsoon months experiencing the heaviest downpour and the number of rainy days in these months is usually more than 20. Rain often continues upto the end of October. Winter months are usually dry with only occasional light showers. The temperature declines considerably; the mean minimum and mean maximum being about 9°C and 18°C, respectively. The relative humidity throughout the year is above 70%; it is maximum (98%) during the rainy season and minimum (70%) during winter.

VEGETATION

The vegetation is of sub-tropical evergreen type. Woodlands of climatic climax forests are seen scattered in the deep sheltered valleys, or on the banks of rivers and streams. They are surrounded by grasslands or pine forests. Trees are generally short. Leaves are usually simple, small in size and often toothed, but at the same time firm and leathery.

The common trees of the top storey are *Castanopsis tribuloides*, *Lithocarpus elegans*, *Engelhardtia spicata*, *Ficus elastica*, *Mangleitia insignis*, *Prunus nepaulensis*. Trees of the second storey are *Viburnum foetidum*, *Viburnum simonsii*, *Quercus glauca*, *Helicia nilagirica*. The shrubby and herbaceous layers are the rich. Common shrubs are *Goniothalamus sesquipedalis*, *Sarcococca saligna*, *Sacandra glabra*, *Baliospermum micranthum*, *Neillia thyrsiflorum* etc. Forest floor is covered with fungi, moss, *Lycopodium*, *Selaginella* and angiosperm like *Begonia palmata*, *Scenecio griffithii*, *Impatiens* sp. Climbers like *Clematis*, *Smilax* and *Nepenthes khasiana* also spread over bushes and shrubs (BALAKRISHNAN, 1981).

Secondary vegetations are the pine forests, the bamboo forests and the savanna. Common bamboos are *Dendrocalamus hamilttonii* and *Bambusa vulgaris*. The broad-leaved tree species, *Schima wallichii* and *Rhododendron arboreum* also grow in the pine forests (BALAKRISHNAN, 1981).

Grasslands of Jarain are similar to those found in Cherrapunjee extending over a vast area. The presence of isolated patches of degraded forests amidst the grasslands imparts a savanna like appearance to the landscape of the region. These grasslands represent disclimax stage. They develop on acidic and highly impoverished shallow soil layer which can not support the forest and are being maintained by regular grazing and burning of varying intensities. Common species of the grasses found are *Eragrostiella leioptera*, *Heersia hexandra*, *Imperata cylindrica*, *Ischaemum geobellii* and *Arundinella* spp,. The herbs associated with these grasses are *Polygonum bisturta*, *Emilia sonchifolia*, *Osbeckia glauca* and *Nepenthes khasiana*. In marshy grasslands *Eragrostis* spp., *Juncus* sp., *Ranunculus cantoniensis*, *Drosera peltata and Burmannia disticha* are common (BALAKRISHNAN 1981). Legume species are very rare in these grasslands and some of those found are *Eriosaema chinense* and *Desmodium sp*. On the mine spoils and along the road side *Axonopus compressus* and *Chrysopogon gryllus* are dominant.

Of the food crops, rice is the most important and it is cultivated mostly in the valleys. Orange is another important cash crop. Besides these, other important crops which are cultivated are maize, turmeric and garlic on the terrace fields and rice, millet and maize on the 'Jhum' fields.

DESCRIPTION OF THE PLANT SPECIES SELECTED FOR GROWTH STUDIES

Legumes with their capacity to enrich the soil nitrogen through symbiotic nitrogen fixation and grasses with their ability to bind the soil particles with the help of their fibrous root system are helpful in making the soil more stable. These categories of plants have always been used in the reclamation of mine spoils. *Eriosaema chinense* has been selected for the study because it is the only legume which is frequently found on the grasslands of Jarain even though it was not recorded on the mine spoils. Besides, it has abundant nodules and is likely to play an important role in nitrogen fixation. *Eragrostiella leioptera* is a dominant grass growing on the undisturbed grassland, while *Axonopus compressus* is another grass which is dominant on road sides, foot paths and mine spoils. Both these grasses have abundant fibrous roots which can help in binding the unstable soil of mine spoils.

I. *Eriosaema chinense* Vogel.

Distribution : *Eriosaema chinense* belongs to the family Fabaceae. It ranges in distribution from Garhwal in the western Himalayas to Meghalaya and Assam in the east, up to an altitude of 1500 m. It also occurs in the Chota Nagpur area. It has been reported from Sri Lanka, Malacca, Pegu, China, Philippines and North Australia.

Morphological characters : *Eriosaema chinense* is an erect undershrub which ranges in height from 20 to 70 cm at flowering stage depending upon the environmental conditions. It has an edible tuberous rootstock which ranges in diameter from 1-3 cm and in length from 3-6 cm. Secondary roots arise at any point on the tuberous rootstock but mostly from the base. Stem is erect, branching near the base and densely pubescent. Leaves are simple, soft and are about 2.5 to 3 cm long and 0.3 to 0.5 cm wide. They are linear, mucronate at the apex and recurved and pilose at margins with obscure lateral nerves, shortly petioled (1 to 3 mm long) greenish with a few appressed hairs above, veins are rusty tomentose, stipules are linear, 2 to 3 mm long, scarious and persistent with minute stipels. Flowers occur singly or in twos in the axils of the upper leaves. They are subsessile or on the common pedicel of about 6-10 mm long. Calyx is pubescent. Corolla is yellowish, purple veined fading to reddish purple when drying with a hairy standard petal. Fruit is a pod which is oblong or orbicular. It is about 8-12 mm long and clothed with long spreading rufours hairs. Each pod has two viable seeds.

Flowering usually occurs during June to October. Multiplication of the plant is by the germination of the seeds and by the perennating tuberous rootstock.

II *Axonopus compressus* P.Beauv.

Distribution : *Axonopus compressus* belongs to the family Poaceae. It is a tropical South American species which occurs naturally in India. In Assam it is very common in Lakhimpur district. In Meghalaya, it abounds along the forest edges and open places.

Morphological characters : *Axonopus compressus* is a perennial grass whose culm is often erect but more usually ascending from a geniculate base, tufted, slender, glabrous, smooth, and seated on a slender rhizome. Stolons are often creeping and rooting at the nodes. Leaf blades are linear-lanceolate to linear from a more or less rounded base, obtuse or shortly acute, 5-12 cm long, 5-15 mm wide, folded or flat, bright green, glabrous or rigidly ciliate, rarely loosely hairy all over midribs and primary laterals are very slender, but quite distinct below. Leaf sheaths compressed and keeled, crowded and flabellate, glabrous or sparingly hairy, striate and smooth. Ligules, a narrow membranous rim, are minutely ciliolate. Inflorescence is of 2-3-5 subdigitate, sessile erect or creeping racemes. Common axis is very slender, angular, glabrous of three or more spikes, the lowest internode often very slender 5-7.5 cm long. Rachis straight or flexes if long, about 0.75 mm wide, triquetrous, angled and narrowly winged, angles scaberulous or almost smooth, pedicels alternately to left and right of the frontal angle, reduced to smooth elliptical, sub-sessile to acute, 2-2.5 mm long. Lower glume is absent, the upper is of the shape of the spikelet with narrowly incurved margins, membranous on the back and papery on the margins, 4-5 nerved bearing 4 lines of very fine hairs, sometimes hairs are scanty or the inner lines are absent. The upper floret is hermaphrodite, much shorter than the spikelet, elliptical to oblong, obtuse and white. The lemma and the palea are thinly crustaceous, the former very faintly 4 nerved, finely and shortly hairy at the top. The grain is elliptical in outline, obtuse and white. The scutellum is rotundate, elliptical and not reaching the middle of the grain.

III *Eragrostiella leioptera* (Stapf) Bor.

Distribution : *Eragrostiella leioptera* belongs to the family Poaceae. It is widely distributed in the Khasi and Jaintia Hills of Meghalaya at an altitude of 4000-6000 ft. It occurs in grasslands in moist open and shaded places and along the paddy fields.

Morphological characters : *Eragrostiella leioptera* is an erect perennial grass. Its culms are densely tufted and their base are covered with the remains of old sheaths. It is about 30 to 60 cm tall, slender, strict smooth and glabrous. The leaf blades are about 20-30 cm long, and are glabrous, stout, terete and pungent. Sheaths are short, slightly compressed and subkeeled on the back, smooth and glabrous, shorter than the internodes, a few hairs at the mouth. Ligules are very narrow hardly more than a rim with a few hairs. Inflorescence is a long slender, erect raceme of about 15 to 25 cm long; the spikelets are secund, with distichously spreading rachis. Spikelets are about 8 mm-1.25 cm long, subsessile, oblong, compressed, 10-20 flowered. Glumes are subequal, tumid and about 1.75 mm long or the lower shorter, lower distinctly keeled, the upper dorsally rounded. Lemmas are broadly ovate, obtuse, or sub-acute and 2.5 mm long . Palea are as long as the lemmas. They are two keeled, keels winged eciliate and hyaline. Anthers are about 1.5 mm long. Flowering and fruiting occur during August to December.

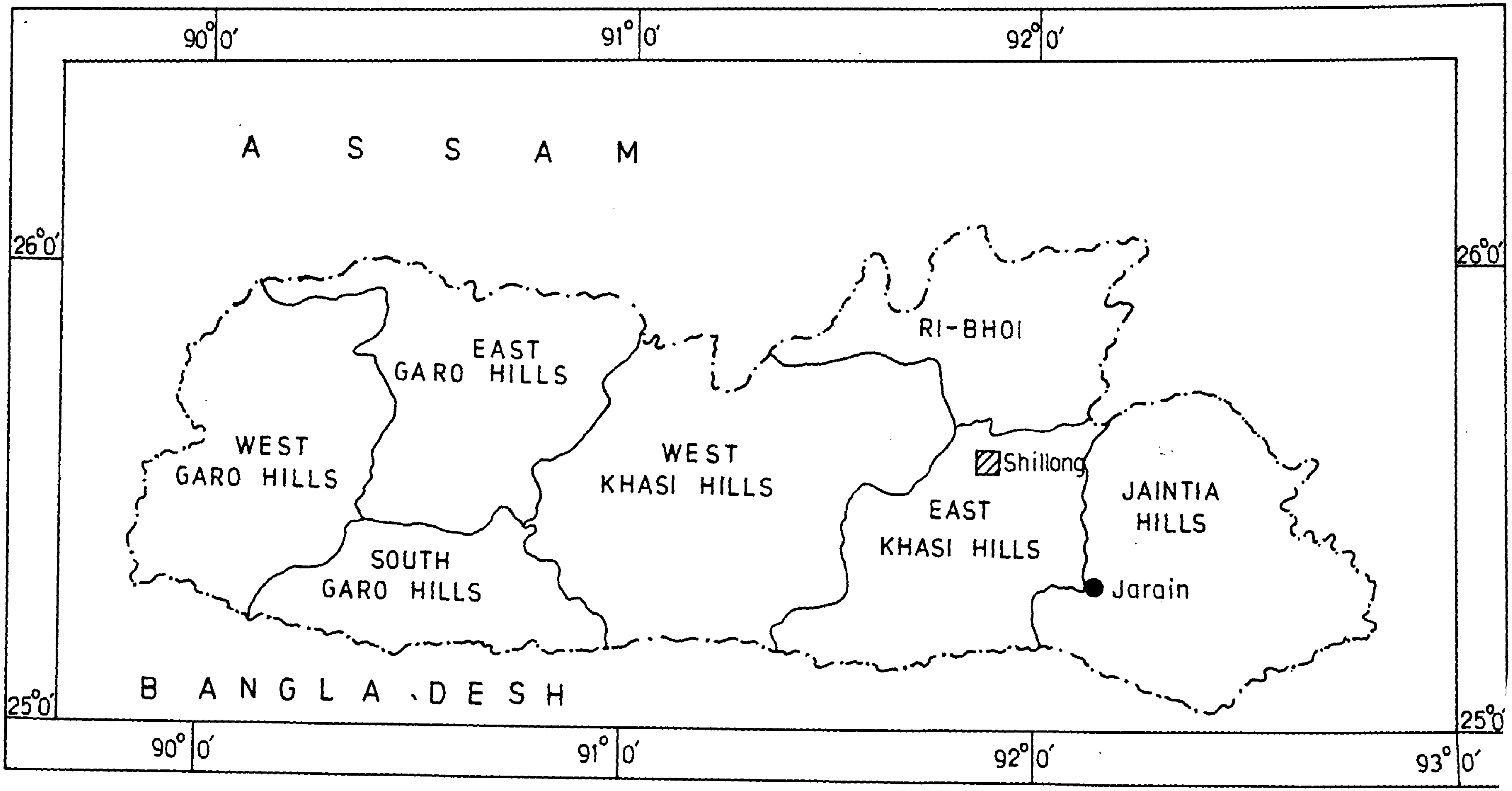


Fig. 3.1 - Map of Meghalaya showing the location of the study si

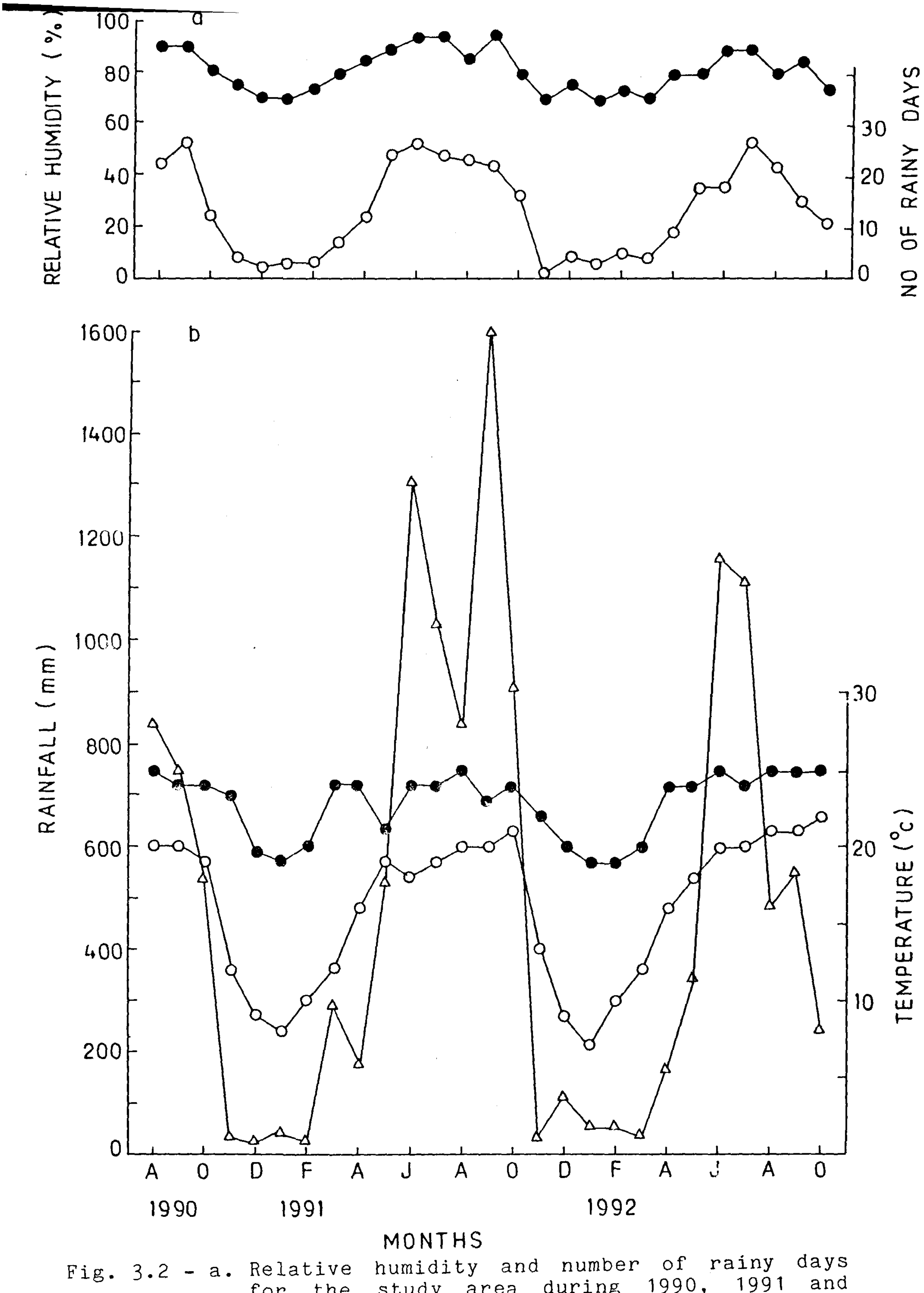


Fig. 3.2 - a. Relative humidity and number of rainy days for the study area during 1990, 1991 and 1992. Open circles, number of rainy days; closed circles, relative humidity.

b. Rainfall and maximum and minimum temperature during 1990, 1991, 1992. Open triangles, rainfall; open circles, mean minimum temperature; closed circles, mean maximum temperature.

Plate 3.1
2 year old spoil

Plate 3.2
5 year old spoil

Plate 3.3
10 Year old spoil

Plate 3.4 - Control site (overview)

control site (closer view)

CHAPTER 4

EDAPHIC CHANGES IN MINE SPOILS UNDERGOING NATURAL RECOVERY

INTRODUCTION

Physico-chemical characteristics of soil influence the plant growth and vegetation characteristics. Any change in soil characteristics brings about correlated change in the plant growth and development. Irrespective of the actual methods of mining being used, mining processes unavoidably cause land-surface disturbances. In fact, vast stretches of coal mine spoils are found in such areas where coal mining is done, as is true for several places in the Jaintia Hills district of Meghalaya. The coal mine spoils not only present a rigorous habitat where conditions are extremely unfavourable for plant growth, but they also tend to cause an adverse impact on the surrounding environment thus reducing its economic value (CHADWICK *et al.* 1987). Obviously, the colonization, establishment and maintenance of vegetation on coal mine spoils are very difficult. Extreme acidity is often the principal factor which limits plant growth. The range of pH varies considerably depending upon the exposure and weathering of the iron pyrite (FeS_2) which on oxidation causes extreme acidity (CHADWICK 1973, DOUBLEDAY 1974, CARUCCIO 1975), which is detrimental to plant growth. It reduces the availability of elements such as iron, aluminium and manganese. Under very acidic conditions, these elements become toxic to plants,(BERG & VOGEL 1968, IVERSON & WALI 1992). Acidification may proceed for several years after tipping on land or regrading, causing the problem of potential acidity (DOUBLEDAY 1974) which can result in die back of vegetation.

Deficiency of essential plant nutrients particularly nitrogen (HANDLEY *et al.* 1978, BRADSHAW & CHADWICK 1980) and phosphorus (IVERSON & WALI 1992) is another factor which limits plant growth on coal mine spoils. Nitrogen is essential for plant growth as it is a constituent of all proteins and nuclei acids and hence of all protoplasm. It is generally taken by the plant either as ammonium or as nitrate ions. Phosphorus as orthophosphate plays a fundamental role in the very large number of enzymic reactions that depend on phosphorylation. It is a constituent of the cell nucleus and is essential for cell division and for the development of the meristematic tissues. Plants take up phosphorus almost exclusively as inorganic phosphate ions. Deficiency of nitrogen and phosphorus is due to their unavailability in acidic condition and their susceptibility to leaching losses (RICHARDSON & DICKER 1972, GEMMELL 1973, IVERSON & WALI 1982).

Moisture stress (RICHARDSON 1975) and surface instability leading to erosion (BRIERLEY 1956, DOWN 1975) are other problems encountered on coal mine spoils. The steep slope as well as the barren condition are responsible for the poor water storage in the soil. Water is easily lost as run-off, and evaporation is also high because of the steep topography and high temperature of the barren spoil.

A large number of studies have been conducted on the physico-chemical properties of coal mine spoils undergoing natural recovery (KIMBER *et al.* 1978, SCHAFER & NIELSEN 1979, PEDERSON *et al.* 1980, BELL & UNGAR 1981, FYLES *et al.* 1985, TOY & SHAY 1987). In India, studies have been conducted by JHA & SINGH (1991) on coal mine spoils of dry tropical environment. In Meghalaya very little work has been done on the edaphic changes of naturally recovering coal mine spoils (UMA SHANKAR *et al.* 1993). The present chapter deals with the changes in the edaphic properties of the coal mine spoils of three different ages undergoing natural recovery. In order to understand the extent of damage caused to land by coal mining, the soil characteristics of an adjacent unmined site (grassland) were also determined.

MATERIALS AND METHODS

Soil Sampling

Soil sampling was done seasonally by collecting six replicate samples from each study site down to 15 cm depth. These replicate soil samples were mixed together to make a composite sample. They were air dried, sieved through a 2 mm mesh sieve and ground through 80 mesh screen. The screened samples were then stored in polythene bags for analysis.

Soil Analysis

Bulk density of soil cores was determined by using a soil corer of 6 cm diameter and 15 cm height according to ALLEN *et al.* (1974). Porosity was calculated from the bulk density data by using the formula, $P = 100-(BD/2.65) \times 100$, where BD = bulk density, 2.65 = particle density (ALLEN *et al.* 1974). Soil texture was determined by Bouyoucos' Hydrometer method (ALLEN *et al.* 1974).

Water holding capacity was determined by Keen's box method by using circular copper cups with an internal diameter of 5.6 cm and a height of 1.6 cm (PIPER 1942). Soil moisture content was determined gravimetrically by taking 10 g of fresh unsieved soils and the results were expressed on oven dry weight basis (ALLEN *et al.* 1974).

Soil pH was determined electrometrically by a digital systronics-335 pH meter in a 1:2.5 suspension of soil in 0.01 M $CaCl_2$. Organic carbon was determined by rapid titration method (WALKLEY & BLACK 1934). Soil organic matter content was obtained by multiplying the organic carbon concentration by 1.724 basing on the assumption that the soil organic matter contains 58% of carbon (ALLEN *et al.* 1974). Cation exchange capacity (CEC) was determined by extracting the exchangeable bases from the soil with 1 M ammonium acetate (pH 7) followed by the displacement of NH_4^+-N with KCl and distillation with MgO (ALLEN *et al.* 1974). Potassium, calcium and magnesium were determined on a Perkin Elmer 2380 atomic absorption spectrophotometer at Regional Sophisticated Instrumentation Centre (RSIC), Shillong.

Total kjeldahl nitrogen (TKN) was determined by digesting air-dried soil samples with conc.H_2SO_4 using K_2SO_4 and HgO catalyst mixture on a block digester. Distillation and titration were done simultaneously in a Tecator Kjeltec Auto 1030 Analyzer.

Available phosphorus was determined by molybdenum blue method (ALLEN *et al.* 1974) after extracting with 0.03 N NH_4F in 0.025 N HCl (Bray's reagent) according to JACKSON (1958).

Each analysis was performed in triplicates. The moisture content of the air dried soil was determined to express the final results on oven dry weight basis. Nutrient content in Kg ha^{-1} was estimated from mean concentration of each nutrient and soil bulk density.

RESULTS

The coal mine spoils of the three ages and the grassland soil showed a wide variation in their physico-chemical properties.

Bulk density, porosity and texture

Bulk density and porosity (Table 4.1) did not vary with the age of the spoils. Bulk density of the spoils was found to be much lower than that of the soil on the control site. Consequently, porosity also varied. Porosity of the spoils was more than that of the control site. The texture of the soil was sandy (>80% sand) in all sites (Fig. 4.1). There was no relationship between the proportion of sand, silt and clay with that of the spoil age.

Water holding capacity and moisture content

Water holding capacity (Fig. 4.1) increased significantly ($P<0.05$) with the age of the spoil. The 2 year old spoil had minimum (20.6%) water holding capacity which increased to 26.5% and 33.3% in the 5 year and 10 year old spoils, respectively. But there was no significant difference between the water holding capacity of the 10 year old spoil and the soil of the control site which showed a water holding capacity of 34%.

There was no significant variation in the moisture content (Fig. 4.2) between spring and winter, but in the rainy season, the moisture content increased significantly in the mine spoils as well as the control site. Moisture content of the control site was more than that of the mine spoils. Moisture content increased with age of the spoil in all seasons. Mean moisture content of all the seasons was 8.3%, 11.6%, 17.7% and 20.3% for the 2 year, 5 year, 10 year old spoils and the control site, respectively.

Soil pH and cation exchange capacity (CEC)

There was not much seasonal variation in the pH (Fig. 4.2) in the case of the control site and the 10 year old spoil, but pH of the 2 year old spoil and 5 year old spoil was much higher during the winter season compared to the other seasons. The pH of these two spoils did not vary significantly from each other during the rainy and winter seasons. Means of all seasons were 3.3, 3.2, 3.9 and 4.2 for the 2 year, 5 year and 10 year old spoils and the control site, respectively.

Cation exchange capacity (CEC) was least in the 2 year old spoil (2.2 meq.100g^{-1}) and it increased significantly ($P<0.01$) in the 5 year and 10 year old spoils where each had a CEC value of 3.8 meq.100g^{-1}. CEC of the control was much lower than that of the 5 year and 10 year old spoils (Fig. 4.1).

Nutrient concentration

Table 4.2 shows the seasonal variation in the nutrient concentration of the mine spoils and the control site. There was a wide fluctuation in the nutrient concentration of both coal mine spoils and the control site with the change in seasons. In the case of the three mine spoils there was no consistent trend in the fluctuation, while in the control site, with the exception of calcium and magnesium where no regular trend had been observed, organic matter, total nitrogen, extractable phosphorus and potassium concentration decreased significantly during spring.

Organic matter (Table 4.4) - In the control site organic matter concentration was maximum in the rainy season (2.12%) and minimum in spring (1.05%). In the 5 year and 10 year old spoils organic matter concentration was very low during winter, but there was no significant variation between the spring and rainy season values. In the 2 year old spoil maximum value was obtained during the rainy season, but it declined during winter and spring. The range in organic matter concentration for the 2 year, 5 year, 10 year old spoils and the control site was 0.54 to 1.56%, 0.92 to 2.07%, 0.95 to 1.97% and 1.05 to 2.12% respectively. The mean concentration of all the seasons was 0.96%, 1.52%, 1.61%, 1.64% for the 2 year, 5 year, 10 year old spoils and the control site, respectively.

Total nitrogen (Table 4.2) - There was a significant increase ($P<0.01$) in the total nitrogen with the age of the coal mine spoils. There was no effect of season on nitrogen concentration of the 2 year and 5 year old spoil, while in the control site and 10 year old spoil it decreased significantly during spring. In the control site maximum value was obtained during rainy season, progressively decreased during winter and spring seasons. In the 10 year old spoil there was no significant difference in nitrogen concentration between the rainy and winter season, but there was a sharp decrease in spring. The range of nitrogen concentration was 0.02 to 0.03%, 0.04 to 0.05%, 0.04 to 0.07% and 0.06 to 0.08% for the 2 year, 5 year and 10 year old spoils and the control site, respectively. Mean of all the seasons was 0.02%, 0.04%, 0.06% for the 2 year, 5 year and 10 year old spoils respectively and 0.07% for the control site.

Phosphorus concentration (Table 4.2) - Phosphorus concentration was extremely low in the 2 year and 5 year old spoils. In the 2 year old spoil phosphorus concentration ranged from 0.25 to 0.32 ppm, in the 5 year old spoil it ranged from 0.46 to 0.93 ppm, in the 10 year old spoil, it ranged from 2.77 to 5.97 ppm and in the control site it ranged from 4.83 to 7.6 ppm. Phosphorus concentration was significantly lower in spring in both control site ($P<0.05$) and 10 year old spoil ($P<0.01$). With the exception of the 2 year old spoil where the effect of season was negligible, phosphorus concentration was maximum during the rainy season. Mean phosphorus concentration was 0.29, 0.72, 4.98 and 6.18 ppm for the 2 year, 5 year and 10 old spoils and the control site, respectively.

Potassium (Table 4.2) - Potassium concentration was maximum during the rainy season at all sites, In the 2 year and 5 year old spoils minimum value was obtained during winter, while in the 10 year old spoil and the control site, minimum value was obtained during spring. The range in potassium concentration was from 0.04 to 0.11, 0.06 to 0.16, 0.11 to 0.34 and 0.14 to 0.38 mg $100g^{-1}$ in the 2 year, 5 year and 10 year old spoils and the control site, respectively. Mean concentration of all seasons was

0.08, 0.10, 0.25 and 0.29 mg 100^{-1} for the 2 year, 5 year and 10 year old spoils and the control sites, respectively.

Calcium (Table 4.2) - There was no significant variation in the concentration of exchangeable calcium between the 2 year and 5 year old spoils. But the concentration increased significantly ($P<0.01$) in the 10 year old spoil and in the control site. Effect of season on calcium concentration was not very strong except in the 2 year old spoil where the concentrations were relatively lower during spring than during other seasons. The range in concentration was 2.58 to 3.59, 5.73 to 6.65 and 7.58 to 8.65 mg $100g^{-1}$ for the 2 year, 5 year and 10 year old spoils and the control site, respectively. Mean calcium concentration was 3.04, 3.17, 6.21 and 8.08 mg $100g^{-1}$ for the 2 year, 5 year and 10 year old spoils and the control sites, respectively.

Magnesium (Table 4.2) - There was a significant increase ($P<0.01$) in magnesium concentration with the increase in spoil age. The magnesium concentration was strongly affected by season at all sites. The range of concentration was 3.11 to 4.82, 7.25 to 10.2, 10.48 to 16.67 and 15.90 to 20.307 mg $100g^{-1}$ for the 2 year, 5 year and 10 year old spoils and the control sites, respectively. Mean of all seasons was 4.22, 8.54, 13.58, and 18.22 mg $100g^{-1}$ for the 2 year, 5 year and 10 year old spoils and the control site, respectively.

Total organic matter content and total quantity of various nutrients (Table 4.3)

There was a wide variation in the total organic matter content and total quantity of various nutrients with the change in the age of the spoils. The quantity of various nutrients was minimum in the 2 year old spoil and maximum in the control site. The effect of season on the nutrient content was also strong at all sites. The nutrient content on the control site was low in spring, but this trend was not observed in the case of the mine spoils (Table 4.3).

On the basis of the mean value of organic matter content and content of various nutrients during all seasons (Fig. 4.3) the coal mine spoils of three ages and the control site could be arranged in the following order.

1. **Organic matter content**

2 year old spoil (17255) < 10 year old spoil (26862)<5 year old spoil (31395) < control site (36161 kg ha^{-1}).

2. **Total nitrogen content**

2 year old spoil (411) < 5 year old spoil (904) < 10 year old spoil (994) < control site (1485 kg ha^{-1}).

3. **Phosphorus content**

2 year old spoil (0.5) < 5 year old spoil (1.5) < 10 year old spoil (8.3) < control site (14 kg ha^{-1}).

4. **Potassium content**

2 year old spoil (1.4) <5 year old spoil (2.0) < 10 year old spoil (4.2) < control site (6.5 kg ha^{-1}).

5. **Calcium content**

2 year old spoil (54.3) < 5 year old spoil (65.7) < 10 year old spoil (103.4) < control (178.2 kg ha^{-1}).

6. **Magnesium content**

2 year old spoil (75) < 5 year old spoil (177) < 10 year old spoil (226) < control site (402 kg ha^{-1}).

DISCUSSION

The results revealed that physico-chemical properties of different ages of coal mine spoils varied widely with the spoil age and with the seasons. Bulk density of the spoils was found to be much lower than that of the control site. This is in accordance with POWER *et al.* (1978a) who reported that the bulk densities of the spoils of Northern Great Plain was about 10 to 30% lower than the original undisturbed soil. In the present study the bulk densities of spoils were found to be 6 to 24% lower than the control site. This is at variance with the findings of SCHAFER *et al.* (1980) who reported the bulk density of mine soils to be higher than that of the natural soils. Bulk density of coal mine spoils depends on the use of different kinds of equipment rather than on soil genesis. Use of heavy equipments during mining subjects the spoil material to some degree of compaction. But in the spoils under investigation since no heavy equipments are used during mining, the spoil material tends to be loose and this accounts for their lower bulk density.

JHA & SINGH (1991) reported an increase in proportion of the particle size of 0.2-0.1 mm with age of mine spoils, and UMA SHANKAR *et al.* (1993) observed an increase in clay and silt fractions. But in the present study, no relationship was observed between the proportion of sand, silt and clay with spoil age. The texture of the soil was sandy in all sites. The control site, though undisturbed with respect to mining, was a degraded grassland. Soil was very thin and stony and the percentage of sand was maximum. This condition can be attributed to the sandy nature of the parent rock and to heavy soil erosion due to heavy rainfall and lack of vegetal cover. Particle size distribution is largely a function of the parent material and topography, and hence, it is not expected to change with age of the spoils. Since all the sites have the same parent material, and similar topography, particle size distribution is also more or less the same at all sites. This is in conformity with the reports of WOOD & PETTRY (1989).

Moisture content of the mine spoils and the control was very low during winter and spring compared to the rainy season, the former two being comparatively the dry seasons. Water holding capacity increased significantly with the age of the spoil. This is in accordance with the report of UMA SHANKAR *et al.* (1993). Water holding capacity and moisture content depend to a large degree on the structural conditions of the soil, organic matter content and colloidal particles. The 2 year old spoil had a very low water holding capacity because of the very low percentage of organic matter, very high percentage of sand and very low percentage of clay. In the 10 year old spoil and control site, water holding capacity was higher because of the relatively higher organic matter content.

pH of the spoil materials was highly acidic primarily due to the oxidation of iron pyrites (CARUCCIO 1975, JOHNSON & BRADSHAW 1979). The control site had a much higher pH compared to the spoils because there was no mining activity. pH of below 4 is considered to be toxic for the growth of plants (SUTTON 1970). But tolerance to acidity varies from species to species (BANNISTER 1976). So only those species which can tolerate the extreme acidity can colonize the spoils. Low pH is detrimental to plant growth in extreme conditions. But pH as such may not be the main problem associated with the revegetation of highly acidic soils. The availability of certain elements such as, Fe, Al and Mn to plants increases as the soil pH decreases, and therefore, under very acidic conditions these elements become toxic to plants (BERG & VOGEL 1973, IVERSON & WALI 1992). The decline in pH of the young spoils during the warm months was probably due to an increase in the rate of oxidation of iron pyrites at higher temperatures and lower rate of leaching leading to greater accumulation of reaction products (WILLIAMS & CHADWICK 1977). During winter months due to low temperature the oxidation of iron pyrites decreases and this probably accounts for the rise in pH during winter months.

The decline in CEC in the control site and 2 year old spoil is attributable to the increase in sand particles of the soil and vice versa in the case of the 5 year and 10 year old spoils.

WILLIAMS & CHADWICK (1977) reported significant seasonal variations in the levels of several elements in acid colliery spoil, but addition of limestone brought a reduction in the concentration of these elements and also in the seasonal variations. WILLIAMS (1974) failed to detect similar seasonal variations on an unamended near neutral colliery spoils. In the present study, seasonal variations in the concentration of nutrients were observed to some extent on both coal mine spoils and the control site.

During rainy season, whatever organic matter was present on the mine spoils has been utilised for the growth of plants; also decreased soil microbial activity, organic matter decomposition and nutrient release coupled with drastic fall in temperature during winter could have resulted in decreased soil organic matter content in the soil.

The control site, on the other hand, was subjected to annual fire just befor the onset of spring. As a result, organic carbon and total nitrogen might have volatalized. This probably accounts for low organic matter and total nitrogen content during spring in the control. This is in agreement with the report of RAM & RAMAKRISHNAN (1988). Organic mattter and nitrogen concentration was least in the 2 year old spoil and increased with spoil age, and their maximum concentration was recorded in the control site. This can be attributed to the very low species content and poor recovery of the 2 year old spoil due to its young age. DOWN (1975) also reported increase in organic matter concentration with age of mine spoils at Somerset coal field. He found 0.79, 1.52 and 1.81 per cent organic matter on sites of age 0, 5 and 12 years, respectively. JENCKS *et al.* (1982) observed an increase in soil nitrogen concentration with age in coal mine spoils of West Virginia. LI & DANIELS (1994) also reported increased N accumulation with site age in Appalachian mine soils. ANDERSON (1977), on the other hand, observed that the mine spoils of 28 years age with accumulation of large amounts of carbon and nitrogen were similar to native soils in Saskatchewan. TOY & SHAY (1987) also found that there was no significant difference in organic matter content between the top decimeter of mine spoils and natural soils in Northern Great Plains.

Organic matter is of critical importance to the functions of plant and soil system and reduction in soil organic matter content by mining activity can be detrimental to pedogenic recovery (SCHAFER & NIELSEN 1979). It has been considered that 700 kg ha^{-1} is the minimum level of nitrogen accumulation at which an ecosystem would become self sustaining (DANCER *et al.* 1977, ROBERTS *et al.* 1981). The 2 year old spoil had a very low nitrogen accumulation of about 411 kg ha^{-1}. This conforms with BRADSHAW & CHADWICK (1980) who reported that nitrogen is very much limiting on spoils. The increase in concentration and accumulation of nitrogen with age is presumably because of its release during partial destruction of the silicate lattices by acids generated during spoil weathering (CONWELL & STONE 1968, POWER *et al.* 1974, and REEDER & BERG 1977a).

Phosphorus was extremely low in both 2 year and 5 year old spoils. This is in agreement with the report of IVERSON & WALI 1992) who observed that phosphorus was a limiting nutrient during colonization and early succession in surface mined lands. Inadequate phosphorus adversely affects plant growth (SAFAYA & WALI 1979). The abrupt increase in phosphorus content in the 10 year old spoil can be attributed to increased spoil weathering accelerated by the growth of vegetation (FYLES *et al.* 1985). Potassium, calcium and magnesium contents also increased with age of the spoil as reported by MARRS *et al.* (1980) on China clay wastes. UMA SHANKAR *et al.* (1993), on the other hand, reported increase in N, P and K, decline in calcium and no change in magnesium concentration with spoil age. JHA (1990) also reported increase with age in the concentration of total nitrogen, extractable phosphorus and exchangeable potassium in Singrauli coal fields.

Table 4.1 : Bulk density and porosity of the soil (0-15 cm) of the mine spoils and unmined (control) site.

Site	Bulk density (g/cm^3)	Porosity %
Mine spoils		
2 year old mine spoil	1.19 ± 0.09	55.09 ± 1.5
5 year old mine spoil	1.38 ± 0.13	47.92 ± 2.0
10 year old mine spoil	1.11 ± 0.09	58.11 ± 1.6
Unmined site (control)	1.47 ± 0.04	44.53 ± 0.9

±SE of the mean

Table 4.2 : **Seasonal Variations in Organic matter and nutrient concentration in the coal mine spoils of different ages and the control.** R Rainy, W Winter, S Spring.

Organic matter/ nutrients	Control site			Age of coal mine spoils (Years)								
				10			5			2		
	R	W	S	R	W	S	R	W	S	R	W	S
Organic matter(%)	2.120 ±0.00	1.750 ±0.00	1.050 ±0.10	1.970 ±0.01	0.950 ±0.06	1.920 ±0.02	1.560 ±0.01	0.920 ±0.01	2.070 ±0.00	1.560 ±0.02	0.800 ±0.03	0.540 ±0.03
Total Nitrogen (%)	0.081 ±0.00	0.064 ±0.00	0.057 ±0.00	0.068 ±0.00	0.068 ±0.00	0.068 ±0.00	0.043 ±0.00	0.042 ±0.00	0.046 ±0.00	0.025 ±0.00	0.020 ±0.00	0.024 ±0.00
Phosphorus ug g^{-1}	7.600 ±0.41	6.090 ±0.24	4.830 ±0.11	5.970 ±0.11	6.200 ±0.32	2.770 ±0.10	0.930 ±0.08	0.460 ±0.02	0.770 ±0.06	0.290 ±0.07	0.320 ±0.09	0.250 ±0.03
Potassium mg 100g^{-1}	0.382 ±0.04	0.363 ±0.01	1.136 ±0.00	0.338 ±0.09	0.313 ±0.06	0.106 ±0.00	0.156 ±0.05	0.060 ±0.00	0.070 ±0.00	0.112 ±0.05	0.038 ±0.01	0.091 ±0.01
Calcium mg 100^{g-1}	8.650 ±0.25	7.575 ±0.18	8.016 ±0.4	5.725 ±0.15	6.650 ±0.19	0.250 ±0.00	3.350 ±0.10	3.588 ±0.06	2.582 ±0.14	3.125 ±0.14	3.413 ±0.06	2.582 ±0.21
Magnesium mg 100g^{-1}	15.902 ±0.11	18.450 ±0.08	20.297 ±0.07	13.615 ±0.25	10.475 ±0.00	16.652 ±0.14	7.250 ±0.00	10.200 ±0.00	8.183 ±0.11	4.824 ±0.11	3.103 ±0.02	4.717 ±0.14

±SE of the mean

Table 4.3 : Seasonal Variations in Organic matter and nutrient content (Kg/ha) in the coal mine spoils of different ages and the control. R Rainy, W Winter, S Spring.

Organic matter/ nutrients	Control site			Age of coal mine spoils (Years)								
				10			5			2		
	R	W	S	R	W	S	R	W	S	R	W	S
Organic matter	46746	38587	23152	32801	15818	31968	32292	19044	42849	27846	14280	9639
Total Nitrogen	1736	1411	1257	1132	1132	1132	890	869	952	446	357	428
Phosphorus	17	13	11	10	10	5	2	1	1.6	0.5	0.6	0.4
Potassium	8.4	8.0	25.0	5.6	5.2	1.8	3.2	1.2	1.4	2.0	0.7	1.6
Calcium	191	167	177	95	111	4	69	74	53	56	61	46
Magnesium	351	409	448	227	174	227	150	211	169	86	55	84

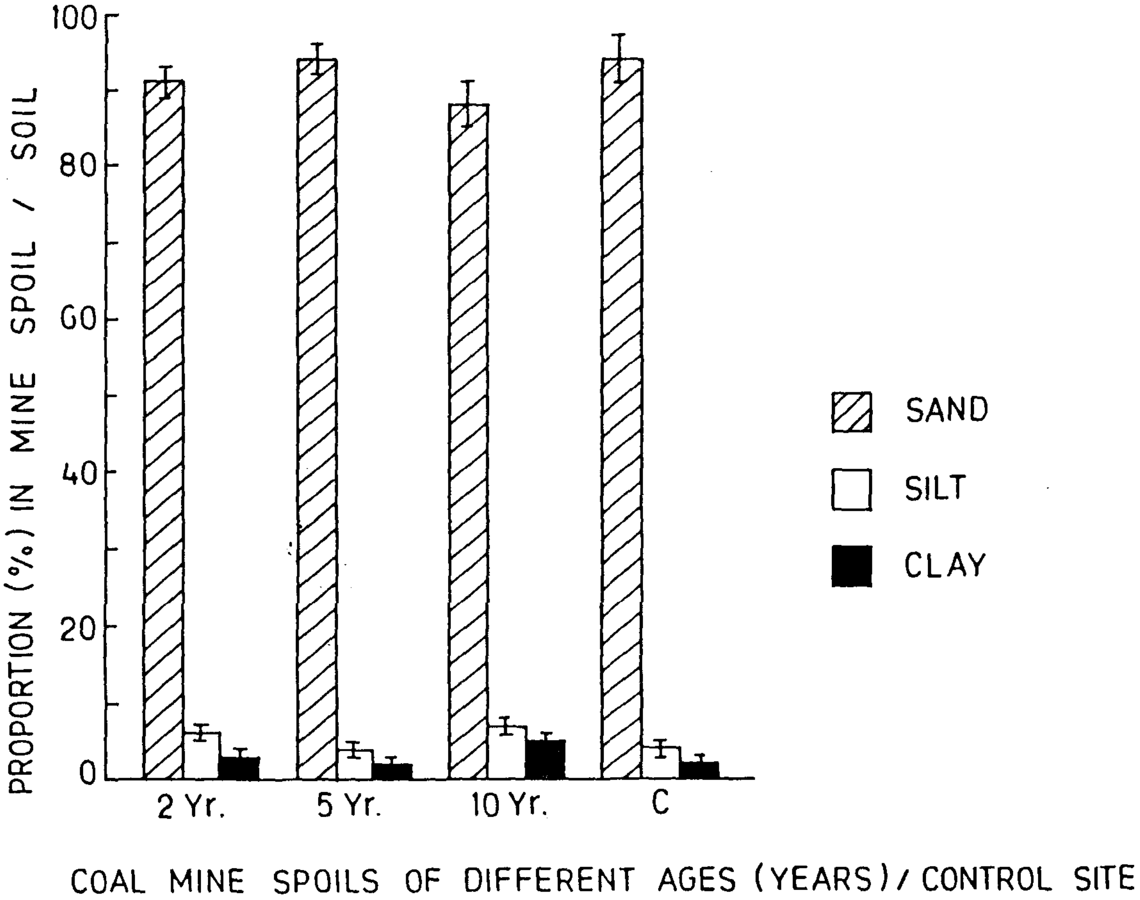


Fig. 4.1 - Proportion (%) of sand, silt and clay in the coal mine spoils of different ages and in soil of the control site. Vertical bars represent standard error of the mean.

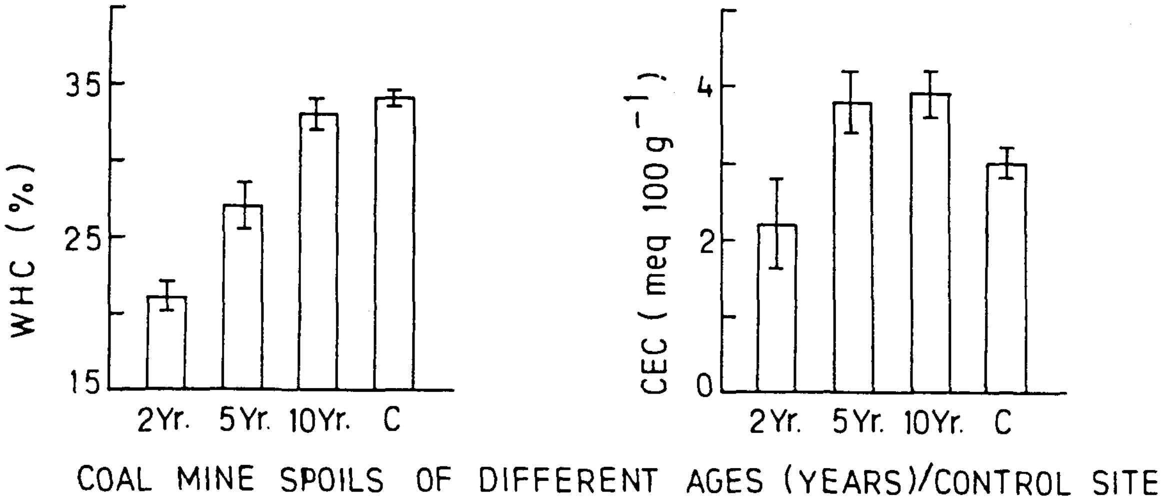


Fig. 4.2 - Water holding capacity (WHC) and catin exchange capacity (CEC) of coal mine spoils of different ages and the control site (C). Vertical bars represent standard error of the mean.

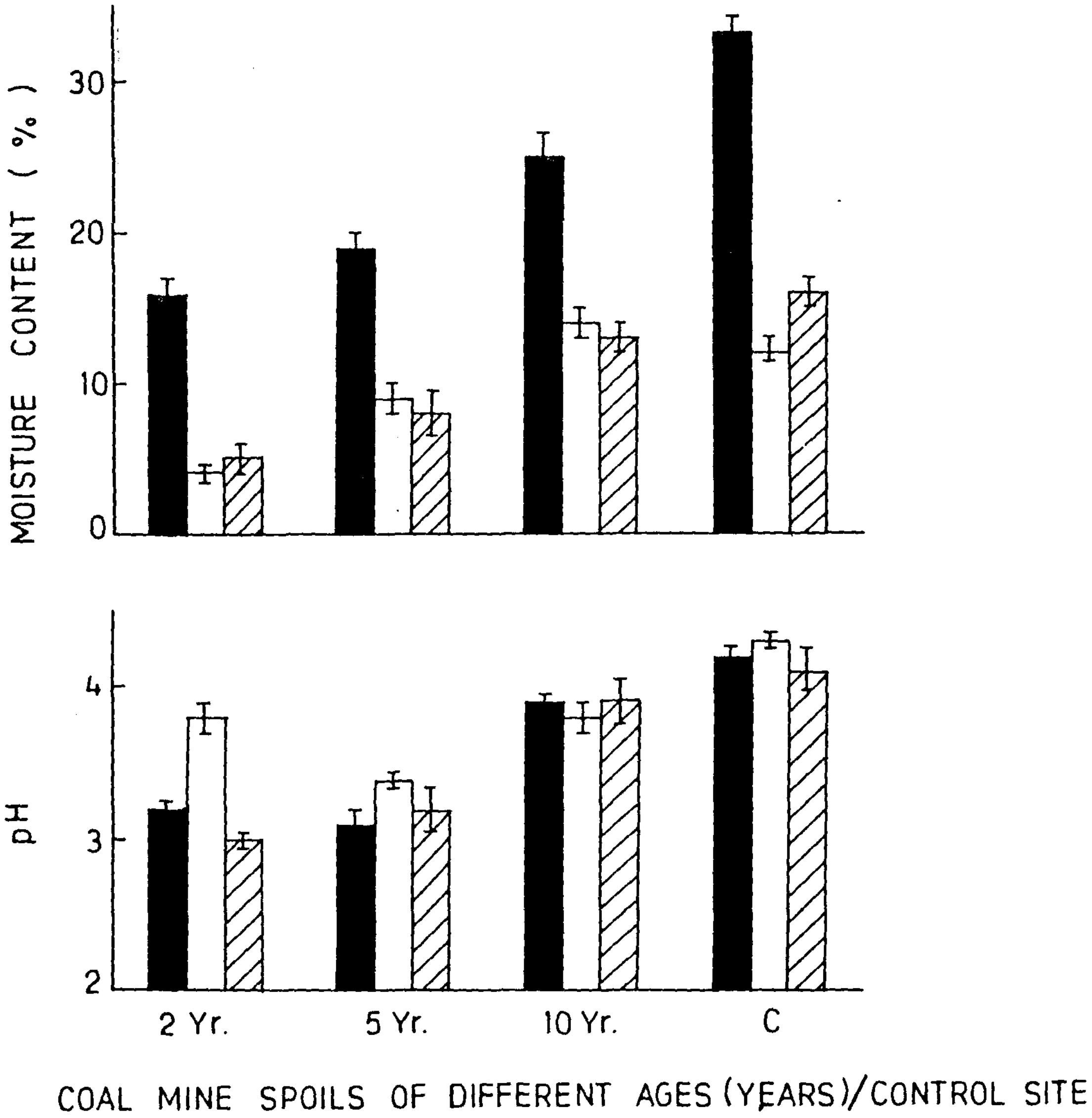


Fig. 4.3 - Seasonal variations in moisture content (%) and pH of coal mine spoils of different ages and the control site (C). Vertical bars represent standard error of the mean. ■ Rainy; □ Winter; ▨ spring.

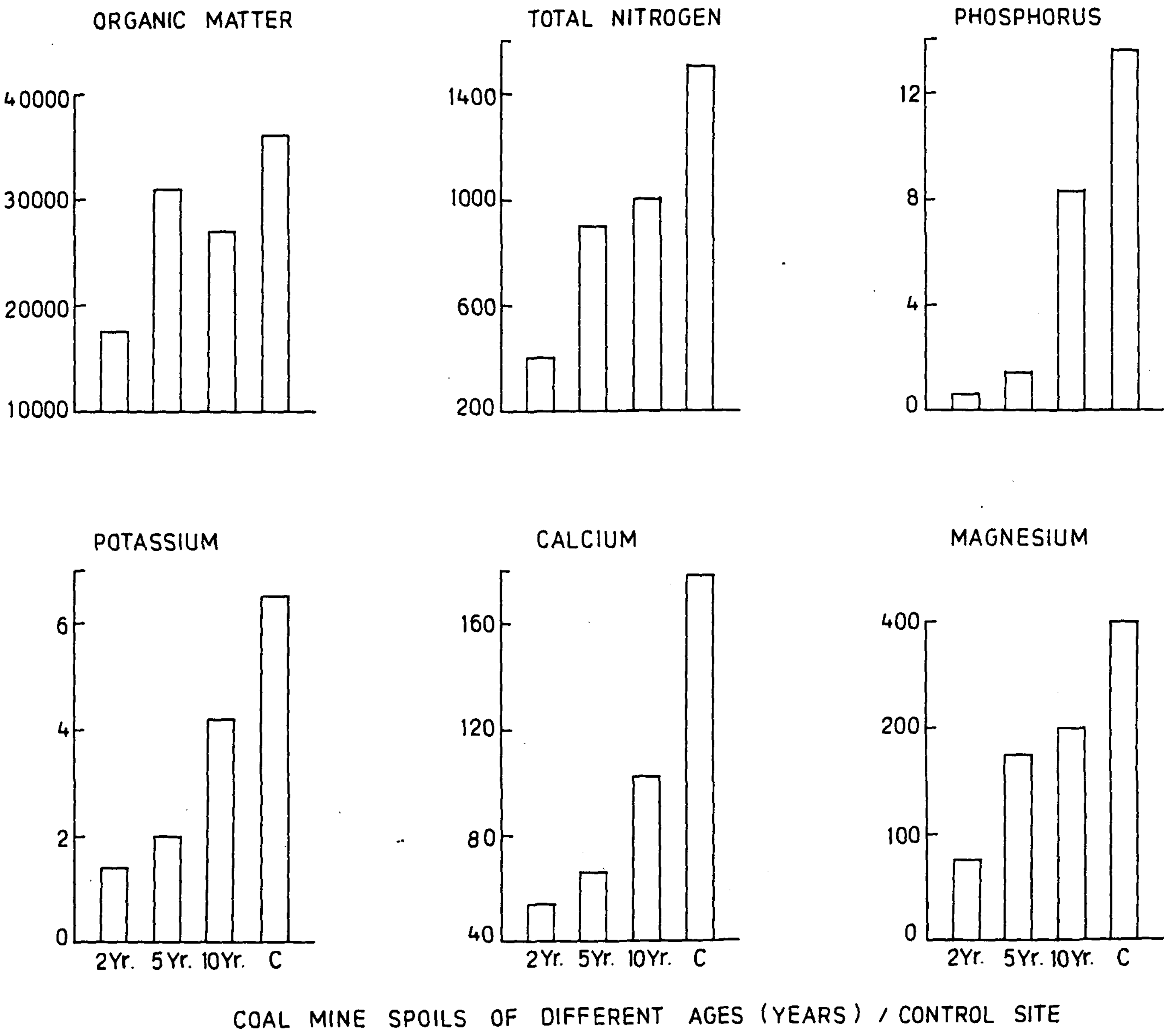


Fig. 4.4 - Mean organic matter content and nutrient content (kg ha^{-1}) of coal mine spoils of different ages and the control site (C).

CHAPTER 5

DYNAMICS OF COMMUNITY STRUCTURE ON THE MINE SPOILS UNDERGOING NATURAL RECOVERY

INTRODUCTION

Plant communities which appear naturally on coal mine spoils are of great interest to the ecologists because they show the processes of ecosystem reconstruction and natural ecosystem development (BRADSHAW 1983). Therefore, studies relating to the floristic composition as well the physico-chemical properties of these spoils have been conducted by various workers in different parts of the world (CORNWELL 1971, FYLES *et al.* 1985, GAME *et al.* 1982, SINGH & JHA 1987, JHA & SINGH 1990).

Meghalaya which is situated in the sub-Himalayan belt of the north eastern region of India is endowed with rich natural vegetation. But the age-old practice of slash and burn agriculture (locally called 'Jhum'), has been responsible for the depletion of natural vegetation and conversion of the forest ecosystems into grasslands (UMA SHANKAR *et al.* 1991). During the last few decades large scale mining of coal, limestone and sillimanite has caused further deterioration of the natural vegetation of the state.

Coal mining in many parts of Meghalaya, especially Jaintia Hills district has converted the original lush green landscape of the area into mine spoils. The primitive 'Rat Hole' method of mining which is done manually by private operators has brought even more destruction to the ecosystem of this region. There is lack of information on the natural plant succession on Indian mine spoils. PRASAD & PANDEY (1985) have studied natural plant succession in the rehabilitated bauxite and coal mine overburden of Madhya Pradesh. JHA & SINGH (1990) have analysed the vegetation developing naturally on dry subtropical mine spoils. But there is no information on the natural succession on the mine spoils of Jaintia Hills, Meghalaya, though some attempt in this direction has been made by LYNGDOH *et al.* (1992) and PANDEY *et al.* (1993). This chapter presents a detailed analysis of the structure and dynamics of plant communities on the abandoned coal mine spoils of three ages and on an adjacent grassland site (control) with a view to understand the dynamics of vegetation development on the coal mine spoils undergoing natural recovery.

MATERIALS AND METHODS

The phytosociological analysis of the vegetation was done periodically over a period of one year (from September, 1990 to August, 1991) at all sites by laying randomly ten quadrats of 50x50 cm size. The size and number of quadrats were determined following the methods described by MISRA (1968). Individuals of all species were counted in each quadrat. In case of grasses, each tiller and in case of creeping plants, any unit of shoot with functional roots was considered as an individual. Basal diameter of 10 to 20 individuals (depending on the availability) of each species was measured by using a slide calliper. Species identification was done in the herberia of Botany Department, North eastern Hill University and Botanical Survey of India, Shillong (Hooker 1872-1897). The various plant species listed were classified into different life form categories of RAUNKIAER (1934) as revised by MUELLER-DOMBOIS & ELLENBERG (1974).

Quantitative phytosociological characteristics such as density, frequency, basal cover and importance value index (IVI) of various plant species were determined from the field data by using the methods and formulae outlined by MISRA (1968). Comparison of the four sites was made by calculating similarity indices between each paired combination using the formula of MUELLER-DOMBOIS & ELLENBERG (1974):

$$SI = (2W \times 100)/(A+B)$$

Where SI = Similarity Index

W = Sum of lower values of IVI of different species.

A+B = Sum of all the IVI values of various species in the two communities.

Species diversity (H) was calculated following PIELOU (1975), using the Shannon-Wiener information function expressed as :

$$\bar{H} = -\sum (n_i/N) \log_e (n_i/N)$$

where $\bar{H}$ = SHANNON'S Index of general diversity,

n_i = importance value index of each species

N = total of importance values of all species.

Species richness (d) was calculated following MARGALEF (1958):

$$d = (S - 1)/\log_e N$$

where S = number of species

N = number of individuals.

Evenness Index (J) was calculated following PIELOU (1975):

$$J = \bar{H}/\log_e S$$

where $\bar{H}$ = SHANNON'S Index and

S = Number of species.

Concentration of dominance (D) was measured following SIMPSON (1949):

$$D = \Sigma(n_i/N)^2$$

where n_i = importance value index of each species and

N = Total importance values of all species.

RESULTS

Floristic composition

Vegetation analysis of the coal mine spoils indicated that there was an increase in the number of plant species with an increase in the age of the spoils. The total number of species on the control site was 44 which decreased to 21, 9 and 7 species respectively, in 10, 5 and 2 year old coal mine spoils. A list of species recorded in the coal mine spoils of different ages and the control site are given in Table 5.1. *Osbeckia crinita* was the only plant species which occurred on both mine spoils and the control site, while other plant species viz *Axonopus compressus* *Arundinella nepalensis*, *Dicranopteris linearis*, *Lycopodium sp.*, *Osbeckia nepalensis*, *Histiopteris incissa*, *Eragrostis gangetica*, *Impatiens bicolor*, *Rubia cordifolia*, and *Isachne albens* were present only on the mine spoils and were absent from the control site. Maximum numbers of species were recorded at all sites during peak vegetative growth (September). On the control site, out of 44 plant species present, 19 were annuals, and 25 were perennials, on the 5 year old spoil only perennials were recorded, and on the 2 year old spoil, 2 species were annuals and 5 were perennials. The proportion of perennials increased significantly with the age of the spoil (Table 5.2).

Density and importance value index (IVI)

There was a significant increase ($P<0.05$) in stand density with the increase in the age of the spoil and this increase was maximum on the control site. Seasonal variation in stand density was also significant ($P<0.01$) at all sites. Both the control site and the coal mine spoils had maximum stand density in the rainy season. On the control site, stand density was minimum during winter, while on the coal mine spoils stand density was minimum during spring. Mean stand density was 39, 109, and 464 on the 2 year, 5 year, and 10 year old spoils respectively and 720 on the control site (Table 5.3).

Table 5.4 shows the density and importance value index (IVI) of important species during the peak vegetative growth. A comparison of density values of *Axonopus compressus* and *Chrysopogon gryllus* which appeared to be quite abundant on the mine spoils revealed that their density increased with age of the spoil. But on the control site, *Axonopus compressus* was absent while *Chrysopogon gryllus* showed much lower density compared to the mine spoils. *Eragrostiella leioptera* and *Fimbristylis falcata* showed considerably high density (210 and 117 m^{-2}, respectively) on the control site, but the former species was absent from the spoils and the latter was recorded only once in the 10 year old spoil in the rainy season and its density was also very low. *Eragrostiella leioptera*, *Eriocaulon nepalensis*, *Fimbristylis falcata* and *F.complanata* appeared to be dominant on the unmined area, as indicated by their high IVI values (Table 5.3). On the 10 year old spoil *Axonopus compressus* showed the highest IVI (128) followed by *Chrysopogon gryllus* (45) and *Osbeckia crinita*

(29). On the 5 year old spoil the IVI of *Chrysopogon gryllus* was the highest (93) followed by *Axonopus compressus* (79) and *Dicranopteris linearis* (52). On the 2 year old spoil again, *Axonopus compressus* had the highest IVI of 129 followed by *Osbeckia crinita* with an IVI of 50. Thus on the control site, IVI was shared by many dominant species, whereas on the coal mine spoil only one or two species shared the maximum values.

Table 5.5 shows the seasonal variation in the relative density, relative dominance and importance value index (IVI) of some important species. On the control site, *Eragrostiella leioptera* had the maximum relative density and IVI during the rainy and winter seasons. But during spring season *Fimbristylis complanata* and *Ischaemum geobellii* had the maximum relative density and IVI. On the 10 year old spoil *Axonopus compressus* was dominant through all the seasons and there was no significant variation in its relative density, relative dominance and IVI with the change in seasons. On the 5 year old spoil, maximum values were attained by *Chrysopogon gryllus*, *Axonopus compressus* and *Dicranopteris linearis* during the rainy season, but *Axonopus compressus* was not recorded in the subsequent seasons. During winter and spring, *Dicranopteris linearis* and *Chrysopogon gryllus* showed the maximum values. Similarly, on the 2 year old spoil, *Axonopus compressus* had the maximum values in the rainy season followed by *Chrysopogon gryllus*.

Basal cover

There was no significant variation in basal cover through seasons but there was a significant ($P<0.01$) increase in the basal cover ($cm^2\ m^{-2}$) with the increase in the age of the spoil

(Fig. 5.1). The least cover was observed in 2 year old spoil, while the maximum cover was attained on the control site. Mean basal cover was 6.6, 14.6, and 62.5 cm^2 m^{-2} for the 2 year, 5 year, 10 year old spoil respectively and 114.5 cm^2 m^{-2} for the control site.

Life form spectrum

Table 5.6 shows the percentage of various life forms on the four sites ie, on the coal mine spoils and the unmined (control) site. On the control site, the percentage of therophytes was maximum (43.2%) followed by hemicryptophytes (18.2%) and chamaephytes (15.9%). On the 10 year old spoil the hemicryptophytes were the predominant (33.4%) life form. On the 5 year old spoil only two life forms viz, hemicryptophytes (55.6%) and chamaephytes (44.4%) were found. On the 2 year old spoil too, the percentage of hemicryptophytes was quite high (57.1%) followed by that of therophytes (28.6%) and chamaephytes (14.3%). Comparison of these life forms with that of RAUNKIAER'S normal spectrum (RAUNKIAER 1934) revealed that the percentage of therophytes was higher than that of RAUNKIAER's on both the control site (nearly 3 times higher) and on the mine spoils (2 times higher) except on the 5 year old spoil where therophytes had not been recorded. Comparison of these life forms with those reported by HALL (1957) and DOWN (1973) revealed the similarity of these mine spoils, in that the percentage of hemicryptophytes was the highest in all the cases.

Similarity Index

Table 5.7 shows the matrix of similarity coefficients among the communities growing on the mine spoils of three ages and on the control site calculated on the basis of IVI. SORENSEN'S similarity index between the spoils and the control site was low. The 2 year and the 5 year old spoils were more than 57% similar to that of the 10 year old spoil. However, the similarity index between the 5 year and the 2 year old spoil was only 31%.

Dominance-diversity

Figure 5.2 shows the dominance-diversity curves for the four communities growing on mine spoils of different ages and on the control site calculated on the basis of importance value index (IVI) and plotted on a log scale. These curves were found to fit the log normal model of PRESTON (PRESTON 1948) for the control site and the 10 year old spoil. However, curves for the 5 year and 2 year old spoils showed geometric series of the niche pre-emption model (POOLE 1974).

Fig. 5.3 shows the dominance and diversity indices from the above four communities. SIMPSON's index of dominance (D) decreased with the increase in the age of the spoil and it was minimum in the case of control site. The reverse was true for SHANNON's index of general diversity ($\bar{H}$). These two indices were negatively correlated in both mine spoils of different ages and the control site (Table 5.8). Evenness Index (e) decreased with increasing age, but it increased again in the case of control site. Species richness was maximum in the control site, followed by the 10, 5, and 2 year old spoils (Fig.5.3).

DISCUSSION

The results reveal that the characteristics of vegetation developing on the spoils were very much related to their age. The vegetation attributes that were influenced by the age of the spoil were species diversity, density and basal cover. This is in agreement with the findings of BAIG (1992). JHA & SINGH (1990a) also reported increased species diversity on the older spoil than on the younger ones. Increase in species diversity with age has also been reported by SINDELAR (1979) in seeded coal mine spoils at Colstrip, Montana. IVERSON & WALI (1982) also observed an increase in species richness with age in reclaimed coal mine spoils in north western Dakota and DEPUIT *et al.* (1977, 1978) at Colstrip Montana. BRADSHAW & CHADWICK (1980) reported that there was no relationship between the species number and the age of the colliery spoil; species number is rather influenced by pH. CORNWELL (1971) has also shown that species richness on coal wastes areas is related more to spoil acidity than to age. RUSSELL & LAROI (1986) reported higher species richness on fine textured spoil than on coarse textured coal mine spoils in Alberta, Canada. But in the present investigation, there was a gradual increase in the pH of these spoils over time. The relationship between species richness and spoil age is also probably related to spoil moisture stress and nutrients over time. DOWN (1973) reported that colonization of coal mine spoils by plant species did not take place before the age of 10 years. Similarly, ROBERTS *et al.* (1981) working on china clay wastes also reported delayed colonization of such areas. KIMMERER (1984) working on lead mine wastes observed that lag of initial colonization on any mine waste may be attributed to lack of propagules capable of growing in such an environment. Similarly LEISMAN (1957), and GIBSON *et al.* (1985) stressed the importance of surrounding vegetation and the dissemination efficiency of propagules upon spoil seed banks. In the present investigation, colonization by plant species was observed even when the age of the spoil was only 2 years although the density and basal cover were very low. The colonization of the young spoils could be attributed to the availability of propagules. Since mining was done manually, spoil heaps are rather patchy. The distance between the unmined lands and the spoil heaps is not very far. As a result, 'seed rain' from the vegetation around these spoil heaps could easily reach them. Similarly, perennial plants with stolons and subterranean rhizomes could also find their way to the foot of these spoil heaps and later extended to other parts of the heaps. Though colonization took place at an early age, it was rather patchy and this patchiness persisted even on the 10 year old spoil. Individuals were clustered together and the clusters were separated by large bare areas. Initial colonization occurred in certain more favourable microsites where apparently moisture was available for the plants to get established during spring and early rainy seasonr. This conforms with the reports of BARNESS & STANDBURY (1951), BRIERLEY (1956), GAME *et al.* (1982) and BAIG (1992).

Total density per stand increased with the age of the spoil because of the increase in species richness and in the ability of the colonizing species to multiply. The control site had a maximum density per stand because of its greater species richness. Stand density was maximum during the rainy season because of the prevailing favourable growth conditions. On the coal mine spoils, stand density was low in spring, presumably because of the low soil moisture content. On the control site the percentage of therophytes was more. These plants being annual had already completed their life cycles in winter. This probably accounts for the low stand density during winter on the control site.

The grass *Axonopus compressus* is well adapted to grow on the coal mine spoils of Jaintia Hills. *Axonopus compressus* has a perennial stolon in which rooting takes place at the nodes. This growth characteristic helps bind the soil particles, making the soil more stable. On the 2 year old spoil the density of *Axonopus compressus* was quite low, presumably, on account of the fact that colonization had just begun. The increase in the density of *Axonopus compressus* with age of the spoil during the rainy season could be due to its ability to multiply rapidly. *Axonopus compressus* is very common in any disturbed environment of this region. Another perennial grass which also appears to be well adapted to grow on the mine spoil is *Chrysopogon gryllus*. The fibrous root system of grasses helps them to grow in an unstable habitat by binding the soil particles and checking soil erosion. This is in agreement with RIES & DEPUIT (1984) who observed that perennial grasses are well suited to grow on the spoils. The predominance of grasses and legumes on mined lands has also been reported by BRIERLEY (1956), ALVAREZ *et al.* (1974), RUSSEL (1985) and PRASAD & PANDEY (1985). In the present study, however. legumes were not recorded on mine spoils. This could be due to the fact that legumes were very rare on the adjacent unmined land.

Basal cover (m^{-2}) was least on the 2 year old spoil (Fig. 5.1) depicting that colonization on this spoil was at its initial stage, while on the control site, total basal cover was highest due to the occurrence of greater number of species as well as their greater density. On the 10 year old spoil too, the basal cover was quite high and this was largely due to the better growth and high basal cover of *Axonopus compressus* and *Chrysopogon gryllus* even though the 10 year old spoil still had many bare patches.

The fern *Dicranopteris linearis* which also colonized the spoils showed considerably high values for cover and IVI in the 5 year and 10 year old spoils (Table 5.3) indicating its rapid colonizing potential. This species, however, was not an important component in the unmined area.

Dominance-diversity curves have been often used to interpret the dominance of different species in the community in relation to resource apportionment and niche space (WHITTAKER 1975). These curves (Fig. 5.2) in the case of the control site and 10 year old spoil fit the log normal model as the number of species was more on these two sites. This suggests that on these sites there was more or less an even apportionment of resources among the members of the component species. The curves for the 5 year and 2 year old spoils showed geometric series of the niche pre-emption model (POOLE 1974). This could be attributed to the lesser number of species occurring on these sites which represented a stressed environment where conditions were not favourable for plant growth. Species diversity was low on these two sites, but the species that grow here appeared to have developed tolerance that enable them to grow in such an environment. The dominant species on these sites used the major fraction of available resources of the community leaving only a small fraction to be pre-empted by other species.

RAUNKIAER's biological spectrum has been widely used in the ecological classification of plants and is considered important in determining the differences and similarities among different communities. The control sites though undisturbed with respect to mining, was exposed to biotic stress such as fire and cattle grazing. This accounts for the highest percentage of therophytes on this site. This is in accordance with SINGH & AMBASHT (1975) who considered therophytes as the indicator of biotic stress. The reasons for the absence of therophytes on the 5 year old spoil remains obscure. On the spoils of all the three ages, the hemicryptophytes showed the highest percentage. This may be related to the extremely poor environment of these sites as also reported by HALL (1957), MOLYNEUX (1963) and DOWN (1973). DOWN (1973) observed that hemicryptophytes and therophytes are well suited to an open, exposed and unstable habitat. He emphasized the importance of rosette hemicryptophytes as pioneers in providing a positive anchorage in the unstable coal mine spoils. In the present study, however, no rosette hemicryptophytes were encountered, although some of the hemicryptophytes belonging to the stoloniferous and rhizomatous grass species such as, *Axonopus compressus*, *Chrysopogon gryllus*, and *Arundinella sp.*, grow successfully on the spoils.

SORENSEN's similarity index was low between the mine spoils and the control site. This could be due to the preponderance of the therophytes on the control site and hemicryptophytes on the mine spoils. The mine spoils that were chosen for the study though they belonged to different ages, were subjected to the same kind of disturbance. This probably accounts for the higher percentage of similarity between them.

Table 5.1 : Floristic composition of the vegetation growing on coal mine spoils of different ages and on the unmined site (control). + indicates presence and - indicates absence.

Plant species	unmmined site (control)	Age of coal mine spoils (years)			Habit	Life form
		10	5	2		
Anaphalis contortes (D.Don) Hk.f.	+	-	-	-	P	Ch
Anotis wightiana Hk.f.	+	+	-	+	P	Hemi
Anthogonium gracile Lindl.	+	-	-	-	P	Geo
Arundinella bengalensis (Spreng) Druce	+	-	-	-	P	Ch
Arundinella khasiana Nees	+	-	-	-	P	Ch
Arundinella nepalensis Trin.	-	+	+	-	P	Ch
Axonopus compressus (S.w.) Beauv.	-	+	+	+	P	Hemi
Bulbostylis densa (Wall. ex Rox.) Handmazz	+	-	-	-	A	Th
Carex vesiculosa Boott	+	-	-	-	P	Hemi
Centella asiatica (L) Urb	+	-	-	-	P	Hemi
Chrysopogon gryllus (L) Trin	+	+	+	-	P	Hemi
Cyanotis vaga (Lour) J.A. et J.H.Schult	+	+	-	-	P	Geo
Desmodium triflorum D.C.	+	-	-	-	P	Hemi
Dicranopteris linearis Holt	-	+	+	-	P	Hemi
Dysophylla auricularia Bl.	+	-	-	-	A	Th
Dysophylla linearis Benth.	+	-	-	-	A	Th
Emilia sonchifolia D.C.	+	+	-	-	A	Th
Eragrostiella leioptera (Stapf.) Bor	+	-	-	-	P	Hemi
Eragrostis gangetica Steud.	-	+	-	-	P	Ch
Eriocaulon nepalense Presc. ex Bong	+	+	-	-	P	Geo
Eriosaema chinense Vogel	+	-	-	-	P	Geo
Eulalia pallense (Hack.) Kuntse	+	-	+	-	P	Hemi
Eurya japonica Thunb.	+	-	-	-	P	Ph
Fimbristylis complanata (Retz.) Link.	+	-	-	+	A	Th
Fimbristylis falcata Kunth	+	+	-	-	A	Th
Gentiana quadrifaria Clark non Blume	+	-	-	-	A	Th
Histiopteris incissa (Thunb.) J.Sur.	-	+	-	-	P	Geo
Impatiens balsamina Linn	+	+	-	-	A	Th
Impatiens bicolor Royle	-	+	-	-	P	Geo
Isachne albense Trin.	-	-	-	+	P	Hemi
Ischaemum geobellii Hack	+	+	-	+	A	Th
Lindernia sp.	+	-	-	-	A	Th
Lycopodium sp	-	+	+	-	P	Hemi
Murdania giganteum (Vahl) Bruck	+	-	-	-	A	Th
Nepenthes khasiana Hook. f	+	-	-	-	P	Ph
Osbeckia crinita Benth.	+	+	+	+	P	Ch
Osbeckia glauca Benth.	+	-	-	-	A	Th
Osbeckia nepalensis Hk.f.	-	+	+	-	P	Ph
Paspalum orbiculare Forst	+	+	-	+	P	Hemi
Phyllanthus urinaria Hb. Russ	+	-	-	-	A	Th
Pteridium aquilinum (L) Kuhn.	+	+	-	-	P	Geo
Rhynchospora walliachiana Kunth	+	-	-	-	P	Ch
Rubia cordifolia Linn.	-	+	-	-	P	Hemi
Rubus moluccanus Linn.	+	-	-	-	P	Ph
Sacciolepis indica A. Chase	+	-	-	-	A	Th

contd. Table 5.1

Plant species	unmmined site (control)	Age of coal mine spoils (years)			Habit	Life form
		10	5	2		
Salmonia cantoniensis Lour	+	-	-	-	A	Th
Schizachyrium brevifolium Nees	+	-	-	-	A	Th
Scutellaria discolor Coleb	+	-	-	-	A	Th
Setaria glauca (L) Beauv.	+	-	-	-	A	Th
Setaria palmifolia (Koen) Stapf.	+	-	-	-	P	Ch
Smilax ferox Wall. ex Kunth.	+	-	-	-	P	Ph
Sphaerocaryum malaccens (Trin.) Pilger	+	+	-	-	A	Th
Sporobolus indicus R.Br.Prod.	+	-	-	-	P	Ch
Symplocos spicata A.DC.	+	-	-	-	P	Ph
Trichosanthes sp.	+	-	-	-	A	Th

A Annual; P Perennial; Th Therophyte; Ch Chemaephyte; Hemi Hemicryptophyte; Geo Geophyte; Ph Phanerophyte

Table 5.2 - Number of species in various species groups

Species groups	Control site	Age of coal mine spoil (years)		
		10	5	2
Annuals	19	5	0	2
Perennials	25	16	9	5
Phanerophytes	5	0	0	0
Hemicryptophytes	8	7	5	4
Chemaephytes	7	4	4	1
Geophytes	5	5	0	0
Therophytes	19	5	0	2
Total	44	21	9	7

Table 5.3 : Seasonal variation in stand density (plants m^{-2})

Seasons	Control site	Age of coal mine spoils (years)		
		10	5	2
Rainy 1990	880 ± 94	393 ± 76	144 ± 60	54 ± 18
Winter 1991	494 ± 49	442 ± 83	107 ± 15	23 ± 8
Summer 1991	727 ± 122	370 ± 93	84 ± 25	19 ± 8
Mean	700	402	112	32

± SE of the mean

Table 5.4 : Density (plants m^{-2}) and importance values index (IVI) of important species occurring on the four sites during peak vegetative growth. Only those species with IVI above 10 have been considered individually.

Name of species	Control site		Age of coal mine spoils (years)					
			10		5		2	
	D	IVI	D	IVI	D	IVI	D	IVI
Arundinella bengalensis	43.2 ± 30.8	12.7	...	...	...	...	...	...
Arundinella nepalensis	... ...	...	25.2 ± 11.1	18.2	9.2 ± 8.7	20.7	...	...
Axonopus compressus	...	...	246.8 ± 93.5	128.4	56.4 ± 56.4	79.2	26.4 ± 16.1	128.7
Chrysopogon gryllus	42.0 ± 33.0	17.1	66.8 ± 45.6	45.0	50.8 ± 35.2	92.9	...	...
Dicranopteris linearis	...	...	10.4 ± 5.5	10.0	20.8 ± 12.3	52.2	...	...
Eragrostiella leiopteral	210.0 ± 88.5	33.6	...	...	...	...	...	...
Eriocaulon nepalense	17.2 ± 8.6	23.0	...	...	...	...	...	...
Eulalia palense	52.4 ± 12.3	15.7	...	...	2.7 ± 1.8	13.3	...	...
Fimbristylis complanata	98.0 ± 35.1	21.1	...	...	...	...	3.2 ± 3.2	13.8
Fimbristylis falcata	117.2 ± 40.8	28.7	...	...	...	...	...	...
Ischaemum geobellii	40.4 ± 21.6	15.1	11.6 ± 8.3	12.3	...	...	2.4 ± 2.4	17.4
Osbeckia crinita	10.8 ± 4.3	16.3	7.6 ± 3.0	29.1	1.2 ± 0.8	13.3	2.4 ± 1.0	50.2
Osbeckia glauca	61.2 ± 20.8	19.1	...	...	...	...	...	...
Others	188.0 ± 56.4	97.5	24.4 ± 10.2	57.2	2.4 ± 0.8	28.1	19.6 ± 12.3	89.4

D-Density, '...' indicates species absence.

Table 5.5 : Seasonal variation in relative density (R.Den), relative dominance (R.Dom) and importance value index (IVI) of some important species.

Species	Seasons								
	Rainy			Winter			Spring		
	R.Den	R.Dom	IVI	R.Den	R.Dom	IVI	R.Den	R.Dom	IVI
Control									
Arundinella bengalensis	4.91	5.21	12.73	....	....	....	....	....	
Chrysopogon gryllus	4.77	10.59	17.10	....	....	....	....	....	
Eragrostiella leioptera	48.46	29.38	86.59	29.51	2.89	36.30	20.60	2.42	30.80
Eriocaulon nepalensis	1.95	17.62	23.05	0.40	1.01	5.31	.....	....	.....
Eulalia palense	8.52	3.67	19.69	12.92	1.69	24.37	6.16	0.51	11.29
Fimbristylis complanata	11.13	3.01	21.10	5.98	0.69	13.16	26.25	56.09	96.19
Fimbristylis falcata	13.31	8.46	28.73	5.66	1.54	11.10	0.94	0.96	4.98
Ischaemum geobellii	5,54	14.72	25.26	17.14	2.29	24.62	24,60	32.03	70.48
Osbeckia crinita	1.23	10.77	16.35	3.31	4.13	15.23	2.48	1.63	13.34
Osbeckia glauca	6.95	5.14	19.05	3.96	1.25	10.40	2.48	0.18	5.74
10 year old spoil									
Arundinella bengalensis	3.87	1.05	11.30	...	...	...	...	...	...
Arundinella nepalensis	6.42	3.12	18.24	4.97	3.06	15.93	...	...	...
Axonopus compressus	82.85	84.24	187.77	65.19	62.89	149.13	71.83	59.40	161.66
Chrysopogon gryllus	17.01	21.51	45.04	12.84	17.22	37.95	7.43	20.59	36.72
Dicranopteris linearis	2.65	0.36	9.53	3.44	1.18	17.77	1.14	0.72	6.21
Eriocaulon nepalensis	3.07	3.96	11.29	...	...	...	...	...	...
Fimbristylis falcata	0.41	0.15	2.73	...	...	...	...	...	...
Ischaemum geobellii	2.95	2.89	12.36	4.07	2.67	14.64	9.29	6.72	20.36
Osbeckia crinita	1.94	14.11	29.09	0.54	4.56	12.99	2.17	3.55	18.76
5 year old spoil									
Arundinella nepalensis	6.41	3.22	20.74	....	...	...	0.48	0.60	12.19
Axonopus compressus	39.30	34.39	79.25	...	...	...	...	...	...
Chrysopogon gryllus	35.40	46.45	92.96	24.63	73.04	118.72	9.51	26.97	47.59
Dicranopteris linearis	14.49	9.97	52.24	69.78	18.31	124.93	81.33	52.48	189.37
Eulalia palense	...	...	...	...	...	...	2.97	0.63	14.71
Osbeckia crinita	11.84	1.35	13.30	0.75	1.10	12.38	...	...	...
2 year old spoil									
Arundinella nepalensis	...	...	...	...	...	...	17.02	8.02	39.33
Axonopus compressus	48.89	61.36	128.70	5.17	1.81	18.09	4.26	1.48	20.03
Chrysopogon gryllus	46.94	43.13	108.18	55.17	28.94	106.33	...	...	...
Eriocaulon nepalensis	4.08	3.23	18.42	...	...	...	...	...	...
Fimbristylis complanata	5.93	1.66	13.84	...	...	...	...	...	...
Ischaemum geobellii	4.44	6.80	17.49	10.34	41.32	62.77	68.09	84.18	195.13
Osbeckia crinita	4.44	20.73	50.17	3.45	4.48	30.15	10.64	6.33	45.54

Table 5.6. Comparison of Life Form Spectrum of vegetation on the four sites with Raunkiaer's, Hall's and Down's Spectra. Values represent percentage of the total number of species in various life forms

	Phanerophytes	Chamaephytes	Hemicryptophytes	Geophytes	Therophytes
Raunkiaer (1937)	46.0	9.0	26.0	6.0	13.0
Hall (1957)	17.9	2.8	57.8	3.2	18.3
Down (1973)	8.0	5.3	73.2	2.0	11.5
Present Study Control site	11.4	15.9	20.5	11.4	45.4
10 yr old spoil	0.0	19.0	33.4	23.8	23.8
5 yr old spoil	0.0	44.0	56.6	0.0	0.0
2 yr old spoil	0.0	14.3	57.1	0.0	28.6

Table 5.7: Matrix of similarity coefficients among the communities at the four sites calculated on the basis of importance value index (IVI).

		Spoils		
Site	Control	10-yr old	5-yr old	2-yr old
Control	100.00	21.18	14.58	16.87
10-yr old spoil		100.00	57.05	58.61
5-yr old spoil			100.00	30.87
2-yr old spoil				100.00

Table 5.8 - Relationship between Shannon's diversity Index ($\bar{H}$) and concentration of dominance (D) in the mine spoils of different ages and the control site

Site	Variables		Regression equation	Correlation coefficient (r)	P
	($\bar{H}$) (Y)	(D) (X)			
Control site	$\bar{H}$	D	$Y = -7.706X + 3.599$	- 0.971	0.01
10 year old spoil	$\bar{H}$	D	$Y = -2.371X + 2.545$	- 0.851	0.05
5 year old spoil	$\bar{H}$	D	$Y = -2.927X + 2.340$	- 0.962	0.01
2 year old spoil	$\bar{H}$	D	$Y = -2.644X + 2.255$	- 0.994	0.001

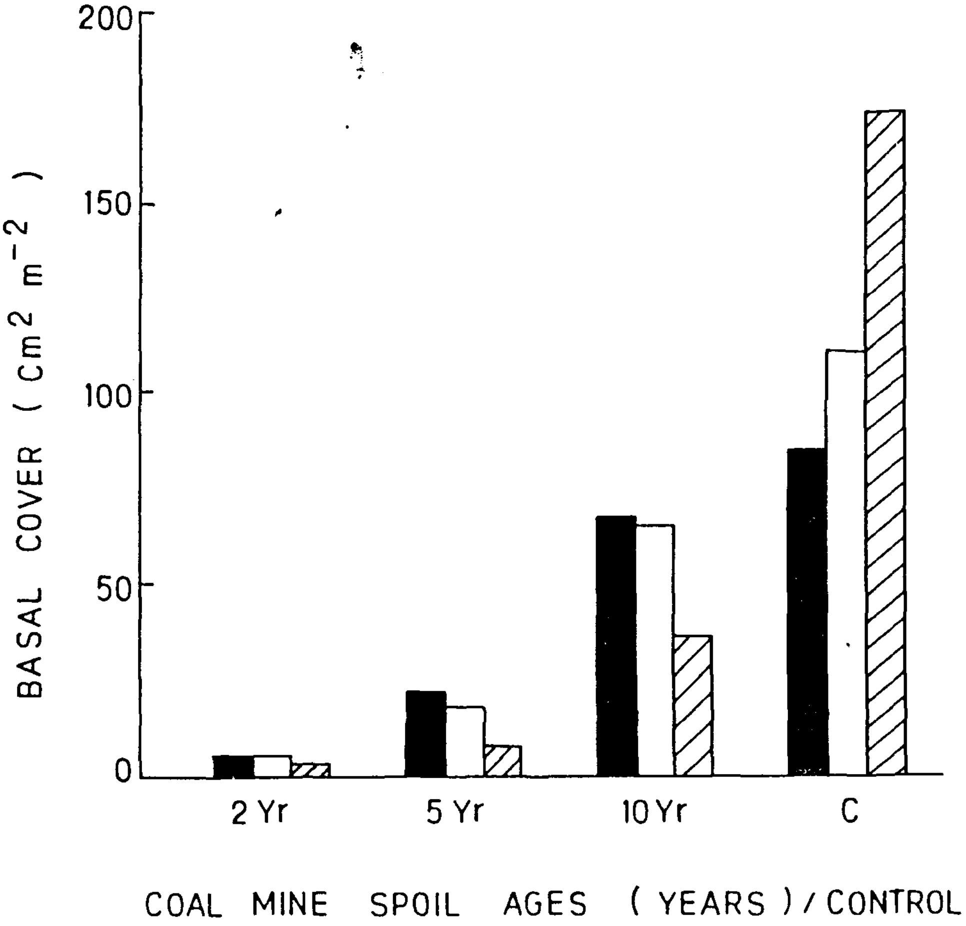


Fig. 5.1 - Seasonal variation in basal cover of plant species growing on coal mine spoils of different ages and the control site (C). ■ Rainy; □ Winter; ▨ Spring.

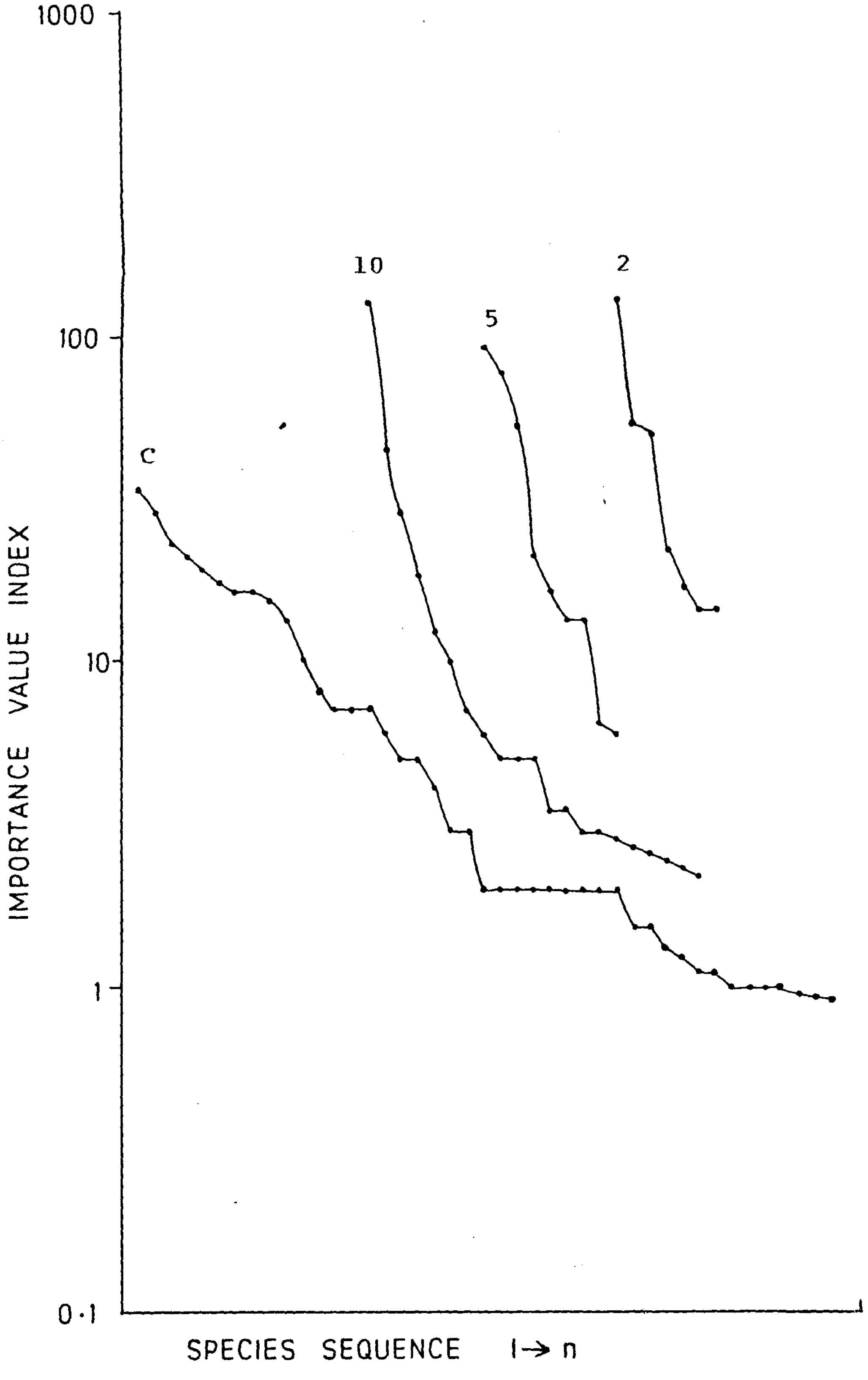
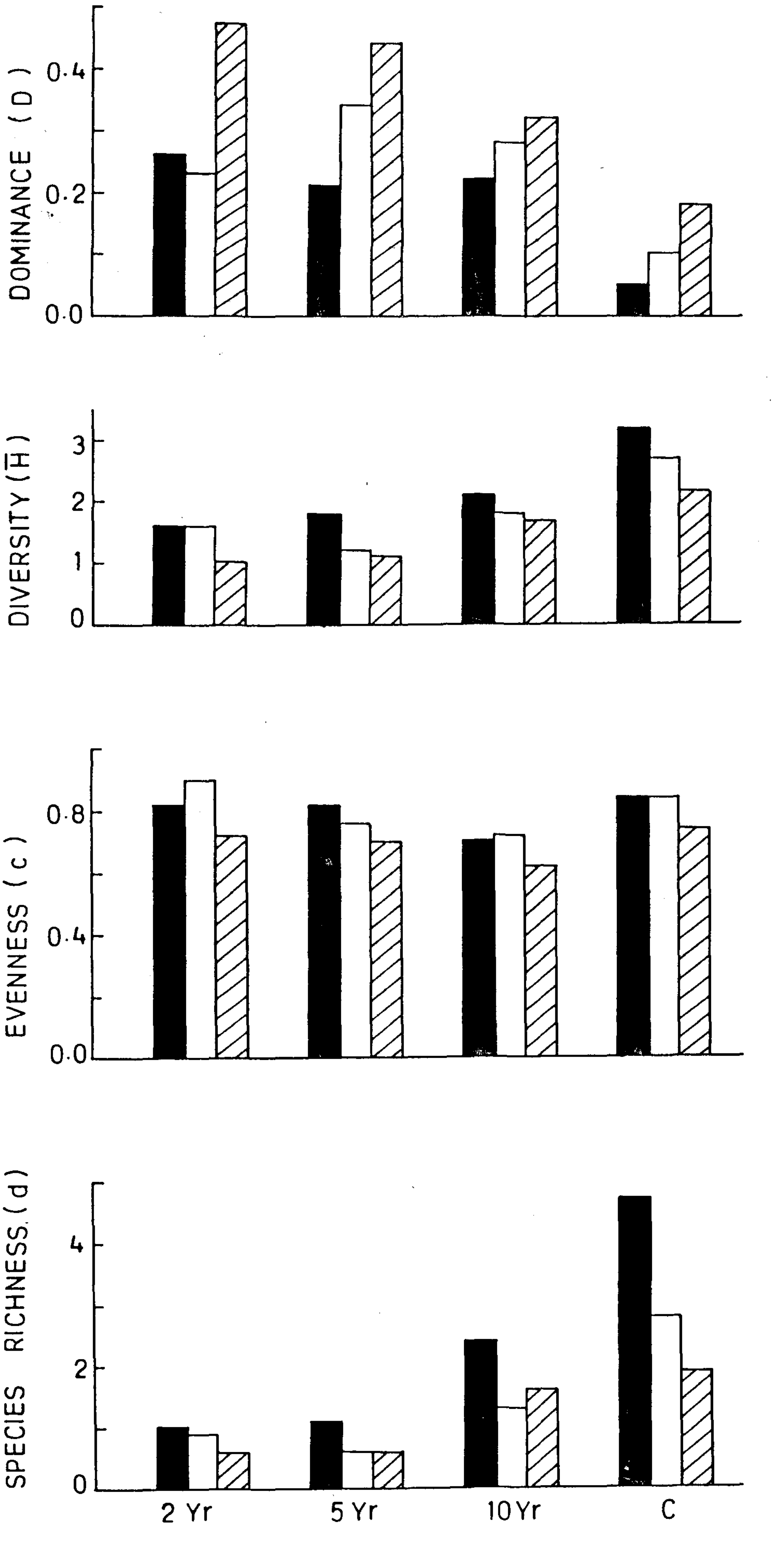


Fig. 5.2 - Dominance-diversity curves for plant species growing on coal mine spoils of different ages and the control site (C).



ig. 5.3 - Dominance (D), species diversity ($\bar{H}$); evenness index (e) and species richness (d) of plant species growing on coal mine spoils of different ages and the control site (C). ■ Rainy; ☐ Winter, ▨ Spring.

CHAPTER 6

BIOMASS AND NET PRIMARY PRODUCTIVITY

INTRODUCTION

Biomass is an important structural characteristic of an ecosystem and net primary productivity, an essential functional attribute. Whilst the former regulates the energy flow and circulation of materials, the latter provides the basic energy for the functioning of all organisms in an ecosystem. In the context of disturbed ecosystems, accumulation of biomass is very important and the success of reclamation of these disturbed ecosystems manifests itself in the site productivity (HOFMANN *et al.* 1981). Productivity has been rightly defined by ODUM (1971) as 'the index of fertility'. On coal mine spoils, species composition and time are the major factors which determine the biomass accumulation. Increased biomass production with spoil age has been reported by many authors (JOHNSON *et al.* 1982, JHA & SINGH 1992). Direct relationship between increasing spoil age and increased productivity has also been reported by SCHAFER 1984).

Studies on biomass and productivity of coal mine spoils have been carried out by several workers (CARREL *et al.* 1979, VAIL & WITTER 1982, JOHNSON *et al.* 1982, SCHAFER 1984, FYLES *et al.* 1985). In India such studies have been carried out by JHA (1989) and JHA & SINGH (1990, 1992) in dry tropical condition. But there has been no report on the biomass and productivity of coal mine spoils of this area. In this chapter, an attempt has been made to study the biomass and productivity of the coal mine spoils of three ages and an adjacent unmined site (control site). It is expected that the data collected will help in understanding the natural recovery of the degraded ecosystems.

MATERIALS AND METHODS

Biomass and productivity of the communities were determined in all the three ages of coal mine spoils and the control site. Aboveground biomass sampling was done seasonally by harvest method for a period of one year. On each sampling date, six quadrats of 50 x 50 cm were laid randomly and then all the species present in the quadrat were harvested close to the ground level by using sharp scissors. The harvested plant material was sorted species-wise and kept separately in polythene bags. Belowground biomass sampling was done by soil core method. From each harvested quadrat soil monoliths of 10 x 10 cm down to 15 cm depth were excavated and kept in polythene bags.

The aboveground and belowground samples were properly labelled and brought into the laboratory. The aboveground herbage of each species was sorted out into live green and standing dead compartment. The belowground biomass was extracted from the soil monoliths which were soaked in water overnight in buckets of 5 litres capacity and then repeatedly washed over 2.0 and 0.5 mm mesh sieves using a fine jet of water. Pieces of stones, coals etc retained over the sieves were picked by hand. The belowground components were separated into root and rhizome compartments.

All the separated samples of live green, standing dead, roots and rhizomes were packed in paper bags, labelled and dried to constant weight in an oven at 80°C and then the final weight of each compartment was taken.

Aboveground net primary productivity (ANP) of the whole plant community as well as few dominant species growing on each site was determined by summing all the positive increments in the aboveground biomass at successive harvests. To account for the fraction of NPP which might have been transferred from live to dead compartment, positive increments in dead shoot during those intervals when there was an increment in respective live biomass were summed and added to ANP following SINGH *et al.* (1975). Similarly, the root and rhizome primary productivity was calculated following the same method. Belowground primary productivity (BNP) was the sum of root and rhizome productivity.

RESULTS

Accumulation of biomass

Analysis of variance showed that biomass varied significantly ($P<0.01$) among the various compartments of the vegetation i.e. live and dead of the aboveground compartment and root and rhizome of the belowground compartment (Fig 6.1 and Fig 6.2). Variations due to site ($P<0.01$) and due to season ($P<0.05$) were also highly significant. Mean biomass values (g m^{-2}) of all the seasons for the 2, 5 and 10 year old spoils and the control site were as follows:

Vegetation Compartment	*Coal Mine spoils* *2 year old*	 *5 year old*	 *10 year old*	*Control site*
(i) Live biomass	21.0	53.6	113.9	107.4
(ii) Dead biomass	10.1	66.8	88.3	98.2
(iii)Root biomass	55.4	91.4	128.1	317.4
(iv) Rhizome biomass	36.9	24.1	95.7	154.0

Table 6.1 shows that total biomass varied considerably with seasons and with spoil age. Total biomass was maximum in the rainy season and minimum during winter on the spoils of different ages and the control site. As revealed by the mean values of all the seasons, there was a conspicuous increase in total biomass with spoil age, the values being minimum on the 2 year old spoil (123.3 g m^{-2}) and maximum on the 10 year old spoil (418.9 g m^{-2}). The control site, however, produced greater biomass (677.0 g m^{-2}) than the oldest spoil. Total biomass was significantly correlated with total stand density (Fig 6.3) at all sites ($P<0.01$ for 2 year old spoil; $P<0.001$ for all the other sites).

The seasonal variation in the aboveground biomass (Table 6.1) on the mine spoils was not significant, however, the variation on the control site was significant ($P<0.05$). Aboveground biomass was maximum in the rainy season on all the sites and minimum during winter with the exception of the control site where the minimum value was observed during spring. Aboveground biomass increased significantly ($P<0.01$) with age of the spoil. It was very low on the 2 year old spoil (31.0 g m^{-2}); it increased to 160.3 g m^{-2} on the 5 year old spoil and showed further increase on the 10 year old spoil (195.1 g m^{-2}). Aboveground biomass of the 10 year old spoil approached that of the control site (205.6 g m^{-2}).

The effect of season on the belowground biomass accumulation (Table 6.1) was not significant in the case of mine spoils, while on the control site it was highly significant ($P<0.01$). On the control site, maximum value was observed during the rainy season (687.8 g m^{-2}) and minimum during winter (325.8 g m^{-2}). Mean value of all seasons was minimum on the 2 year old spoil (92.3 g m^{-2}). It increased to 115.5 g m^{-2} on the 5 year old spoil and to 223 g m^{-2} on the 10 year old spoil. But the belowground biomass on 10 year old spoil unlike that of the aboveground biomass was very much lower than that on the control site (471.4 g m^{-2}).

The percentage distribution of aboveground biomass (Table 6.2) was very high in the live compartment and very low in the dead compartment during the rainy season on the mine spoils of different ages as well as the control site. During winter, distribution was very high in the dead compartment and very low in the live compartment. During spring, the distribution was not significantly different on the control and 10 year old spoil, but on the 2 year and 5 year old spoils, a very high percentage of total biomass was contributed by the live compartment.

The percentage distribution of belowground biomass (Table 6.3) was higher in the root compartment than in the rhizome compartment in the mine spoils and the control site through all the seasons except in the 10 year old spoil where the belowground biomass in the winter season was more in the rhizome than in the root.

Aboveground biomass of dominant species

On the control site (Table 6.4), *Eragrostiella leioptera, Fimbristylis complanata, Ischaemum geobellii and Osbeckia crinita* being the dominant species were considered individually. During the rainy season the major portion of the biomass was recorded in the live compartment of each of the above species, and very little biomass was recorded in the dead compartment. But the dead biomass increased considerably during winter and it again decreased in spring. Peak biomass of *Eragrostiella leioptera* (39.1 g m^{-2}) and *Ischaemum geobellii* (36.6 g m^{-2}) was recorded during the rainy season while that of *Fimbristylis complanata* (21.6 g m^{-2}) and *Osbeckia crinita* (25.3 g m^{-2}) peaked during spring.

On the 10 year old spoil (Table 6.4) *Axonopus compressus, Chrysopogon gryllus, Dicranopteris linearis, Ischaemum geobellii* and *Osbeckia crinita* were the dominant species. Maximum biomass was recorded during rainy season for *Ischaemum geobellii* (62.6 g m^{-2}) and *Osbeckia crinita* (28.9 g m^{-2}), during spring for *Axonopus compressus* (50.6 g m^{-2}) and *Chrysopogon gryllus* (16.5 g m^{-2}), and during winter for *Dicranopteris linearis* (31.5 g m^{-2}).

On the 5 year old spoil (Table 6.4) *Dicranopteris linearis* and *Osbeckia crinita* were the dominant species. In both species, major portion of biomass was found in the live compartment during rainy season, whereas the dead biomass increased in winter. The latter, however, again decreased during spring. Both *D. linearis* (135.5 g m^{-2}) and *O. crinita* (15.5 g m^{-2}) peaked during the rainy season.

In the case of 2 year old spoil (Table 6.4) the dominant species were *Ischaemum geobellii* and *Osbeckia crinita*. Peak biomass was recorded during spring for *Ischaemum geobellii* (9.1 g m^{-2}) and during the rainy season for *Osbeckia crinita* (5.8 g m^{-2}).

Total biomass values of dominant species (Table 6.4) were found to be maximum during the rainy season and minimum in winter except 2 year old spoil where a reverse trend was observed.

Percentage contribution of dominant species to the total aboveground biomass (Table 6.5) was quite high at all sites. On the control site, *Eragrostiella leioptera* and *Ischaemum geobellii* contributed 14.4% and 13.5% respectively, during the rainy season. While the contribution of *Eragrostiella leioptera* decreased in other seasons, the contribution of *Ischaemum geobellii* increased and its contribution during spring was as high as 19.8%. The total contribution of dominant species was 37.8%, 39.0% and 54.2% in the rainy, winter and spring seasons, respectively.

On the 10 year old spoil (Table 6.5) the contribution of *Ischaemum geobellii* was the highest (30.3%) during the rainy season followed by *Axonopus compressus* (20.9%). During winter and spring, contribution of *Axonopus compressus* was as high as 25.7% and 25.9% followed by *Dicranopteris linearis* with 17.2% and 12.5% respectively. The total contribution of the dominant species was 73.0%, 56.5% and 63.3% during rainy, winter and spring seasons, respectively.

On the 5 year old spoil (Table 6.5) *Dicranopteris linearis* contributed more than 73% throughout the year. *Osbeckia crinita* also contributed a good percentage during the rainy season. The total contribution of these two dominant species was 93.3, 80.8 and 74.4% during rainy, winter and spring seasons, respectively.

On the 2 year old spoil (Table 6.5) *Ischaemum geobellii* contributed 46.0% and 39.5% during winter and spring, but during the rainy season, it contributed only 4.9%. Contribution of *Osbeckia crinita* was 11.7% and 12.5% in the rainy and winter seasons, respectively. Total contribution of these two dominant species during rainy, winter and spring seasons was 16.6%, 58.5% and 45.1%, respectively.

Primary productivity

Root productivity (RNP) (Table 6.6) was more or less similar on the 2 year and 5 year old spoils. But it increased significantly on the 10 year old spoil, although here too, it was much lower than that of the control site. There was no regular trend in the rhizome productivity (RhNP) (Table 6.6). Belowground primary productivity (BNP) (Table 6.7), which represents the sum of RNP and RhNP was higher in the 2 year old spoil (27.2 g m^{-2} yr^{-1}) than the 5 year old spoil (23 g m^{-2} yr^{-1}). BNP increased significantly on the 10 year old spoil (184.8 g m^{-2} yr^{-1}), but it was still much lower than the BNP of the control site (381.1 g m^{-2} yr^{-1}).

Aboveground primary productivity (ANP) (Table 6.7) was very low on the coal mine spoils compared to that of the control site. ANP increased significantly with spoil age. ANP was minimum on the 2 year old spoil (50.7 g m^{-2} yr^{-1}). It increased to 72.8 g m^{-2} yr^{-1} on the 5 year old spoil and 145 g m^{-2} yr^{-1} on the 10 year old spoil, but the values were much lower than that on the control site (186.8 g m^{-2} yr^{-1}). Total net primary productivity (TNP) (Table 6.7) increased significantly with age, however, the TNP on the control site was much greater than that on the spoils.

On the control site (Table 6.8) *Eragrostiella leioptera* had the highest productivity of 35.7 g m^{-2} yr^{-1} followed by *Ischaemum geobellii* (20.2 g m^{-2} yr^{-1}) and *Fimbristylis complanata* (19.1 g m^{-2} yr^{-1}).

On the 10 year old spoil (Table 6.8) *Ischaemum geobellii* showed the highest productivity (52.6 g m^{-2} yr^{-1}) followed by *Dicranopteris linearis* (22.7 g m^{-2} yr^{-1}) and *Osbeckia crinita* (16.1 g m^{-2} yr^{-1}).

On the 5 year old spoil (Table 6.8) *Dicranopteris linearis* showed the highest productivity (46.9 g m^{-2} yr^{-1}) followed by *Osbeckia crinita* (14.2 g m^{-2} yr^{-1}).

On the 2 year old spoil (Table 6.8), the two dominant species were not so productive. The productivity of *Ishaemum geobellii* was only 7.0 g m^{-2} yr^{-1} and that of *Osbeckia crinita* was as low as 4.8 g m^{-2} yr^{-1}.

On the control site (Table 6.9) maximum contribution to the total aboveground net primary productivity (ANP) was made by *Eragrostiella leioptera* (19.1%) followed by *Ischaemum geobellii* (10.8%) and *Fimbristylis complanata* (10.2%). In the 10 year old spoil (Table 6.9) maximum contribution was made by *Ischaemum geobellii* (36.3%) followed by *Dicranopteris linearis* (15.7%) and *Axonopus compressus* (10.6%). On the 5 year old spoil (Table 6.9) *Dicranopteris linearis* contributed the maximum value (64.4%) followed by *Osbeckia crinita* (19.6%). On the 2 year old spoil *Ischaemum geobellii* contributed the maximum value (13.8%) followed by *Osbeckia crinita* (9.4%).

DISCUSSION

Nutrient status, texture and water holding capacity of soil are among the important factors that determine the biomass production on coal mine spoils. Plant density and growth behaviour of dominant species also play an important role in influencing biomass accumulation. The increase in total biomass (aboveground+belowground) with spoil age, can be attributed to increased nutrient accumulation and increased water holding capacity of these spoils with age (see Chapter IV). JOHNSON *et al* (1982) found that older sites which contained high calcium and nitrogen had higher biomass, but on sites with less favourable conditions biomass remained low for several years. FYLES *et al.* (1985) reported that the peak standing crop of a 6 year old unfertilised mine spoil in Canadian Rockies approached that of the native grassland. PANDEY & SINGH (1985) working on a disturbed ecosystem also reported an increase in biomass over time and after 40 years the biomass was not different from the corresponding reference site. In the present study, however, total biomass of even a 10 year old spoil was still much lower than that of the control site. Thus, it appears that it would take much longer for these spoils to become comparable to the unmined (control) site. Unfortunately, the coal mine spoils of more than 10 years age were not available in the nearby areas for study and so, it is not possible to state as to how long these spoils would take to recover fully.

The increase in biomass with age has also been reported in other mine spoils like China clay wastes (MARRS *et al.* 1980 and ROBERTS *et al.* 1981). ROBERTS *et al.* (1981) reported that even after seven years of abandonment the biomass production on the mine spoils was much lower than that on the undisturbed sites. The aboveground biomass increased with spoil age and was maximum on the control site in all seasons except during spring where the aboveground biomass of the control site was lower than that of the 10 year old spoil. The low aboveground biomass on the control site during spring can be attributed to the partial burning of the native vegetation during this period. Maximum aboveground biomass was recorded on all sites during the rainy season possibly due to the fact that most of the species growing on the control site have attained their peak growth. With the onset of winter the aboveground biomass decreased due to the death and shattering of annual plants and tillers of perennial grasses following maturity. The increase in aboveground biomass during spring can be attributed to the new growths triggered by the early showers during this season. Maximum dead biomass was recorded during winter presumably due to the transfer of the live biomass of the annual plants and tillers of the perennial grasses into this compartment after they completed their life cycle (SINGH & YADAV 1974). The values of the aboveground biomass of the vegetation growing on the different ages of coal mine spoils are similar to those reported by JHA & SINGH (1992).

Belowground biomass also increased with age, which is in agreement with JHA & SINGH (1992). However, the belowground biomass values for different ages of coal mine spoils reported by them were much higher than those recorded in the present study. WYATT *et al.* (1980) reported that root biomass in old spoils of Northern Great Plains was nearly three times greater than that in the new spoils. Generally, naturally revegetated spoils have lower values of root biomass that fertilised spoils (HOLECHEK 1982, FYLES *et al.* 1985, FYLES & McGILL 1987). The higher belowground biomass in the 10 year old spoil observed in the present study indicates some degree of stablisation with increase in age of the spoils. ARUNACHALAM *et al.* (1995) also reported increased belowground biomass with age on a disturbed ecosystem.

Belowground to aboveground biomass ratio in the 2 year old spoil was very high during winter (4.2) and spring (4.1). As suggested by CHAPIN III (1980), high belowground to aboveground biomass ratio in nutrient poor habitats is a phenotypic response to reduced nutrient availability and increased root longevity. BERNSTEIN (1975) also believed it to be an adaptive strategy to increase the ratio of water absorbing to water transpiring organs.

On the control site most of the aboveground biomass was contributed by a relatively smaller number of species, i.e. dominant species during the winter and spring. But the contribution of dominant species to the total aboveground biomass was low during the rainy season probably because, a relatively greater number of species which grew during this season contributed significantly to the total aboveground biomass. On coal mine spoils, however, only few species contributed a very high percentage to the aboveground biomass through all the seasons. This can be attributed to lower species content on these spoils and the apportionment of resources to only a few species.

On the control site, the contribution of *Eragrostiella leioptera* during the rainy season to the aboveground biomass was 11.4% but its contribution decreased in winter and spring. This is due to its death during winter. During spring since it had just sprouted from its rhizome, it did not contribute much to the total aboveground biomass. During winter and spring, maximum contribution was by *Ischaemum geobellii* and *Osbeckia crinita.*

On the 10 year old spoil, *Axonopus compressus* contributed more than 20% of the aboveground biomass. This can be attributed to its growth characteristics. *Axonopus compressus* being a stoloniferous species, gives out fibrous roots at every node which bind the soil particles and capture the available nutrients from the soil more efficiently. Hence, it grows on coal mine spoils better than other species. *Dicranopteris linearis* contributed more than 70% of the total aboveground biomass on the 5 year old spoil. This can also be attributed to its growth characteristics. *Dicranopteris linearis* spreads in all directions with the help of its creeping rhizome and gives out fibrous roots throughout its length. As reported by RIES & DEPUIT (1984), fibrous roots have greater binding capacity in unstable mine spoils.

Total primary productivity (ANP+BNP) increased considerably with the age of the spoil. This is in agreement with SCHAFER (1984) who reported direct relationship between spoil age and increased productivity in Northern Great Plain. However, DEPUIT (1978) reported a fall in productivity with age which is at variance with the findings of the present study. Better productivity was also reported by HOFMAN *et al.* (1981, 1983) in revegetated mined land than in non mined land in North Dakota.

On the younger spoils, aboveground primary productivity (ANP) was higher than the belowground productivity (BNP) while on the 10 year old spoil and the control site, ANP was lower than BNP. This indicates that the communities growing on the 10 year old spoil and the control site allocate more resources to the belowground compartment. Better productivity on the 10 year old spoil than the 2 year and 5 year old spoils can be attributed to the greater stand density and better growth of the species growing on the older site. This is in contrast with several studies where the net primary productivity has been reported to decrease as the community matures (DEPUIT *et al.* 1978).

Table 6.1 - Seasonal variation in aboveground (Ag), belowground (Bg) and total (T) biomass (g m^{-2}), and belowground t To aboveground ratio (Bg:Ag) in coal mine spoils of different ages and the control site.

					Age of Coal mine spoil (years)											
	Control site				10				5				2			
Season	Ag	Bg	T	Bg:Ag	Ag	Bg	T	Bg:Ag	Ag	Bg	T	Bg:Ag	Ag	Bg	T	Bg:Ag
Rainy	272.2	687.8	960.0	2.5	206.5	277.9	484.4	0.7	167.1	125.0	292.1	0.8	49.5	96.6	146.1	2.0
Winter	190.2	325.8	516.0	1.7	183.7	189.4	373.1	1.0	155.5	102.0	257.5	0.7	20.5	86.6	107.1	4.2
Spring	154.5	400.5	555.0	2.6	195.2	204.2	399.4	1.1	158.3	119.5	277.8	0.8	23.1	93.7	116.9	4.1
Mean	205.6	471.4	677.0	2.3	195.1	223.8	419.0	0.9	160.3	115.5	275.8	0.7	31.0	92.3	123.3	3.4

Table 6.2 - Percentage distribution of aboveground biomass between live and dead in coal mine spoils of different ages and the control site.

	Control site		Age of Coal mine spoil (years)					
			10		5		2	
Season	Live	Standing Dead	Live	Standing Dead	Live	Standing Dead	Live	Standing Dead
Rainy	66.5	33.5	76.6	23.4	71.2	28.8	86.6	13.4
Winter	32.4	67.6	43.4	56.6	40.7	59.3	26.9	73.1
Spring	51.6	48.4	53.1	46.9	68.5	31.5	63.1	36.9
Mean	50.2	49.8	57.7	42.3	60.1	39.9	58.9	41.1

Table 6.3 - Percentage distribution of belowground biomass between root and rhizome in coal mine spoils of different ages and the control.

	Control site		Age of Coal mine spoil (years)					
			10		5		2	
Season	Root	Rhizome	Root	Rhizome	Root	Rhizome	Root	Rhizome
Rainy	76.6	23.5	65.1	34.9	79.0	21.0	64.4	35.6
Winter	63.1	36.9	46.0	54.0	78.6	21.4	50.8	49.2
Spring	55.0	45.0	56.9	43.1	79.6	20.4	64.2	35.9
Mean	64.9	35.1	56.0	44.0	79.1	20.9	59.8	40.2

Table 6.4 - Seasonal variation in live, standing dead and total aboveground biomass (g m^{-2}) of important species growing on coal mine spoils of different ages and the control site.

Species	Rainy			Winter			Spring		
	Live	Standing Dead	Total	Live	Standing Dead	Total	Live	Standing Dead	Total
Control site									
Eragrostiella leioptera	39.9	0.2	39.1	3.4	10.0	13.4	6.1	0.0	6.1
	±12.4	±0.1	±12.5	±1.1	±5.6	±6.7	±2.1	±0.2	±2.1
Fimbristylis complanata	11.1	2.2	13.3	1.1	8.5	9.6	20.2	1.4	21.6
	±8.6	±0.1	±8.7	±0.3	±7.6	±7.8	±5.6	±0.7	±6.4
Ischaemum geobellii	36.1	0.5	36.6	15.9	14.4	30.3	25.0	5.6	30.6
	±22.3	±0.1	±22.4	±5.1	±8.7	±13.3	±10.2	±2.3	±12.5
Osbeckia crinita	12.8	1.2	14.0	16.4	4.5	20.9	22.8	2.5	25.3
	±3.6	±0.2	±3.8	±4.7	±3.0	±7.7	±9.6	±1.2	±10.8
Total	**98.8**	**4.1**	**103.0**	**36.8**	**37.4**	**74.2**	**74.2**	**9.5**	**83.7**
10 year old spoil									
Axonopus compressus	30.9	12.3	43.2	17.6	29.6	47.2	18.8	31.8	50.6
	±13.2	±5.2	±18.4	±11.0	±5.1	±16.1	±10.0	±11.5	±21.5
Chrysopogon gryllus	3.7	2.9	6.6	0.7	1.0	1.8	11.1	5.3	16.4
	±1.6	±1.2	±2.8	±0.2	±0.3	±0.5	±3.9	±3.6	±7.0
Dicranopteris linearis	8.4	1.2	9.6	20.0	11.5	31.5	20.8	3.5	24.3
	±3.7	±0.5	±4.2	±7.5	±3.8	±11.3	±7.8	±2.1	±9.9
Ischaemum geobellii	50.0	12.6	62.6	4.6	5.4	10.0	6.2	8.5	14.7
	±13.2	±3.7	±16.9	±2.0	±3.1	±5.1	±3.4	±3.1	±6.5
Osbeckia crinita	16.6	12.3	28.9	11.6	1.7	13.3	16.3	1.2	17.5
	±6.1	±6.7	±12.8	±5.3	±1.0	±6.3	±5.7	±0.8	±6.5
Total	**109.6**	**41.3**	**150.9**	**54.5**	**49.2**	**103.8**	**73.2**	**50.3**	**123.5**
5 year old spoil									
Dicranopteris linearis	94.8	40.7	135.5	48.2	61.9	110.1	85.8	30.4	116.2
	±15.9	±17.5	±33.4	±16.1	±26.5	±42.6	±20.1	±7.2	±27.3
Osbeckia crinita	13.0	2.5	15.5	5.3	0.3	5.6	1.2	0.4	1.6
	±2.4	±1.8	±4.2	±3.2	±0.2	±3.4	±0.8	±0.2	±1.0
Total	**107.8**	**43.2**	**151.0**	**53.5**	**62.2**	**115.7**	**87.0**	**30.8**	**117.8**
2 year old spoil									
Ischaemum geobellii	1.6	0.8	2.4	3.8	5.6	9.4	2.2	6.9	9.1
	±0.6	±0.0	±0.6	±1.1	±2.6	±3.7	±0.5	±2.4	±2.9
Osbeckia crinita	5.6	0.2	5.8	1.0	1.6	2.6	1.2	0.1	1.3
	±3.1	±0.0	±3.1	±0.6	±0.7	±1.3	±0.6	±0.0	±0.0
Total	**7.2**	**1.0**	**8.2**	**4.8**	**7.2**	**12.0**	**3.4**	**7.0**	**10.4**

Table 6.5 - Percentage contribution of dominant species to the total aboveground biomass in coal mine spoils of different ages and the control site.

Species	Seasons		
	Rainy	Winter	Spring
Control site			
Eragrostiella leioptera	14.4	7.0	4.0
Fimbristylis complanata	4.9	5.1	14.0
Ischaemum geobellii	13.5	15.9	19.8
Osbeckia crinita	5.1	11.0	16.4
Total	37.8	39.0	54.1
10 year old spoil			
Axonopus compressus	20.9	25.7	25.9
Chrysopogon gryllus	3.2	1.0	8.4
Dicranopteris linearis	4.6	17.2	12.5
Ischaemum geobellii	30.3	5.5	7.5
Osbeckia crinita	14.0	7.2	9.0
Total	73.0	56.5	63.3
5 year old spoil			
Dicranopteris linearis	87.1	77.2	73.4
Osbeckia crinita	9.3	3.6	1.0
Total	96.3	80.8	74.4
2 year old spoil			
Ischaemum geobellii	4.9	46.0	39.5
Osbeckia crinita	11.7	12.5	5.6
Total	16.6	58.5	45.1

Table 6.6 - Root (RNP) and rhizome (RhNP) productivity (g m^{-2} yr^{-1}) in coal mine spoils of different aages and the control site.

Compartment	Control site	Age of coal mine spoil (years)		
		10	5	2
Root	320.9	93.7	18.6	18.2
Rhizome	60.2	91.1	4.4	9.0

Table 6.7 - Aboveground (ANP), belowground (BNP) and total (TNP) primary productivity (g m^{-2} yr^{-1}) in coal mine spoils of different ages and the control site.

Productivity	Control site	Age of coal mine spoil (years)		
		10	5	2
ANP	186.8	145.0	72.8	50.7
BNP	381.1	184.8	23.0	27.2
TNP	567.9	329.8	95.8	77.9

Table 6.8 - Aboveground net primary productivity (ANP) of important species in coal mine spoils of different ages and the control site.

Species	ANP (g m^{-2} yr^{-1})
Control site	
Eragrostiella leioptera	35.7
Fimbristylis complanata	19.1
Ischaemum geobellii	20.2
Osbeckia crinita	13.4
Total	88.4
10 year old spoil	
Axonopus compressus	15.4
Chrysopogon gryllus	14.7
Dicranopteris linearis	22.7
Ischaemum geobellii	52.6
Osbeckia crinita	16.1
Total	121.5
5 year old spoil	
Dicranopteris linearis	46.9
Osbeckia crinita	14.2
Total	61.1
2 year old spoil	
Ischaemum geobellii	7.0
Osbeckia crinita	4.8
Total	11.8

Table 6.9 - Percentage contribution of dominant species to the total aboveground primary productivity (ANP) in coal mine spoils of different ages and the control.

Species	% Contribution
Control site	
Eragrostiella leioptera	19.12
Fimbristylis complanata	10.21
Ischaemum geobellii	10.84
Osbeckia crinita	7.16
Total	47.33
10 year old spoil	
Axonopus compressus	10.62
Chrysopogon gryllus	10.14
Dicranopteris linearis	15.65
Ischaemum geobellii	36.29
Osbeckia crinita	11.08
Total	83.78
5 year old spoil	
Dicranopteris linearis	64.40
Osbeckia crinita	19.57
Total	83.97
2 year old spoil	
Ischaemum geobellii	13.84
Osbeckia crinita	9.36
Total	23.20

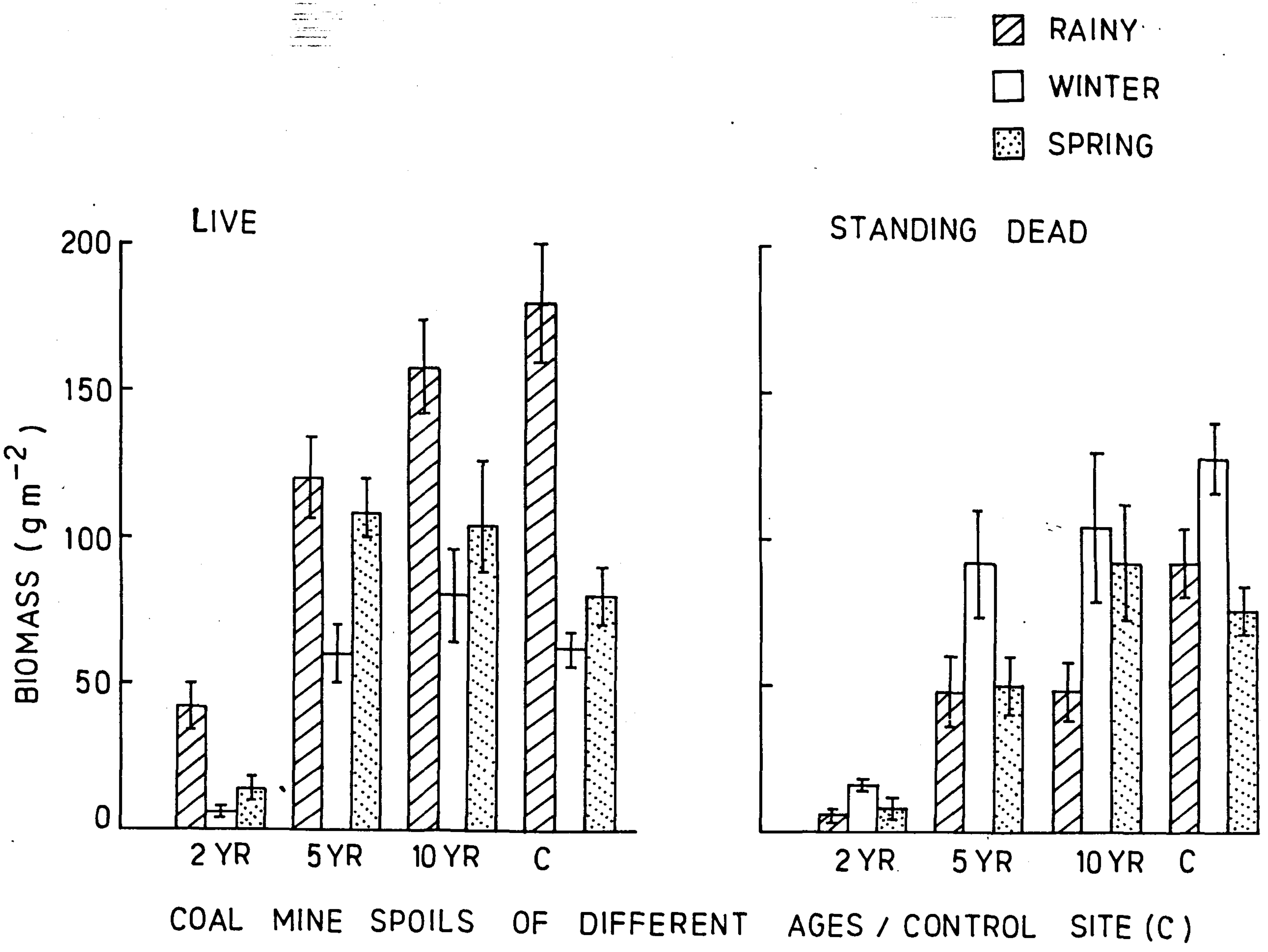


Fig. 6.1 - Seasonal variation in aboveground live and standing dead biomass (g m^{-2}) of plant species growing on coal mine spoils of different ages and the control site (C). Vertical bars represent standard error of the mean.

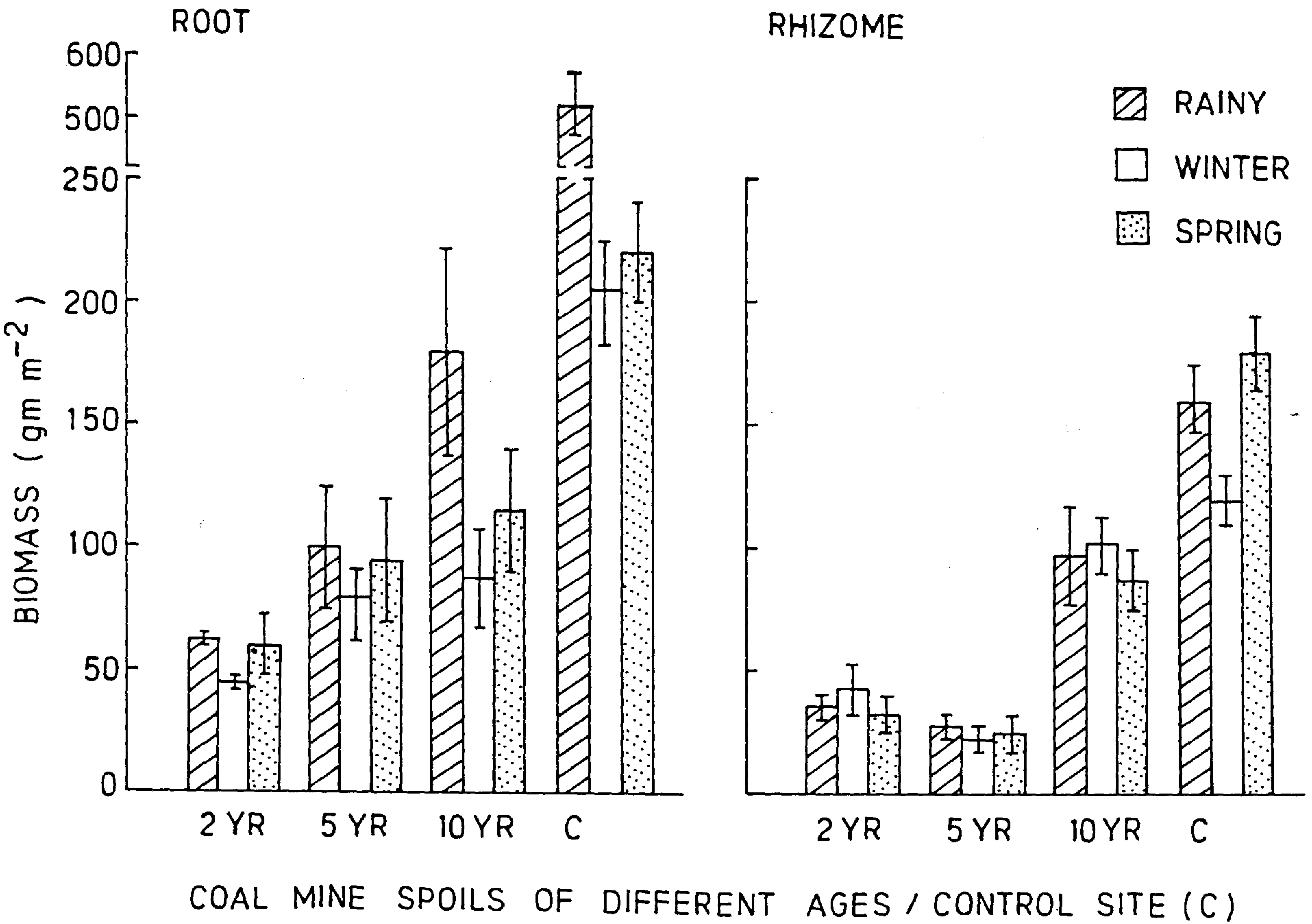


Fig. 6.2 - Seasonal variation in root and rhizome biomass (g m^{-2}) of plant species growing on coal mine spoils of different ages and the control site (C). Vertical bars represent standard error of the mean.

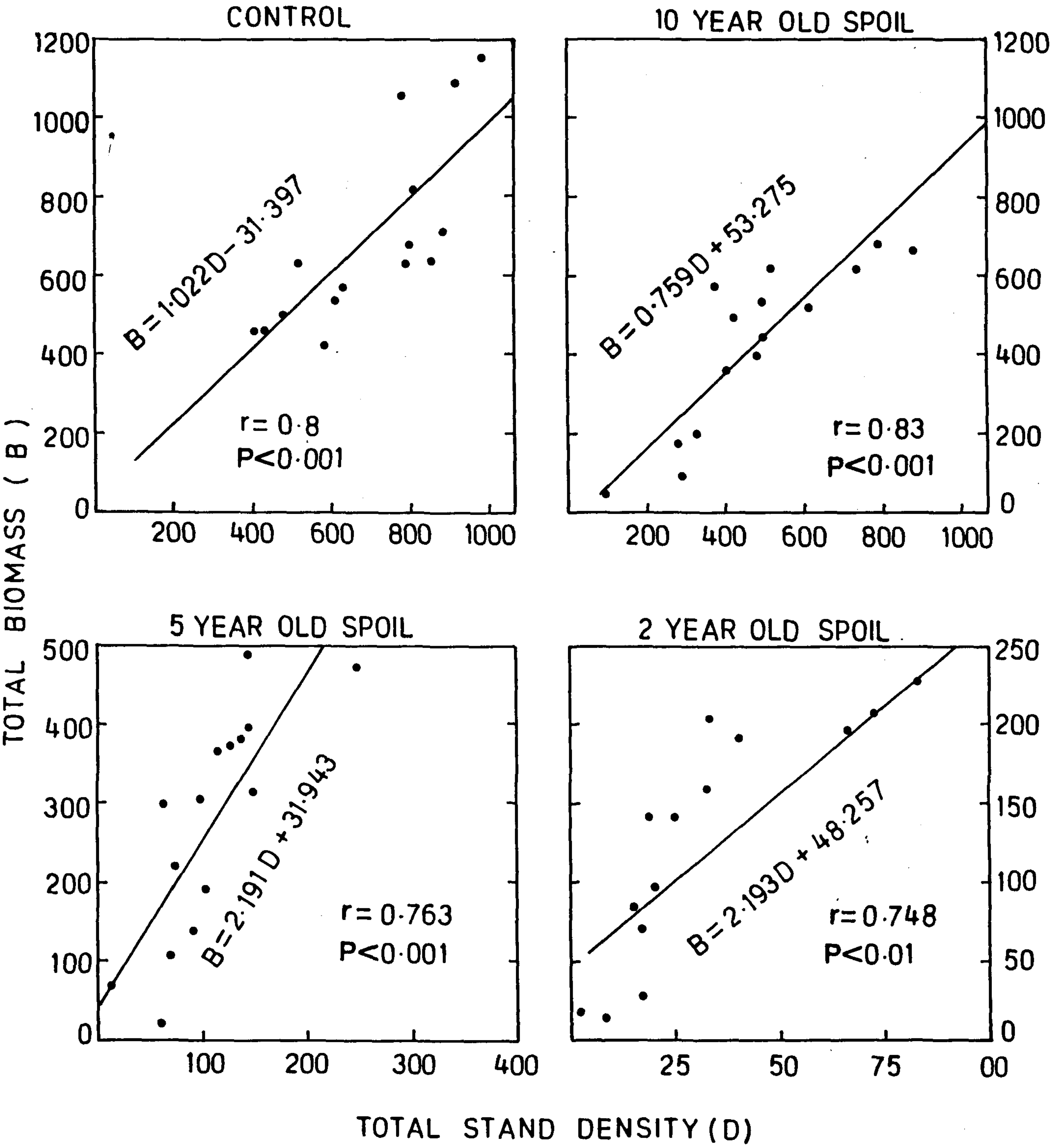


Fig. 6.3 - Relationship between total biomass (B) and total stand Density (D) of plant species growing on coal mine spoils of different ages and the control site.

CHAPTER 7

NUTRIENT COMPARTMENTATION

INTRODUCTION

Of all the macro-nutrients, nitrogen, phosphorus and potassium are the most important. The level of their availability in a utilizable form largely determines the growth of plants. Nitrogen is extremely important in controlling biomass production. It is an essential constituent of protoplasm. Phosphorus like nitrogen, is an essential constituent of protoplasm and often limits biomass production due to its lesser availability. Its large reservoir is in the storage pool represented by phosphate rocks. Potassium is also one of the essential elements in the nutrition of plants and is commonly in short supply to limit production. It is essential for photosynthesis and for protein synthesis. It exists in soil in available solution pool which is in equilibrium with exchangeable potassium adsorbed on colloidal particles.

These nutrients from the available pool in the soil enter the vegetation through the root system. Their uptake by the plant depends upon their availability in the soil pool, soil texture and soil moisture regime and on nutrient uptake capacity of the root system. After their absorption, they are partitioned into different compartments of vegetation. They are also retained in the dead organs of the plant and are finally returned into the soil as litter and root detritus. Subsequent transformation leads to mineralization of the dead organic matter; carbon is released to the atmosphere in the form of carbon dioxide and minerals are returned to the soil nutrient pool. Potassium is released primarily by physical weathering processes called leaching *i.e.* removal from plants by the action of acqueous solutions associated with rain, dew, mist etc.

The accumulation of nutrients in different compartments of an ecosystem *viz.* vegetation and the soil compartments has been identified as an important part of ecosystem development in both natually colonized (CROCKER & MAJOR 1955, DANCER *et al.* 1977, ROBERTS *et al.* 1981, MARRS *et al.* 1981) and reclaimed environments (BRADSHAW *et al.* 1975, MARRS & BRADSHAW 1982). In well developed stable ecosystems, productivity and nutrient cycling are assumed to be in equilibrium. In contrast, coal mine spoils are severely deficient in nutrients (HANDLEY *et al.* 1978, BRADSHAW & CHACKWICK 1980, IVERSON & WALI 1992) and the development of ecosystems on these spoils is limited by poor nutrient supply.

Compartmentation and cycling of nutrients have been investigated in long established stable ecosystems like forests (VOGT *et al.* 1986) heathlands (GIMMINGHAM 1972), grasslands (BUSHBACHER *et al.* 1988, UMA SHANKAR 1991) and secondary successional communities (TOKY & RAMAKRISHNAN 1983). Very few studies (MARRS *et al.* 1981, ROBERTS *et al.* 1981) have been conducted on the compartmentation and utilization of nutrients in developing ecosystems during primary succession. In the developing chronosequences, productivity and nutrient cycling are not in *equilibrium, and hence, the process involved in ecosystem functioning may be very much different from those in well developed ecosystems.

In this chapter an attempt has been made to ascertain the developemental changes in the compartmentation of three essential nutrients *viz.* nitrogen, phosphorus and potassium during colonization and successional changes in vegetation on naturally recovering coal mine spoils.

MATERIALS AND METHODS

Nutrient concentration in the samples of each component of the vegetation *viz* live green and standing dead of the aboveground component and root and rhizome of the belowground component was determined at all sites. The samples used for determining the biomass and productivity in Chapter 6, were analysed for nitrogen, phosphorus and potassium. The oven-dried samples were ground in a Wiley mill to pass through a 1 mm mesh screen and stored in polythene bags for determining nitrogen, phosphorus and potassium concentration. The nitrogen concentration of the ground samples was determined by micro-Kjeldahl procedure (ALLEN *et al.* 1974) after digesting the ground sample with conc H_2SO_4 using K_2SO_4 and HgO catalyst mixture in a block digester. Distillation and titration were done simultaneously in a Tecator Kjeltec Auto 1030 Analyser. Mixed acid digestion procedure (ALLEN *et al.* 1974) was followed for the determination of phosphorus and potassium. Phosphorus was determined by molybdenum blue method (ALLEN *et al.* 1974). Potassium was determined by a Perkin Elmer 2380 atomic absorption spectrophotometer. All anlayses were run in triplicates. Nutrient concentration was corrected to oven dry weight basis. The standing state of nutrients (g m^{-1}) was computed from mean biomass value of different vegetation compartments and their corresponding nutrient concentration. To estimate the rate of nutrient accumulation, linear regression equations were calculated against spoil age by using raw data. Regression coefficients obtained were used as crude estimates of accumulation rate (ROBERTS *et al.* 1981).

Nutrient content of some dominant species at all sites was also determined.

RESULTS

N, P, K concentration in the belowground parts

Seasonal variation in nutrient concentration in the root and rhizome fractions of the belowground compartments of vegetation in the mine spoils of different ages and the control site are shown in Table 7.1. In the control site there was no significant seasonal variation in N concentration in both root and rhizome. But concentration in rhizome was much higher than in the root. In the 10 year old spoil, N concentration in root was lowest during the rainy season and highest during spring. In the rhizome, there was no singificant difference in N concentration with the change in season. During winter and spring the concentration in rhizome was significantly lower than in the root. In the 5 year old spoil, there was no significant difference in nitrogen concentration in roots between the rainy and winter seasons, but the concentration was significantly greater during spring. In rhizome, the concentration was lowest during winter and highest during spring. During winter season, the concentration in root was significantly greater than in rhizome. In the 2 year old spoil no significant difference was observed in N concentration in roots with the change of season. But in rhizome the concentration was highest during the rainy season.

Mean N concentration in roots was lowest in the 2 year old spoil and it increased significantly with spoil age. But concentration in the control site was lower than in the 5 year and 10 year old spoil. Mean N concentration in rhizome was highest in the control site and it decreased in the mine spoils of different ages. Mean concentration of N in roots were 0.629%, 0.798%, 0.92%, 0.643% for 2 year, 5 year and 10 year old mine spoils and control site, respectively, and the corresponding values for nitrogen concentration in rhizome were 0.818%, 0.709%, 0.526% and 0.838%.

On the control site, P concentration in both root and rhizome was highest during rainy season and it registered a gradual decrease in winter and spring. The concentration was more in rhizome than in root except in winter where the difference in concentration in the two plant parts was not significantly different. On the 5 year and 10 year old spoils too, P concentration was highest in rainy season in both root and rhizome. It decreased in winter but again increased in spring. On the 10 year old spoil P concentration in rhizome was more than that in the root, while the reverse was generally true in the case of the 5 year old spoil. On the 2 year old spoil, P concentration was highest in winter and lowest in spring in both root and rhizome. During rainy and winter seasons, P concentration was higher in rhizome than in root. But in spring it was significantly higher in root than in rhizome.

Phosphorus concentration in both root and rhizome was not related to age of the spoil. P concentration in both root and rhizome was lowest in the 5 year old spoil and highest in the 2 year old spoil. But on the control site the concentration was much higher than the spoils. Mean concentration of P in root was *ca.* 312, 94, 239, 416 μg g^{-1} for the 2 year, 5 year and 10 year old spoils and the control site, respectively, while the corresponding values for P concentration in rhizome were *ca.* 353, 78, 288 and 423 μg g^{-1}, respectively.

On the control site, K concentration in the root was highest in winter and lowest in spring. In rhizome, highest value was observed during the rainy season, and lowest in spring. Concentration was much higher in rhizome than in root. On the 10 year old spoil, concentration in root was lowest in the rainy season and highest in spring. In rhizome, it was highest in the rainy season but lowest in winter. Concentration in rhizome was much higher than that in the root. On the 5 year old spoil, concentration was lowest in the rainy season in both root and rhizome. In the root, highest value was observed during spring, while in the rhizome, it was observed during winter. Concentration was more in the rhizome than in the root except in the spring. In the 2 year old spoil, K concentration was highest in winter and lowest in spring in both root and rhizome. The concentration was more in the rhizome than in the root, except during winter where it was more in the root.

In the root, mean K concentration was lowest in the 2 year old spoil, it increased in the 5 year old spoil but it showed no change from the 5 year to the 10 year old spoil. K concentration in the belowground parts was more in the control site than on the spoils. The concentration in rhizome was lowest on the 2 year old spoil and it increased on the older spoils. However, the concentration on the control site was lower than that on the 10 year old spoil. Mean concentration in roots was *ca.* 1.9, 2.1, 2.1 and 1.4 mg g^{-1} on the 2 year, 5 year and 10 year old spoils and the control site, respectively and the corresponding values for K concentration in rhizomes were *ca.* 1.3, 2.2, 3.3 and 3.1 mg g^{-1}.

N, P, K concentration in the aboveground parts

Seasonal variation in nutrient concentration in the aboveground compartment of vegetation on the coal mine spoils and the control site are given in Table 7.2. The effect of season on nitrogen concentration was very strong in the mine spoils and the control site. On the control site, nitrogen concentration was maximum during spring in both live and dead compartments. In the live compartment, minimum value was observed during winter, while in the dead compartment it was observed during the rainy season. The concentration in the live compartment was much higher than that in the dead. In the case of 10 year old spoil, nitrogen concentration was highest in spring and lowest in winter, but in the dead compartment, it was highest in winter and lowest in spring. The concentration in live compartment was much higher than that in the dead. In the 5 year old spoil, maximum value was observed during spring and minimum during winter in both live and dead compartments. Nitrogen concentration was much higher in the live compartment than in the dead. In the 2 year old spoil too maximum nitrogen concentration was observed during spring in both live and dead compartments. The minimum values in the live and dead compartments were observed during winter and rainy seasons, respectively.

Mean nitrogen concentration in both live and dead compartments was not related to the spoil age. Thus, in the live compartment, the concentration was much higher on the young spoils than on the older spoils. Further the concentration on the control site was lower than that on the spoils. The concentration in the dead compartment was maximum in the 5 year old spoil. There was no significant difference in the concentration in rhizome between the 2 year and 10 year old spoils. But concentration on the control site was much lower than that of the spoils.

The effect of season on phosphorus concentration in the aboveground parts was quite strong on all sites. On the control site, phosphorus concentration in the live compartment was maximum during spring while in the dead compartment, it was maximum during rainy season. The minimum values were recorded during winter in the live, and during spring in the dead compartment. The concentration was much higher in the live than in the dead compartment. On the 10 year old spoil maximum phosphorus concentration was observed during the rainy season in both live and dead compartments, while minimum value was observed during spring in the live compartment, and during winter in the dead compartment. Phosphorus concentration was much higher in the live compartment than in the dead compartment. On the 5 year old spoil, maximum concentration was observed during winter in both live and dead compartments. The minimum values on the other hand, were recorded either during the rainy season (for the live compartment) or during spring (for the dead compartment). The concentration was much higher in the live compartment compared to the dead. On the 2 year old spoil, maximum concentration was recorded during winter in both live and dead compartments, and minimum values were recorded either during spring (in the live compartment) or during rainy season (in the dead compartment). The concentration in the live compartment was much higher than that in the dead.

Mean phosphorus concentration in the live compartment showed a decreasing trend with the age of the spoil, while in the dead compartment it showed a reverse trend. The concentration on the control site, however, was much lower than that on the spoils in both live and dead compartments. Mean phosphorus concentration in the live compartment was *ca.* 371, 355, 332, 323 $\mu g\ g^{-1}$ on the 2 year, 5 year and 10 year old spoils and the control site, respectively, while the corresponding values in the dead compartment were much lower *ca.* 202, 221, 241 and 155 $\mu g\ g^{-1}$.

Distinct seasonality in potassium concentration was observed at all sites in both live and dead compartments. On the control site, maximum potassium concentration was observed during winter in the live compartment and during rainy season in the dead compartment. The minimum concentration was observed either during the rainy season (in the live compartment) or during winter (in the dead compartment). Potassium concentration in the live compartment was more than 2 times that in the dead. In the case of 10 year old spoil, maximum value was observed during winter in both live and dead compartments, while minimum value was observed during rainy season for the live compartment and during spring for the dead compartment. Potassium concentration in the live compartment was more than 2 times that in the dead. On the 5 year old spoil, maximum concentration was recorded during spring and minimum during winter in the live compartment, whereas in the dead compartment the maximum and minimum concentrations were recorded during winter and spring, respectively. Potassium concentration in the live compartment was much higher than that in the dead. A similar trend was observed on the 2 year old spoil as well.

There was no relationship between mean K concentration in live compartment with the age of the spoil. The concentration of potassium in the live compartment on the 2 year old spoil was more than that on the 5 year old spoil, and the concentration on the 10 year old spoil was even more than that on the control site.

Mean K concentration in the dead compartment was lowest in the 2 year old spoil and it increased with spoil age. But concentration in the control site was much lower than that on the 5 year and 10 year old spoils. Mean K concentration in the live compartment (3.7-4.7 mg g^{-1}) was much greater than that in the dead compartment (1.4-2.4 mg g^{-1}).

Nutrient concentration in dominant species

Seasonal variation in nutrient concentration in the dominant species found the both coal mine spoils and the control site are presented in Table 7.3-7.6.

Nitrogen concentration (Table 7.3)

N concentration in the dominant species of the control site *viz. Eragrostiella leioptera, Fimbristylis complanata, Ischaemum geobellii* and *Osbeckia crinita*, varied considerably with season. The concentration in the live compartment was higher during spring for *Eragrostiella leioptera* and *Ischaemum geobellii* while it was higher during the rainy season for *Fimbristylis complanata* and *Osbeckia crinita*. The N concentration in live compartment of each of these species was significantly higher ($P<0.01$) than in the dead compartment in all the seasons except during winter in the case of *Osbeckia crinita* where the concentration in the dead compartment was higher than that in the live compartment. Due to mild annual fire during winter, dead biomass of *E. leioptera* was not available during spring. There was no significant difference in N concentration in the dead compartment between rainy and winter seasons. In the dead compartment of *Fimbristylis complanata* and *Ischaemum geobellii* much higher concentration was observed during spring compared to other seasons. But in the dead compartment of *Osbeckia crinita* higher concentration was observed during winter compared to the other seasons. The highest mean nitrogen concentration was recorded in *Ischaemum geobellii* (Table 7.6).

On the 10 year old spoil (Table 7.3) N concentration in the individual dominant species *viz. Axonopus compressus, Chrysopogon gryllus, Dicranopteris linearis, Ischaemum geobellii* and *Osbeckia crinita* varied considerably with the change of seasons. The concentration in the live compartment was higher during the rainy season for *Axonopus compressus, Dicranopteris linearis* and

Osbeckia crinita, while in the case of *Chrysopogon gryllus* and *Ischaemum geobellii* it was higher during spring. There was not much seasonal variation in N concentration in the dead compartment except in *Dicranopteris linearis* and *Osbeckia crinita*. In *D. linearis* N concentration was higher during rainy season and in *O. crinita* it was much higher during winter than in other seasons. The highest mean N concentration was recorded in *Dicranopteris linearis* (Table 7.6).

On the 5 year old spoil (Table 7.3), there was no significant variation in N concentration in the live compartment of the two dominant species *viz.*, *Dicranopteris linearis* and *Osbeckia crinita* between the rainy and the spring seasons. The concentration in the live compartment of both species was much lower during winter than in other seasons. Concentration in dead compartment of *D. linearis* did not vary much with season but in *O. crinita* N concentration was much higher during winter compared to other seasons. The highest mean N concentration was recorded in *D. linearis* (Table 7.6).

On the 2 year old spoil (Table 7.3), N concentration in the dominant species *viz.* *Ischaemum geobellii* and *Osbeckia crinita* showed wide seasonal variation. In both live and dead compartments of *Ischaemum geobellii* highest concentration was recorded during spring. But in *Osbeckia crinita*, it was recorded during rainy season in the live compartment and during winter in the dead compartment. The highest mean N concentration (live and dead compartments considered together) was recorded in *Ischaemum geobellii* (Table 7.6).

Phosphorus concentration (Table 7.4)

P concentration in the live and dead compartments of dominant species was found to vary considerably with season. On the control site (Table 7.4), in *Eragrostiella leioptera*, highest P concentration was recorded during rainy season in the live compartment and during winter in the dead compartment. In *Fimbristylis complanata* highest concentration was observed during spring in both live and dead compartments. In *Ischaemum geobellii*, highest concentration was observed in winter. The concentration in the live compartment of each of these species was more than the concentration in the dead compartment. The highest mean phosphorus (live+dead) was recorded in *Eragrostiella leioptera* (Table 7.6).

On the 10 year old spoil (Table 7.4) highest P concentration was recorded during spring in the live and during rainy season in the dead compartment of *Axonopus compressus* and *Osbeckia crinita.* In *Chrysopogon gryllus* highest concentration was recorded during rainy season in both the live and dead compartments. In *Dicranopteris linearis* and *Ischaemum geobellii* highest concentration in the live compartment was recorded during the rainy season. However, in the dead compartment highest concentration was recorded during spring in *Dicranopteris linearis* and during winter in *Ischaemum geobellii.* In most cases, concentration in live compartment was more than in the dead except in *Axonopus compressus* during the rainy season and *Chrysopogon grullus* and *Dicronopteris linearis* in spring, where the concentration was more in the dead compartment. Highest mean P concentration (live+dead) was recorded in *Chrysopogon gryllus* (Table 7.6).

On the 5 year old spoil (Table 7.4) the P concentration in the live compartment of dominant species did not vary much with season. Maximum concentration was recorded during winter in the live and during rainy season in the dead compartment of *Dicranopteris linearis*. In *Osbeckia crinita* maximum concentration was recorded during winter in both live and dead compartments. The P concentration in the live compartment was much higher than in the dead except during winter where the concentration in *Osbeckia crinita* was more in the dead compartment than in the live. Highest mean P concentration (live+dead) was found in *Osbeckia crinita* (Table 7.6).

In contrast to the 5 year old spoil, P concentration on the 2 year old spoil varied considerably with the change in season (Table 7.4). In *Ischaemum geobellii* concentration in the live compartment was maximum during rainy season while in the dead compartment it was maximum during winter. In *Osbeckis crinita* concentration in both live and dead biomass was maximum in winter. In both species P concentration in the live biomass was much higher than in the dead biomass. Highest mean P concentration (live+dead) was found in *Ischaemum geobellii*.

Potassium concentration (Table 7.5)

Seasonal variation in potassium concentration in the aboveground parts of dominant species growing on both coal mine spoils and the control site. The K concentration in both live and dead compartments varied significantly ($P<0.05$) with season. On the control site, maximum concentration in the live compartment of *Eragrostiella leioptera* was observed during spring while in the dead compartment, the maximum concentration was recorded during rainy season. In *Fimbristylis complanata* and *Ischaemum geobellii* maximum K concentration was recorded during rainy season in both live and dead compartments whereas in *Osbeckia crinita*, it was observed during winter. The concentration of K in the live compartment of each of these species was more than two times the concentration in the dead compartment. The mean concentration of K (live and dead biomass considered together) was maximum in *Osbeckia crinita* (Table 7.6).

On the 10 year old spoil (Table 7.5) maximum K concentration in the live compartment was recorded during rainy season in *Axonopus compressus*, *Dicranopteris linearis* and *Ischaemum geobellii*, however, in *Chrysopogon gryllus* and *Osbeckia crinita* the maximum concentration was recorded during winter. In the dead compartment maximum concentration was observed during rainy season for *Axonopus compressus*, and during winter for *Chrysopogon gryllus*, *Dicranopteris linearis*, *Ischaemum geobellii* and *Osbeckia crinita*. K concentration in the live compartment of each of the dominant species was more than two times the concentration in the dead compartment. Among the dominant species growing on this spoil, the highest mean K concentration (live and dead compartments together) was recorded in *Axonopus compressus* (Table 7.6).

On the 5 year old spoil (Table 7.5) maximum concentration of K in the live biomass was recorded during rainy season for both *Dicranopteris linearis* and *Osbeckia crinita*. However, in the dead compartment, the maximum concentration was recorded during rainy season for *Dicranopteris linearis* and during winter for *Osbeckia crinita*. With the exception of *Osbeckia crinita* during winter where the concentration in the live compartment was slightly higher than that in the dead biomass, the live compartment always had much greater concentration of K as compared to the dead compartment. Highest mean K concentration (live and dead taken together) was recorded in *Osbeckia crinita* (Table 7.6).

On the 2 year old spoil (Table 7.5), maximum concentration of K was recorded during spring in the live compartment and during winter in the dead compartment of both *Ischaemum geobellii* and *Osbeckia crinita*. With the exception of *Osbeckia crinita* during winter where no significant difference was observed between the concentrations in the live and dead biomass, the concentration of K in the live compartment of both species was much higher than that in the dead. Highest mean K concentration (live+dead) was recorded in *Ischaemum geobellii* (Table 7.6).

Nutrient accumulation in the belowground compartments

Seasonal variation in nutrient accumulation in the belowground compartments of vegetation on coal mine spoils and the control site are presented in Fig. 7.1-7.3.

Nitrogen accumulation (Fig 7.1)

The nitrogen accumulation in both root and rhizome on the mine spoils and the control site was not affected by season. However, accumulation in the root compartment was significantly ($P<0.05$) greater than in the rhizome. On the control site, highest accumulation in the root (3296 mg m^{-2}) was during rainy season and in the rhizome (1582 mg m^{-2}) it was highest during spring. The lowest values were recorded during winter in both root (1371 mg m^{-2}) and rhizome (980 mg m^{-2}). On the 10 year old spoil highest accumulation of N in the root (1757 mg m^{-2}) was observed during spring and lowest (587 mg m^{-2}) during winter, while in the case of rhizome highest accumulation (534 mg m^{-2}) was observed during rainy season and lowest (483 mg m^{-2}) during winter. On the 5 year old spoil highest accumulation (1089 mg m^{-2} in root; 266 mg m^{-2} in rhizome) was observed during spring and lowest during winter (500 mg m^{-2} in root; 81 mg m^{-2} in rhizome). On the 2 year old spoil highest accumulation (391 mg m^{-2}) in the root was recorded during spring and lowest (278 mg m^{-2}) during winter. In the rhizome highest value (331 mg m^{-2}) was observed during the rainy season and lowest (253 mg m^{-2}) during spring.

In the root mean accumulation (Table 7.7) was minimum on the 2 year old spoil, it increased with spoil age and was maximum on the control site. In the rhizome, minimum value was observed in the 5 year old spoil. These variations in accumulation in both root and rhizome fractions of the belowground compartment varied significantly with site ($P<0.05$). Mean accumulation of nitrogen (Table 7.7) in the root was 349, 736, 1128, 2023 mg m^{-2} for the 2 year, 5 year and 10 year old spoils and the control site, respectively, whereas in the rhizome the corresponding values were 300, 174, 502, and 1296 mg m^{-2}.

Phosphorus accumulation (Fig 7.2)

Analysis of variance showed no significant effect of season on phosphorus accumulation in both root and rhizome fractions of the belowground compartment. There was also no significant variation in accumulation between root and rhizome. But variation due to site was highly significant ($P<0.01$). On the control site, maximum accumulation (279 mg m^{-2}) in root was recorded during the rainy season and minimum (70 mg m^{-2}) during spring. In the rhizome maximum value (87 mg m^{-2}) was recorded during the rainy season and minimum (47 mg m^{-2}) during winter. On the 10 year old spoil maximum value was recorded during the rainy season in both root (71 mg m^{-2}) and rhizome (39 mg m^{-2}) and minimum (11 mg m^{-2} in root, 13 mg m^{-2} in rhizome) during winter. On the 5 year old spoil too maximum values for root (14 mg m^{-2}) and rhizome (4 mg m^{-2}) were recorded during the rainy season but minimum values was recorded during winter (4 mg m^{-2} in root,1 mg m^{-2} in rhizome). On the 2 year old spoil, however, maximum values for root (19 mg m^{-2}) and rhizome (21 mg m^{-2}) were recorded during winter and minimum during spring (14 mg m^{-2} in root and 5 mg m^{-2} in rhizome). Mean accumulation of phosphorus (Table 7.7) in the root ranged from 9 to 35 mg m^{-2} and in the rhizome it ranged from 5-27 mg m^{-2} on the coal mine spoils. Phosphorus accumulation in both root and rhizome was lowest on the 5 year old spoil and highest on the control site.

Potassium accumulation (Fig 7.3)

Analysis of variance showed significant ($P<0.05$) effect of season on potassium accumulation in both root and rhizome. However, the difference in the accumulation between root and rhizome was not significant. On the control site, maximum value was observed during the rainy season in both root (678 mg m^{-2}) and rhizome (855 mg m^{-2}) and minimum during spring (214 mg m^{-2} in root; 249 mg m^{-2} in rhizome). On the 10 year old spoil maximum value was recorded during rainy season in both root (332 mg m^{-2}) and rhizome (354 mg m^{-2}), while minimum value was observed during winter in the root (179 mg m^{-2}) and during spring in the rhizome (274 mg m^{-2}). On the 5 year old spoil, highest value in the root (253 mg m^{-2}) was recorded during spring, and in the rhizome (58 mg m^{-2}) it was recorded during winter. Lowest K accumulation was observed during the rainy season in both root and rhizome. On the 2 year old spoil maximum values were recorded during winter in both root (159 mg m^{-2}) and rhizome (64 mg m^{-2}) and minimum (50 mg m^{-2} in root; 37 mg m^{-2} in rhizome) during spring. Mean K accumulation in both root and rhizome (Table 7.7) increased significantly ($P<0.01$) with age of the spoils. Mean accumulation in root was 96, 194, 266 and 442 mg m^{-2} and in rhizome it was 50, 53, 314 and 470 mg m^{-2} for the 2 year, 5 year and 10 year old spoils and control site, respectively.

Nutrient accumulation in aboveground compartment

Seasonal variation in nutrient accumulation in the live and dead parts of the aboveground compartment are presented in Fig 7.4-7.6.

Nitrogen accumulation (Fig 7.4)

Analysis of variance showed a very strong effect of season ($P<0.01$) on the nitrogen accumulation in both live and dead fractions of the aboveground compartment at all sites. The variation in the accumulation between the live and dead compartment was also very significant ($P<0.01$), and so was the variation due to site ($P<0.01$). On the control site, maximum nitrogen accumulation (1480 mg m^{-2}) in the live compartment was recorded during the rainy season and minimum (363 mg m^{-2}) during winter. In the dead compartment maximum value (496 mg m^{-2}) was observed during winter and minimum (245 mg m^{-2}) during the rainy season. During the rainy season and spring accumulation was much greater in the live compartment than in the dead, but during winter accumulation was more in the dead than in the live compartment.

On the 10 year old spoil also, a similar trend was observed. On the 5 year old spoil, maximum accumulation (1589 mg m^{-2}) in the live compartment was recorded during spring and minimum (527 mg m^{-2}) during winter. In the dead compartment, however, maximum value (721 mg m^{-2}) was recorded in winter and minimum (379 mg m^{-2}) during the rainy season. On the 2 year old spoil maximum accumulation (465 mg m^{-2}) in the live compartment was recorded during the rainy season and minimum (43 mg m^{-2}) during winter. In the dead compartment maximum value (102 mg m^{-2}) was obtained during winter and minimum (28 mg m^{-2}) in the rainy season. Mean nitrogen accumulation (Table 7.7) in the live compartment was 243, 1170. 1076 and 902 mg m^{-2} and in the dead it was 65, 532, 523 and 366 mg m^{-2} on the 2 year, 5 year and 10 year old spoils and control site, respectively. In both live and dead compartments, minimum nitrogen accumulation was observed on the 2 year old spoil. The accumulation on the control site was lower than that on the 5 year and 10 year old spoils.

Phosphorus accumulation (Fig 7.5)

Analysis of variance showed a very significant ($P<0.01$) difference in phosphorus accumulation between the live and dead compartments. Variation due to sites was also significant ($P<0.05$), but there was no significant effect of season on phosphorus accumulation. On the control site, maximum accumulation (61 mg m^{-2}) in the live parts was observed during the rainy season and minimum (17 mg m^{-2}) during winter. In the dead compartment maximum (17 mg m^{-2}) and minimum (10 mg m^{-2}) values were recorded during winter and spring respectively. On the 10 year old spoil maximum accumulation in both live and dead compartments was observed during the rainy season and minimum during winter. On the 5 year old spoil maximum value (38 mg m^{-2}) was observed in the live parts during the rainy season and minimum (26 mg m^{-2}) in winter. In the dead compartments however, maximum value (30 mg m^{-2}) was recorded during winter and minimum (8 mg m^{-2}) during spring. On the 2 year old spoil maximum value (16 mg m^{-2}) was recorded during the rainy season and minimum (2 mg m^{-2}) during winter. On the contrary, in the dead compartment maximum value (4 mg m^{-2}) was recorded in winter and minimum (1 mg m^{-2}) during the rainy season. Mean accumulation (Table 7.7) in the live compartment was 8, 34, 40 and 35 mg m^{-2} and in the dead compartment it was 2, 16, 17 and 15 mg m^{-2} for the 2 year, 5, year and 10 year old spoils and the control site respectively.

Potassium accumulation (Fig 7.6)

Analysis of variance showed no significant effect of season on potassium accumulation in both live and dead compartments. However, the difference in accumulation between the live and dead compartments and variation due to site were highly significant ($P<0.01$). On the control site, highest value (746 mg m^{-2}) in live compartment was observed during the rainy season and lowest (319 mg m^{-2}) during winter. In the dead compartment highest value (160 mg m^{-2}) was observed during winter and lowest (114 mg m^{-2}) during spring. On the 10 year old spoil highest value (796 mg m^{-2}) in the live compartment was recorded during rainy season, and lowest (455 mg m^{-2}) during winter. Accumulation of K in the live compartment on the 5 year and 2 year old spoils also showed a trend similar to that observed on the 10 year old spoil. In the dead compartment maximum K accumulation was recorded during winter on all the spoils; the lowest value on the 5 year old spoil was observed during spring and on the 2 year old spoil during winter. Mean K accumulation (Table 7.7) in the live compartment was 85, 370, 600, 486 mg m^{-2} and in the dead it was 15, 108, 194 and 144 mg m^{-2} for the 2 year, 5 year and 10 year old spoils and the control site respectively.

Both nitrogen and potassium accumulation in the above and belowground compartments (Table 7.8) showed a significant increase with age of the spoils, minimum accumulation being on the 2 year old spoil and maximum on the control site. But there was no definite trend in the accumulation of phosphorus in the aboveground and belowground compartments (Table 7.8) though there was significant increase in the total accumulation with age of the spoils.

Proportional allocation of nutrients in root and rhizome and in live and dead compartments

Proportional allocation of nutrients in the root and rhizome is shown in Fig 7.7. With the exception of the control site during spring and 2 year old spoil during winter where the allocation of nitrogen was slightly higher in the rhizome compartment, the proportion of nitrogen allocation was much more in the root than in the rhizome. Similarly, phosphorus allocation was higher in the root than in the rhizome compartment except during spring in the 10 year old spoil and during winter in the 2 year old spoil where the proportion was slightly higher in the root. There was no significant difference in proportional allocation of potassium between root and rhizome on the control site and the 10 year old spoil, but on the 2 year and 5 year old spoils proportion of K in the rhizome was very low.

Proportional allocation of nutrient between live and dead compartments is shown in Fig 7.8. Proportional allocation of nitrogen was much greater in the live compartment than in the dead compartment during the rainy season and spring, while the reverse was true during winter. Allocation of phosphorus was also more in the live compartment than in the dead in most cases at all sites except during winter in the 2 year and 5 year old spoils and the control site where the allocation was more in the dead compartment. Potassium allocation was much greater in the live than in the dead compartment at all sites except during winter on the 2 year old spoil.

Ratio between belowground and aboveground accumulation (Table 7.8)

Ratios between belowground and aboveground accumulation of both nitrogen and phosphorus were greater than one at all the sites except the 5 year old spoil indicating greater accumulation of nitrogen and phosphorus in the belowground compartment. In case of K accumulation, ratio was greater than one for the 2 year old spoil and the control site but on the 5 year and 10 year old spoils, it was less than one. This indicates that K accumulation was greater in the belowground parts than in the aboveground parts on the 2 year old spoil and the control site, whereas on the 5 year and 10 year old spoils, it was more in the aboveground parts.

Nutrient accumulation in dominant species

Seasonal variations in nutrient accumulation in the dominant species on the coal mine spoils and the control site are presented in tables 7.9-7.11.

Nitrogen (Table 7.9)

There was no definite trend in the accumulation of nitrogen in the case of individual species. On the control site maximum accumulation (212.4 mg m^{-2}) was recorded during the rainy season for *Eragrostiella leioptera* and during spring for *Fimbristylis complanata* (156.5 mg m^{-2}), *Ischaemum geobellii* (354.1 mg m^{-2}) and *Osbeckia crinita* (262.1 mg m^{-2}). On the 10 year old spoil maximum accumulation was recorded during the rainy season for *Axonopus compressus* (425.9 mg m^{-2}), *Ischaemum geobellii* (354.1 mg m^{-2}) and *Osbeckia crinita* (262.1 mg m^{-2}). On the 10 year old spoil maximum accumulation was recorded during the rainy season for *Axonopus compressus* (425.9 mg m^{-2}), *Ischaemum geobellii* (476.3 mg m^{-2}) and *Osbeckia crinita* (274.7 mg m^{-2}) while in *Chrysopogon gryllus* (182.8 mg m^{-2}), it was recorded during spring and in *Dicranopteris linearis* (275.3 mg m^{-2}) during winter. On the 5 year old spoil maximum accumulation was recorded during the rainy season both in *Dicranopteris linearis* (1519.2 mg m^{-2}) and *Osbeckia crinita* (1667.0 mg m^{-2}). On the 2 year old spoil maximum accumulation was recorded during spring for *Ischaemum geobellii*

(96 mg m^{-2}) and during the rainy season for *Osbeckia crinita* (77.1 mg m^{-2}).

Maximum mean nitrogen accumulation (Table 7.12) in *Ischaemum geobellii* (290.5 mg m^{-2}) was recorded on the control site, in *Axonopus compressus* (387.8 mg m^{-2}) on the 10 year old spoil, in *Dicranopteris linearis* (1287.1 mg m^{-2}) on the 5 year old spoil and in *Ischaemum geobellii* (61.9 mg m^{-2}) on the 2 year old spoil.

Phosphorus (Table 7.10)

Pattern of phosphorus accumulation varied from species to species (Table 7.10). On the control site, maximum accumulation was recorded during the rainy season for *Eragrostiella leioptera* (13.7 mg m^{-2}) and *Ischaemum geobellii* (16.9 mg m^{-2}), during spring for *Fimbristylis complanata* (5.1 mg m^{-2}), and during winter for *Osbeckia crinita* (10.3 mg m^{-2}). On the 10 year old spoil maximum accumulation was recorded during the rainy season for *Axonopus compressus* (14.5 mg m^{-2}), *Chrysopogon gryllus* (6.2 mg m^{-2}), *Ischaemum geobellii* (25.5 mg g^{-2}) and *Osbeckia crinita* (10.0 mg m^{-2}) and during spring for *Dicranopteris linearis* (7 mg m^{-2}).

Maximum mean P accumulation (Table 7.12) was recorded in *Ischaemum geobellii* (9.9 mg m^{-2}) on the control site, in *Axonopus compressus* (10.8 mg m^{-2}) on the 10 year old spoil, in *Dicranopteris linearis* (29.6 mg m^{-2}) on the 5 year old spoil and in *Ischaemum geobellii* (1.8 mg m^{-2}) on the 2 year old spoil.

Potassium (Table 7.11)

Potassium accumulation in dominant species on the mine spoils and the control site is shown in Table (7.11). On the control site, maximum values were recorded during the rainy season for *Eragrostiella leioptera* (188.1 mg m^{-2}) and *Ischaemum geobellii* (213.8 mg m^{-2}), in spring for *Fimbristylis complanata* (97.3 mg m^{-2}) and in winter for *Osbeckia crinita* (155.5 mg m^{-2}). On the 10 year old spoil maximum values were recorded during the rainy season for *Axonopus compressus* (230.9 mg m^{-2}), *Ischaemum geobellii* (336.4 mg m^{-2}) and *Osbeckia crinita* (115.9 mg m^{-2}), in spring for *Chrysopogon gryllus* (69.5 mg m^{-2}) and in winter for *Dicranopteris linearis* (124.3 mg m^{-2}). On the 5 year old spoil maximum values were recorded during the rainy season for both *Dicranopteris linearis* (404.4 mg m^{-2}) and *Osbeckia crinita* (69.7 mg m^{-2}). On the 2 year old spoil maximum value was recorded during winter for *Ischaemum geobellii* (25.4 mg m^{-2}), and during rainy season for *Osbeckia crinita* (8.5 mg m^{-2}).

Maximum mean potassium accumulation (Table 7.12) on the control site was recorded in *Ischaemum geobellii* (147.7 mg m^{-2}), on the 10 year old spoil in *Axonopus compressus* (201 mg m^{-2}), on the 5 year old spoil in *Dicranopteris linearis* (299.8 mg m^{-2}) and on the 2 year old spoil in *Ischaemum geobellii* (16.4 mg m^{-2}).

Contribution of dominant species to total nutrient (Table 7.13)

The percentage contribution of each of the dominant species to the total nutrient accumulated in the aboveground compartment of vegetation varied considerably with species, with seasons and with sites. On the control site, *Ischaemum geobellii* contributed the maximum percentage to the total accumulation of each of the three major nutrients in the aboveground compartment. Its mean contribution to N accumulation was *ca.* 24.4%, to P accumulation 18.8% and to K accumulation 23.2%. On the 10 year old spoil *Axonopus compressus* contributed the maximum percentage to the total nutrient accumulated in the aboveground vegetation compartment. Its contribution was 24.3% to N accumulation, 19.8% to P accumulation and 25.3 % to K accumulation. On the 5 year old spoil maximum contribution to the total nutrients accumulated in the aboveground vegetation compartment was by *Dicranopteris linearis*. Its contribution to N accumulation was 75.6%, to P accumulation it was 61.8% and to K accumulation it was 61.9%. On the 2 year old spoil *Ischaemum geobellii* contributed the maximum percentage to the total nutrients accumulated in the aboveground vegetation compartment. It contributed *ca*. 28.7% to N accumulation, 26.9% to P accumulation and 25.7% to K accumulation.

Distribution of nutrients in major ecosystem compartments

Total nutrient content present in the major ecosystem compartments and proportional distribution in these compartments are presented in Fig 7.9 and Table 7.14. Soil was the major store for N and P on both mine spoils and the control site (Fig 7.9). But in the case of K (Fig 7.9) the amount in the soil was lesser than the amount present in the belowground compartment. Total nutrient content (g m^{-2}) present in the whole system (Table 7.14) was lowest on the youngest spoil and maximum on the control site and it increased with the age of the spoil. Of the total nitrogen (Table 7.14) present in the ecosystem more than 96% was present in the soil on the coal mine spoils and the control site and less than 1% in the aboveground compartments except in the 10 year old spoil where it was slightly greater than 1%. The proportion of N distributed in the different compartments of ecosystem in the mine spoils and the control site can be ranked as follows: Soil>Belowground vegetation compartment>Aboveground vegetation compartment.

Proportional distribution of P (Table 7.14) was also very high in the soil. In the 10 year old spoil and the control site the proportion of phosphorus in the soil was more than 83%. But in the 2 year and 5 year old spoils, it was only 56.1% and 69.9% respectively. The proportion of phosphorus distribution in different ecosystem compartments can be ranked as follows:

For the 2 year and 10 year old spoils and for the control site Soil>Belowground vegetation compartment>Aboveground vegetation compartment, and for the 5 year old spoil it may be ranked as follows:

Soil> Aboveground vegetation compartment> Belowground vegetation compartment.

The proportion of K in the soil was much lower than the proportion in the belowground vegetation compartment (Table 7.14). Distribution of K in the different compartments on the control site and 2 year old spoil was in the following order:

Belowground vegetation compartment>Soil>Aboveground vegetation compartment, and

for the 5 year and 10 year old spoils the order was as follows:

Aboveground vegetation compartment>Belowground vegetation compartment>Soil.

Rate of nutrient accumulation (Table 7.15)

Rate of nutrient accumulation in the different ecosystem compartments of coal mine spoils was very low. Rate of nitrogen accumulation was 6726, 124.8, 142.8 mg m^{-2} per year in the soil, belowground compartment and aboveground compartment, respectively. Rates of P and K accumulation were far lower compared to N accumulation rates. The annual accumulation rates of P in soil, belowground vegetation compartment and aboveground vegetation compartment were 101.2, 4.6 and 5.4 mg m^{-2} per year respectively, while the corresponding values for K accumulation were 35.6, 55.6 and 84.3 mg m^{-2} per year.

DISCUSSION

Variations in nutrient concentration between the different parts of the plants have been known for many years (CHAPIN III 1980), but few studies have examined these concentrations in ecological context. Nutrient concentration in different compartments of vegetation is related to species composition of the community (UMA SHANKAR 1991). On the control site, there was no significant effect of season on nitrogen concentration in the different parts (root and rhizome) of the belowground compartment. However, on the mine spoils a significant increase in nitrogen concentration in the root and a moderate increase in N concentration in rhizome were observed during spring. This could be attributed to the increased metabolic activity of the plants during spring.

With the exception of the 5 year old spoil, concentration of N in the rhizome was much greater than in the roots although the latter by virtue of having higher metabolic rate are supposed to have more nitrogen concentration than the rhizome particularly in such rhizomatious species where rhizomes act primarily as carbohydrate stores. On the contrary, in those species where rhizomes are also used as propagating structures there is pronounced concentration of nutrients in rhizomes (FITTER & SETTERS 1988). The plant species growing on the study sites belong to the latter category.

The concentration of nitrogen in the dead fraction of the aboveground compartment was very low both on the control site and on the mine spoils. This indicates that there has been much withdrawal of nitrogen from shoot following senescence (MORTON 1977, UMA SHANKAR 1991, BORAL 1993). MORTON (1977) reported 75% withdrawal of nitrogen and phosphorus from leaves of *Molinea caerulea*, a tussock forming grass before abscission. The lower nitrogen concentration in the standing dead than in live shoot of the dominant species as observed in the present study is in agreement with MORTON's (1977) observations.

During winter the concentration of nitrogen in the live shoot decreased substantially at all sites which could probably be related to low metabolic rate of the plants due to cold temperature. A significant increase in nitrogen concentration observed during spring could be attributed to new growth in shoots (UMA SHANKAR 1991) and to the increased metabolic activity of the plants with the rise in temperature. This conforms with the report of WOODMANSEE & DUNCAN (1980) in *Bromus mollis* and *Erodium sp.*

Unlike nitrogen, the difference in phosphorus concentration between root and rhizome was not very prominent. However, like nitrogen the concentration of phosphorus in the live fraction was much higher than in the standing dead fraction.

In the case of potassium the highest concentration was recorded in the live fraction of the aboveground compartment at all sites. Potassium is reported to be more concentrated in the mesophyll cells of the leaves. Potassium is involved in the translocation of photosynthetic products from the leaves (HARTT 1969) and it also plays a very important role in the opening and closing of stomata. Hence its concentration is expected to be higher in live shoot than in any other parts of the plant. This is also in agreement with the findings of UMA SHANKAR (1991).

The extremely low concentration of potassium in the dead shoot at all sites could be attributed to withdrawal of potassium from live shoot during senescence as well as to leaching losses from the aerial parts (MORTON 1977, UMA SHANKAR 1991). MORTON (1977) reported 90% leaching of potassium into the soil from the leaves of *Molinea caerulea*. Potassium being more mobile is readily leached from leaves particularly those which are senescent or dead. Heavy leaching of potassium during the rainy season probably accounts for its low concentration in both live and standing dead compartments during this season. Translocation between plant components for example, from leaves to roots and rhizome during senescence is usually assumed to be important particularly for those nutrients whose supply is frequently limited (CLARK *et al.* 1980).

Intersite variation in concentrations of N, P and K in different compartments of vegetation was quite large. This could be attributed to difference in the standing state of these nutrients in the soil and to the difference in the species composition of the study sites and the difference in the absorbing capacity of the component plant species.

Concentration of N, P and K in different components of the vegetation was extremely low at all sites. It was much lower than the concentration range given by ALLEN *et al.* (1974). This is probably related to the poor nutrient content and high acidity of the soil (Chapter 4). Besides the mine spoils, the control site being a degraded grassland was also poor in nutrients. Vegetations growing in infertile habitats are characterised by low nutrient concentration in their different component organs (GAY *et al.* 1982, BORAL 1993).

Standing state of nutrients (N, P, K) is strongly influenced by the dominant species in any community. With the exception of phosphorus in root and rhizome fractions of the belowground compartment, standing state of nutrients in the different compartments of vegetation varied significantly. Mean standing state of all the three nutrients was much lower in the rhizome fraction than in the root. Also, it was much lower in the dead than in the live fraction. This could be attributed to their low biomass despite relatively higher nutrient concentration, while, in the dead it could be attributed to the low biomass and low nutrient concentration. The total accumulation of nutrients in the vegetation compartment was least in the 2 year old spoil, but it increased significantly with age of the spoil.

Standing state of nutrients in the live and dead shoot of dominant species varied widely with the change in season. But in all the cases, the accumulation in the dead shoot was very low compared to live shoot. This could also be attributed to their low nutrient concentration in the dead shoot and low biomass production by these species. *Ischaemum geobellii* contributed the maximum percentage to the total nutrients in the aboveground compartment in the 2 year old spoil and the control site, whereas on the other two sites *Dicranopteris linearis* (on the 5 year old spoil) and *Axonopus compressus* (on the 10 year old spoils) were the major contributors. The high contribution by these species could be partly attributed to their growth characteristics which contribute to their high nutrient concentration and biomass production.

The four major ecosystem compartments on the coal mine spoils are plant, litter, root and rhizome, and soil. In the present study, however, litter could not be collected on mine spoils due to its unavailability as it was lost from the system on account of slopy topography of the site and soil erosion caused by high precipitation and high wind velocity in the area. In this study, the aboveground vegetation compartment was further divided into the live and dead fractions and the belowground vegetation compartment into root and rhizome. The successional development of vegetation on mine spoils appears to involve changes in the relative size of the above ecosystem compartments.

Among the two major vegetation compartments, the greater accumulation of N, P and K occurred in the belowground compartment both on the mine spoils as well as on the control site. MARRS *et al.* (1981) also reported higher accumulation of nutrients in the belowground compartment on those sites that were dominated by *Lupinus arboreus* and on mature woodland sites. In the present study, the principal accumulation site on the 5 year old spoil was the aboveground compartment. This could be attributed to the species composition of the site. The 5 year old spoil was dominated by *Dicranopteris linearis* which had a very low belowground biomass compared to the aboveground. As *Dicranopteris linearis* contributed maximum to the total nutrients accumulated in the vegetation compartment on this spoil and its belowground biomass was far lower compared to its aboveground biomass, the belowground/aboveground ratio for nutrient accumulation was very low on the 5 year old spoil.

Soil is the largest store for both nitrogen and phosphorus. But it contains a relatively small proportion of potassium compared to the proportion found in the vegetation compartment. In stable ecosystems, the soil generally contains more than 90% (and often as much as 97%) of the total nutrients present in the ecosystem. But in the present investigation, the distribution pattern of nutrients in the different ecosystem compartments varied widely from the stable ecosystems and this indicates the unstable and disturbed nature of these mine spoils. All sites (including the control) site are sandy in nature with more than 80% sand. Potassium from the soil is easily leached down to the deeper layers of the soil (TUKEY 1970, UMA SHANKAR 1991). This accounts for the very low content of potassium in the soil.

The present study has direct relevance to reclamation programmes. Nutrient compartmentation studies in these degraded ecosystems undergoing recovery may indicate the nutrient concentrations which have to be reached in order to achieve a specific vegetation end point in reclamation schemes. The results obtained demonstrate that nutrient accumulation and the development of distinct compartmentalized stores are characteristic features of ecosystem development on coal mine spoils and the size of each of these stores varies according to the stage of ecosystem development.

Table 7.1 - Seasonal variation in nutrient concentrations (± S.E.) in the belowground compartments (root & rhizome) of vegetation on the coal mine spoils of different ages and the control site. (± S.E. of the mean)

		Control site			Age of coal mine spoil (years)								
					10			5			2		
		Seasons			Seasons			Seasons			Seasons		
Nutrient concentrations	Compartment	Rainy	Winter	Spring	Rainy	Winter	Spring	Rainy	Winter	Spring	Rainy	Winter	Spring
Nitrogen (%)	Root	0.626 ±0.01	0.667 ±0.11	0.637 ±0.02	0.575 ±0.00	0.673 ±0.00	1.512 ±0.04	0.627 ±0.01	0.623 ±0.01	1.145 ±0.01	0.606 ±0.02	0.632 ±0.03	0.650 ±0.007
	Rhizome	0.823 ±0.03	0.815 ±0.01	0.877 ±0.01	0.550 ±0.02	0.473 ±0.01	0.554 ±0.01	0.665 ±0.04	0.370 ±0.03	1.092 ±0.02	0.961 ±0.02	0.739 ±0.00	0.754 ±0.04
Phosphorus ($\mu g\ g^{-1}$)	Root	529.15 ±3.90	401.73 ±48.04	317.79 ±16.39	389.80 ±14.44	121.73 ±5.30	205.07 ±15.10	138.96 ±44.67	45.02 ±7.50	98.27 ±19.8	285.56 ±12.45	426.84 ±27.56	224.94 ±6.89
	Rhizome	542.25 ±23.75	389.53 ±15.1	338.55 ±10.13	397.16 ±18.04	128.22 ±2.76	338.85 ±38.42	167.27 ±56.87	19.03 ±4.76	48.74 ±2.21	434.09 ±4.04	483.4 ±8.46	141.74 ±12.56
Potassium ($mg\ g^{-1}$)	Root	1.287 ±0.05	2.114 ±0.20	0.97 ±0.18	1.835 ±0.3	2.056 ±0.09	2.475 ±0.13	1.595 ±0.19	2.131 ±0.39	2.659 ±0.04	1.248 ±0.11	3.617 ±0.11	0.825 ±0.06
	Rhizome	5.301 ±0.28	2.537 ±0.07	1.380 ±0.02	3.650 ±0.12	3.082 ±0.14	3.115 ±0.31	1.903 ±0.10	2.665 ±0.05	2.114 ±0.06	1.407 ±0.08	1.499 ±0.10	1.102 ±0.08

Table 7.2 - Seasonal variation in nutrient concentration in the aboveground compartment (live and dead plant parts) of the vegetation on the coal mine spoils of different ages and the control site. ± S.E. of the mean.

		Control site			Age of coal mine spoil (years)								
					10			5			2		
		Seasons			Seasons			Seasons			Seasons		
Nutrients	Compartment	Rainy	Winter	Spring	Rainy	Winter	Spring	Rainy	Winter	Spring	Rainy	Winter	Spring
Nitrogen (%)	*Live*	0.818 ±0.006	0.590 ±0.010	1.083 ±0.020	0.964 ±0.008	0.769 ±0.010	1.052 ±0.010	1.172 ±0.013	0.834 ±0.021	1.465 ±0.034	1.087 ±0.044	0.769 ±0.053	1.518 ±0.009
	Standing dead	0.269 ±0.004	0.386 ±0.006	0.479 ±0.011	0.639 ±0.021	0.708 ±0.006	0.573 ±0.011	0.786 ±0.021	0.781 ±0.060	1.000 ±0.030	0.416 ±0.008	0.677 ±0.071	0.751 ±0.035
Phosphorus ($\mu g\ g^{-1}$)	Live	335,84 ±21.071	277.31 ±15.051	355.42 ±13.124	436.2 ±9.81	306.48 ±8.79	254.27 ±11.231	317.13 ±16.37	406.41 ±17.63	341.18 ±9.880	362.74 ±13.65	410.96 ±19.35	345,8 ±21.823
	Standing dead	*184,28* ±22.102	*147.29* ±18.215	*133.17* ±6.75	394.46 ±20.25	145.76 ±19.53	181.67 ±24.811	189.20 ±19.500	320.90 ±25.09	155.05 ±17.15	79.73 ±7.26	284.76 ±20.56	242.97 ±20.122
Potassium ($mg\ g^{-1}$)	Live	4.122 ±0.813	5.183 ±0.971	4.940 ±0.513	5.032 ±0.621	5.704 ±0.750	5.298 ±0.342	3.884 ±0.551	3.287 ±0.768	4.046 ±0.613	3.616 ±0.280	3.335 ±0.557	5.631 ±0.630
	Standing dead	1.722 ±0.517	1.241 ±0.483	1.525 ±0.097	2.723 ±0.052	2.859 ±0.045	1.662 ±0.109	1.567 ±0.252	2.076 ±0.510	1.161 ±0.078	1.236 ±0.461	1.837 ±0.392	1.163 ±0.185

Table 7.3 - Seasonal variation in N concentration (%) in the live and dead parts of the aboveground compartment of dominant species growing on the Coal mine spoils of different ages and the control site.

Species	Seasons					
	Rainy		Winter		Spring	
	Live	Standing Dead	Live	Standing Dead	Live	Standing Dead
Control						
Eragrostiella leioptera	0.544±0.01	0.455±0.03	0.578±0.00	0.462±0.01	0.960±0.02	-
Fimbristylis complanata	0.814±0.09	0.465±0.04	0.451±0.01	0.419±0.02	0.730±0.02	0.640±0.02
Ischaemum geobellii	0.801±0.03	0.541±0.02	0.844±0.02	0.635±0.00	1.223±0.02	0.860±0.01
Osbeckia crinita	1.288±0.04	0.625±0.03	0.446±0.01	0.709±0.01	1.087±0.01	0.552±0.03
10 year old spoil						
Axonopus compressus	1.117±0.01	0.660±0.01	0.869±0.02	0.638±0.01	0.937±0.02	0.689±0.01
Chrysopogon gryllus	1.034±0.04	0.607±0.03	0.801±0.00	0.615±0.03	1.295±0.03	0.726±0.01
Dicranopteris linearis	1.377±0.01	0.858±0.05	0.945±0.00	0.750±0.02	0.898±0.04	0.752±0.00
Ischaemum geobellii	0.826±0.07	0.501±0.01	0.565±0.02	0.623±0.00	1.031±0.01	0.534±0.00
Osbeckia crinita	1.160±0.03	0.670±0.01	0.648±0.01	0.897±0.02	1.204±0.01	0.675±0.02
5 year old spoil						
Dicranopteris linearis	1.257±0.01	0.805±0.06	0.814±0.02	0.822±0.02	1.361±0.03	0.898±0.02
Osbeckia crinita	1.168±0.03	0.600±0.02	0.740±0.00	0.865±0.00	1.254±0.02	0.562±0.04
2 year old spoil						
Ischaemum geobellii	0.947±0.01	0.526±0.00	0.911±0.00	0.636±0.04	1.799±0.03	0.811±0.02
Osbeckia crinita	1.354±0.09	0.628±0.07	0.564±0.00	0.694±0.03	1.025±0.02	0.511±0.02

- No biomass

± SE of the mean

Table 7.4 - Seasonal variation in P concentration (µg g^{-1}) in the live and dead parts of the aboveground compartment of dominant species growing on the coal mine spoils of different ages and the control site.

Species	Seasons					
	Rainy		Winter		Spring	
	Live	Dead	Live	Dead	Live	Dead
Control						
Eragrostiella leioptera	350.17±2.5	287.19±13.8	320.98±26.7	293.15±19.3	296.98±55.3	-
Fimbristylis complanata	107.28±8.3	56.34±5.2	99.54±8.9	35.62±7.7	239.74±31.1	189.90±26.9
Ischaemum geobellii	465.75±76.4	65.31±6.5	180.01±38.9	272.65±0.6	223.63±26.3	70.19±15.8
Osbeckia crinita	235.35±7.1	48.68±1.5	538.80±95.6	314.41±21.4	335.40±64.5	219.53±14.1
10 year old spoil						
Axonopus compressus	274.71±0.9	489.17±8.7	259.18±17.4	104.01±21.0	276.09±21.5	154.92±19.9
Chrysopogon gryllus	1154.43±50.5	664.64±96.2	804.31±43.5	125.09±18.3	186.34±6.8	287.25±8.8
Dicranopteris linearis	339.57±82.2	305.65±6.8	146.46±18.6	122.09±11.5	278.23±8.2	335.96±27.0
Ischaemum geobellii	445.17±36.3	452.12±7.4	329.25±33.3	284.01±19.2	211.47±6.8	204.08±25.9
Osbeckia crinita	396.06±27.8	281.31±5.1	194.75±27.4	119.36±5.2	465.14±91.1	127.65±26.8
5 year old spoil						
Dicranopteris linearis	321.76±2.8	189.37±6.3	367.54±6.3	14.54±1.2	318.94±57.1	148.18±21.6
Osbeckia crinita	240.12±17.7	100.25±21.2	344.76±7.1	378.70±5.9	302.47±22.2	139.13±25.2
2 year old spoil						
Ischaemum geobellii	449.34±11.3	61.12±4.3	375.68±42.2	203.51±9.4	420.69±98.3	192.50±21.1
Osbeckia crinita	332.68±28.1	123.53±11.7	430.41±6.6	322.17±5.1	356.18±27.2	117.15±19.1

± S.E. of the mean

Table 7.5 - Seasonal variation in K concentration (mg g^{-1}) in the live and dead parts of the aboveground compartment of dominant species growing on the Coal mine spoils of different ages and the control site.

Species	Seasons					
	Rainy		Winter		Spring	
	Live	Dead	Live	Dead	Live	Dead
Control						
Eragrostiella leioptera	4.82±0.1	3.34±0.5	4.65±0.2	2.33±0.1	5.13±0.2	-
Fimbristylis complanata	6.17±0.6	2.08±0.4	4.32±0.2	1.15±0.1	4.71±0.1	1.54±0.1
Ischaemum geobellii	5.88±0.2	3.17±0.6	4.05±0.0	0.99±0.2	5.77±0.2	1.13±0.1
Osbeckia crinita	5.27±0.2	2.41±0.2	8.49±0.1	3.59±0.1	3.97±0.0	1.09±0.0
10 year old spoil						
Axonopus compressus	6.32±0.1	2.91±0.3	6.06±0.3	2.84±0.0	6.02±0.0	2.17±0.1
Chrysopogon gryllus	6.39±0.2	2.14±0.0	7.47±0.0	3.25±0.0	5.89±0.6	0.75±0.0
Dicranopteris linearis	5.44±0.3	1.94±0.2	4.77±0.1	2.50±0.1	4.95±0.0	0.72±0.1
Ischaemum geobellii	6.47±0.5	1.01±0.1	5.34±0.1	2.09±0.0	6.29±0.5	1.43±0.1
Osbeckia crinita	4.83±0.2	2.91±0.1	4.99±0.0	2.98±0.1	4.56±0.5	2.14±0.6
5 year old spoil						
Dicranopteris linearis	3.66±0.0	1.41±0.1	3.44±0.1	0.96±0.1	2.79±0.1	0.98±0.1
Osbeckia crinita	4.96±0.6	2.12±0.5	4.52±0.1	4.26±0.1	3.52±0.6	1.16±0.4
2 year old spoil						
Ischaemum geobellii	3.85±0.1	1.13±0.1	3.29±0.1	2.31±0.2	5.31±0.1	0.74±0.1
Osbeckia crinita	1.49±0.1	0.78±0.1	1.49±0.0	1.53±0.0	3.28±0.1	1.04±0.1

± SE of the mean

Table 7.6 - **Seasonal mean nutrient concentrations in the aboveground compartment of dominant species growing on the coal mine spoils of different ages and the control site. (* mean of 2 seasons only).**

Species	Nitrogen %		Phosphorus ug g		Potassium mg g	
	Live	Dead	Live	Dead	Live	Dead
Control						
Eragrostiella leioptera	0.694±0.133	*0.459±0.004	322.71±15.379	*290.171±0.707	4.866±0.141	*2.833±0.508
Fimbristylis complanata	0.665±0.110	0.508±0.067	148.85±45.498	93.954±48.344	5.068±0.564	1.589±0.268
Ischaemum geobellii	0.956±0.134	0.679±0.095	289.797±88.873	136.05±68.315	5.231±0.591	1.763±0.705
Osbeckia crinita	0.940±0.254	0.629±0.045	369.85±89.276	194.206±77.748	5.911±1.347	2.365±0.721
10 year old spoil						
Axonopus compressus	0.974±0.74	0.662±0.015	269.993±5.421	249.367±120.799	6.130±0.096	2.69±0.238
Chrysopogon gryllus	1.043±0.143	0.649±0.038	715.027±83.007	258.993±159.832	6.581±0.466	2.043±0.725
Dicranopteris linearis	1.073±0.152	0.787±0.036	254.753±56.969	254.567±66.814	5.054±0.200	1.720±0.526
Ischaemum geobellii	0.807±0.135	0.553±0.036	328.63±67.464	246.737±23.230	6.034±0.351	1.512±0.317
Osbeckia crinita	1.004±0.178	0.747±0.075	351.983±81.106	176.107±52.656	4.793±0.126	2.676±0.270
5 year old spoil						
Dicranopteris linearis	1.144±0.168	0.842±0.029	336.080±15.751	117.363±52.769	3.299±0.260	1.115±0.148
Osbeckia crinita	1.054±0.159	0.676±0.095	295.783±30.391	206.027±87.063	4.329±0.426	2.512±0.915
2 year old spoil						
Ischaemum geobellii	1.219±0.290	0.658±0.083	415.237±21.438	152.377±45.739	4.147±0.601	1.390±0.473
Osbeckia crinita	0.981±0.229	0.611±0.054	373.091±29.452	187.617±67.302	2.086±0.595	1.114±0.221

± indicates variability through seasons

* values are the means of two seasons only

Table 7.7 – Mean nutrient accumulations (mg m^{-2}) in the belowground (root and rhizome) and aboveground (live and dead) compartments of vegetations on the coal mine spoils of different ages and the control site.

Nutrients	Compartments		Control site	Age of Coal mine spoil (years)		
				10	5	2
Nitrogen	Above-	Live	902±323	1076±263	1170±326	243±122
	ground	Standing Dead	366±73	523±123	532±100	65±21
	Below-	Root	2023±637	1128±341	736±180	349±36
	ground	Rhizome	1296±174	502±16	174±53	300±24
Phosphorus	Above-	Live	35±13	40±15	34±4	8±4
	ground	Standing Dead	15±3	17±1	16±7	2±1
	Below-	Root	144±70	35±18	9±3	16±1
	ground	Rhizome	65±38	27±8	5±3	14±4
Potassium	Above-	Live	486±132	600±102	370±81	85±40
	ground	Standing Dead	144±15	194±52	108±42	15±6
	Below-	Root	442±134	266±45	194±30	96±33
	ground	Rhizome	470±193	314±23	53±2	50±8

Table 7.8 – Nutrient accumulation (mg g^{-2}) in belowground and aboveground compartments, total accumulation and belowground/aboveground nutrient accumulation ratio in vegetations growing on coal mine spoils of different ages and the control site.

Nutrients		Control	Age of coal mine spoil (years)		
			10	5	2
Nitrogen	Aboveground compartment	1268	1599	1702	308
	Belowground compartment	3319	1630	910	649
	Total accumulation	4587	3229	2612	957
	Belowground:aboveground nutrient accumulation ratio	2.618	1.019	0.535	2.107
Phosphorus	Aboveground compartment	50	57	50	10
	Belowground compartment	209	62	14	30
	Total accumulation	259	119	64	40
	Belowground: Aboveground nutrient accumulation ratio	4.180	1.088	0.280	3.000
Potassium	Aboveground compartment	630	794	487	100
	Belowground compartment	912	580	247	146
	Total accumulation	1542	1374	725	246
	Belowground:Aboveground nutrient accumulation ratio	1.448	0.730	0.517	1.460

Table 7.9 - Seasonal variation in nitrogen accumulation (mg m^{-2}) in the live and dead biomass of the aboveground compartment of dominant species growing on coal mine spoils of different ages and the control site.

Species	Seasons								
	Rainy			Winter			Spring		
	Live	Standing Dead	Total	Live	Standing Dead	Total	Live	Standing Dead	Total
Control site									
Eragrostiella leioptera	211.5	0.9	212.4	19.4	46.2	65.6	58.6	0.0	58.6
Fimbristylis complanata	90.5	10.2	100.7	5.1	35.6	40.7	147.5	9.0	156.5
Ischaemum geobellii	289.4	2.7	292.1	134.1	91.4	225.5	305.9	48.2	354.1
Osbeckia crinita	164.9	7.2	172.1	73.1	31.8	104.9	248.3	13.8	262.1
10 year old spoil									
Axonopus compressus	344.7	81.2	425.9	153.0	189.0	342.0	176.3	219.0	395.3
Chrysopogon gryllus	38.4	17.4	55.8	5.8	6.4	12.2	144.0	38.8	182.8
Dicranopteris linearis	115.4	10.3	125.7	189.3	86.0	275.3	186.8	26.3	213.1
Ischaemum geobellii	413.2	63.1	476.3	26.3	33.4	59.7	63.9	45.4	109.3
Osbeckia crinita	192.6	82.1	274.7	75.2	14.9	90.1	196.3	8.1	204.4
5 year old spoil									
Dicranopteris linearis	1191.9	327.3	1519.2	392.3	508.8	901.1	1168.1	273.1	1441.2
Osbeckia crinita	151.8	14.9	166.7	38.9	2.6	41.5	15.0	2.2	17.2
2 year old spoil									
Ischaemum geobellii	15.2	4.2	19.4	34.4	35.9	70.3	39.8	56.2	96.0
Osbeckia crinita	75.8	1.3	77.1	5.4	11.1	16.5	12.3	0.5	12.8

Table 7.10 - Seasonal variation in phosphorus accumulation (mg m^{-2}) in the live and dead biomass of the aboveground compartment of dominant species growing on coal mine spoils of different ages and the control site.

Species	Seasons								
	Rainy			Winter			Spring		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Control site									
Eragrostiella leioptera	13.61	0.06	13.67	1.08	2.93	4.01	1.81	0.00	1.81
Fimbristylis complanata	1.19	0.12	1.31	0.11	0.30	0.41	4.84	0.27	5.11
Ischaemum geobellii	16.83	0.03	16.86	2.86	3.93	6.79	5.59	0.39	5.98
Osbeckia crinita	3.01	0.06	3.07	8.84	1.41	10.25	7.66	0.55	8.21
10 year old spoil									
Axonopus compressus	8.46	6.02	14.48	4.56	3.08	7.64	5.20	4.92	10.12
Chrysopogon gryllus	4.28	1.91	6.19	0.58	0.13	0.71	2.07	1.53	3.60
Dicranopteris linearis	2.85	0.37	3.22	2.93	1.40	4.33	5.79	1.18	6.97
Ischaemum geobellii	22.27	3.18	25.45	1.53	1.52	3.05	1.31	1.73	3.04
Osbeckia crinita	6.57	3.45	10.02	2.26	0.20	2.46	7.58	0.15	7.73
5 year old spoil									
Dicranopteris linearis	30.51	7.70	38.21	17.72	0.90	18.62	27.37	4.51	31.88
Osbeckia crinita	3.12	0.25	3.37	1.81	0.11	1.92	0.36	0.06	0.42
2 year old spoil									
Ischaemum geobellii	0.72	0.05	0.77	0.42	1.15	2.57	0.93	1.33	2.26
Osbeckia crinita	1.86	0.02	1.88	0.41	0.52	0.93	0.43	0.01	0.44

Table 7.11 - Seasonal variation in potassium accumulation (mg m^{-2}) in the different fractions of the aboveground compartment of dominant species growing on coal mine spoils of different ages and the control site.

Species	Seasons								
	Rainy			Winter			Spring		
	Live	Standing Dead	Total	Live	Standing Dead	Total	Live	Standing Dead	Total
Control site									
Eragrostiella leioptera	187.44	0.67	188.11	15.62	23.25	38.87	31.29	0.00	31.29
Fimbristylis complanata	68.64	4.57	73.21	4.88	9.79	14.67	95.14	2.16	97.31
Ischaemum geobellii	212.23	1.59	213.82	64.35	14.21	78.56	144.31	6.33	150.64
Osbeckia crinita	67.39	2.77	70.16	139.38	16.11	155.49	90.67	2.73	93.40
10 year old spoil									
Axonopus compressus	195.04	35.81	230.85	106.65	84.27	190.92	112.20	68.80	181.00
Chrysopogon gryllus	23.69	6.13	29.82	5.38	3.38	8.76	65.50	3.98	69.48
Dicranopteris linearis	45.59	2.33	47.92	95.58	28.70	124.28	102.96	2.52	105.48
Ischaemum geobellii	323.73	12.71	336.44	24.83	11.25	36.08	39.00	12.16	51.16
Osbeckia crinita	80.14	35.73	115.87	57.90	4.94	62.84	74.33	2.56	76.89
5 year old spoil									
Dicranopteris linearis	347.04	57.37	404.41	165.95	59.11	225.06	239.89	29.80	269.69
Osbeckia crinita	64.42	5.25	69.67	23.75	1.28	25.03	4.22	0.46	4.68
2 year old spoil									
Ischaemum geobellii	6.16	0.9	7.06	12.42	13.02	25.44	11.72	5.10	16.82
Osbeckia crinita	8.34	0.16	8.50	1.42	2.45	3.87	3.93	0.10	4.03

Table 7.12 - Seasonal mean nutrient accumulation (mg g^{-2}) in the dead and live parts of the aboveground compartment of dominant species growing on coal mine spoils of different ages and the control site.

Species	Nitrogen			Phosphorus			Potassium		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Control site									
Eragrostiella leioptera	96.5	15.7	112.2	5.5	1.0	6.5	78.1	8.0	86.1
Fimbristylis complanata	81.0	18.3	99.3	2.0	0.2	2.2	56.2	5.5	61.7
Ischaemum geobellii	243.1	47.4	290.5	8.4	1.5	9.9	140.3	7.4	147.7
Osbeckia crinita	174.1	17.6	191.7	6.5	0.7	7.2	99.1	7.2	106.3
10 year old spoil									
Axonopus compressus	224.7	163.1	387.8	6.1	4.7	10.8	138.0	63.0	201.0
Chrysopogon gryllus	62.7	20.9	83.6	2.3	1.2	3.5	31.5	4.5	36.0
Dicranopteris linearis	163.8	40.9	204.7	3.9	1.0	4.9	81.4	11.2	92.6
Ischaemum geobellii	167.8	47.3	215.1	8.4	2.1	10.5	129.2	12.0	141.2
Osbeckia crinita	154.7	35.0	189.7	5.5	1.3	6.8	70.8	14.4	85.2
5 year old spoil									
Dicranopteris linearis	917.4	369.7	1287.1	25.2	4.4	29.6	251.0	48.8	299.8
Osbeckia crinita	68.6	6.6	75.2	1.8	0.1	1.9	30.8	2.3	33.1
2 year old spoil									
Ischaemum geobellii	29.8	32.1	61.9	1.0	0.8	1.8	10.1	6.3	16.4
Osbeckia crinita	31.2	4.3	35.5	0.9	0.2	1.1	4.6	0.9	5.5

Table 7.13 - **Seasonal variation in (%) contribution of dominant species to the total nutrients accumulated in the aboveground compartment of vegetations growing on the coal mine spoils of different ages and the control site.**

Species	Nitrogen				Phosphorus				Potassium			
	Rainy	Winter	Spring	Mean	Rainy	Winter	Spring	Mean	Rainy	Winter	Spring	Mean
Control site												
Eragrostiella leioptera	12.31	7.64	4.80	8.25	17.56	11.11	4.74	11.14	20.83	8.12	6.16	11.70
Fimbristylis complanata	5.84	4.74	12.81	7.80	1.67	1.11	13.4	5.39	8.11	3.07	19.15	10.11
Ischaemum geobellii	16.93	26.25	29.98	24.39	21.67	18.89	15.79	18.78	23.68	16.41	29.66	23.25
Osbeckia crinita	9.98	12.21	21.45	14.55	3.97	28.61	21.58	18.05	7.77	32.46	18.39	19.54
10 year old spoil												
Axonopus compressus	23.22	25.35	24.48	24.35	16.48	19.49	23.49	19.82	24.88	25.39	25.78	25.35
Chrysopogon gryllus	3.04	0.90	11.32	5.09	7.05	1.79	8.37	5.74	3.21	1.17	9.90	4.76
Dicranopteris linearis	6.85	20.41	13.20	13.49	3.64	11.03	16.28	10.32	5.16	16.53	15.03	12.24
Ischaemum geobellii	25.97	4.43	6.77	12.39	29.99	7.95	6.98	14.97	36.25	4.80	7.29	16.11
Osbeckia crinita	14.98	6.68	12.66	11.44	11.36	6.41	17.91	11.89	12.49	8.35	10.95	10.60
5 year old spoil												
Dicranopteris linearis	85.69	72.20	69.06	75.65	81.28	33.21	70.89	61.79	75.31	56.28	54.27	61.95
Osbeckia crinita	9.40	3.33	0.82	4.52	7.23	3.93	0.89	4.02	12.98	6.25	0.95	6.73
2 year old spoil												
Ischaemum geobellii	3.94	48.48	33.57	28.66	4.71	43.33	32.86	26.97	4.36	54.35	18.26	25.66
Osteckia crinita	15.64	11.38	4.48	10.50	11.06	15.00	5.71	10.59	5.21	8.48	4.35	6.01

Table 7.14 - Total nutrient content (g m^{-2} bold face) and the percentage distribution among the major ecosystem compartments on the coal mine spoils of different ages and the control site.

Sites	Compartments	Nitrogen	Phosphorus	Potassium
Control site	**Total**	**153.06**	**1.62**	**2.19**
	Aboveground	0.83	3.15	28.77
	Belowground	2.17	12.90	41.65
	Soil	97.00	83.95	29.58
10 year old spoil	**Total**	**102.58**	**0.95**	**1.79**
	Aboveground	1.56	6.01	44.26
	Belowground	1.59	6.54	32.33
	Soil	96.85	87.45	23.41
5 year old spoil	**Total**	**93.00**	**0.21**	**0.92**
	Aboveground	1.83	23.46	51.83
	Belowground	0.98	6.56	26.78
	Soil	97.19	69.98	21.39
2 year old spoil	**Total**	**42.02**	**0.09**	**0.39**
	Aboveground	0.73	10.96	25.68
	Belowground	1.55	32.89	37.49
	Soil	97.72	56.15	36.83

Table 7.15 - Linear regression analysis of nutrient content (g m^{-2}) in different ecosystem compartments of naturally recovering coal mine spoils against their age. NS not signifficant; df = n-2 = 10.

Nutrients	Regression Coefficient	Constant	Correlation Coefficient	Significance Level
		Soil compartment		
Nitrogen	6.726	38.819	0.805	<0.01
Phosphorus	0.1012	-0.2303	0.902	<0.001
Potassium	0.0356	0.0518	0.749	<0.01
		Belowground plant parts		
Nitrogen	0.1248	0.3553	0.812	<0.01
Phosphorus	0.0046	0.0087	0.546	NS
Potassium	0.0556	0.0092	0.950	<0.001
		Aboveground plant parts		
Nitrogen	0.1428	0.3939	0.705	<0.05
Phosphorus	0.0054	0.0082	0.754	<0.01
Potassium	0.0843	-0.0204	0.959	<0.001

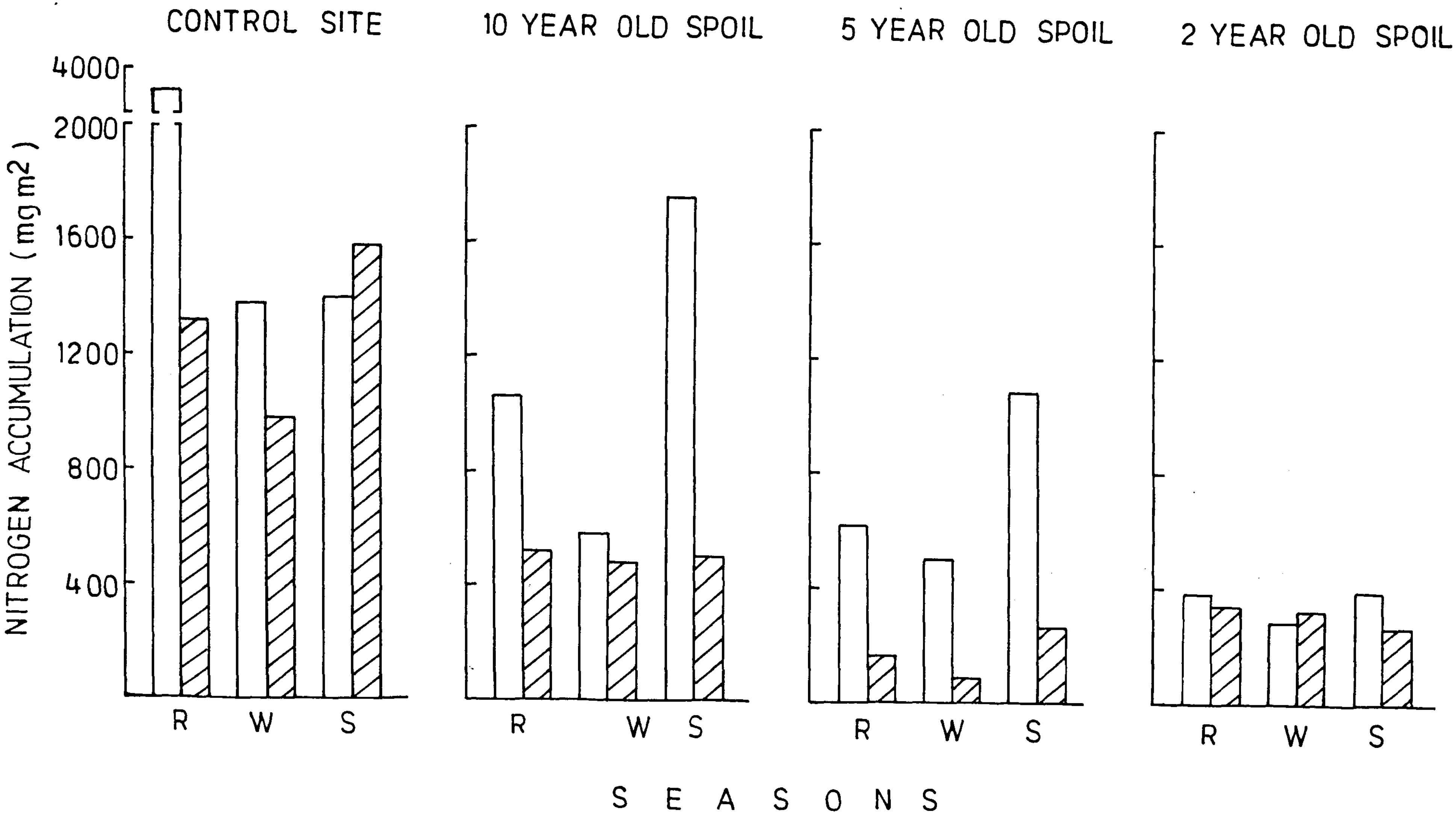


Fig. 7.1- Seasonal variation in nitrogen accumulation (mg m^{-2}) in the belowground compartment of vegetation growing on coal mine spoils of different ages and the control site. ☐ Root; ▨ Rhizome; R Rainy; W Winter; S Spring.

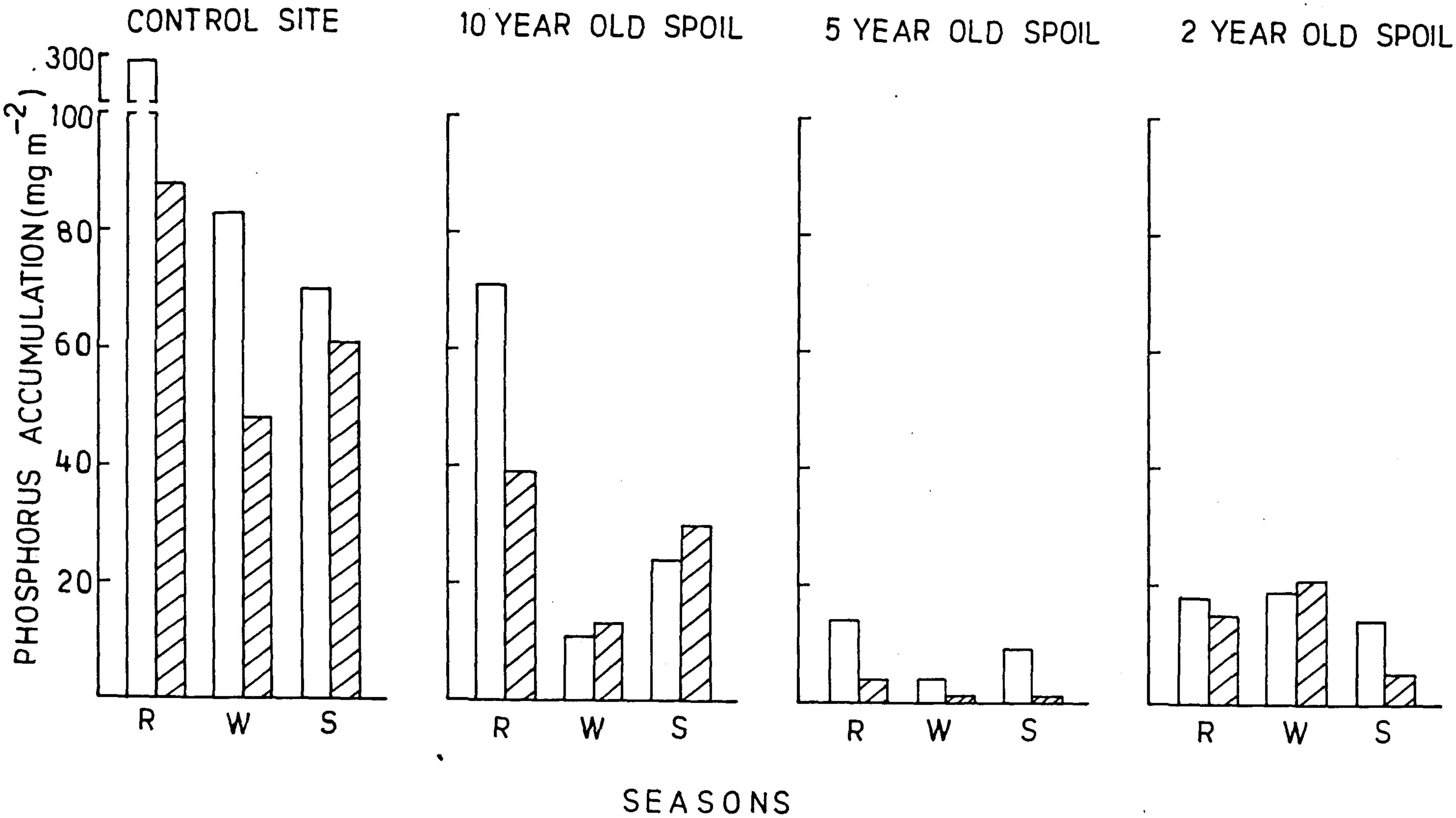


Fig. 7.2 - Seasonal variation in phosphorus accumulation (mg m^{-2}) in the below-ground compartment of vegetation growing on coal mine spoils of different ages and the control site. □ Root; ▨ Rhizome; R Rainy; W Winter; S Spring.

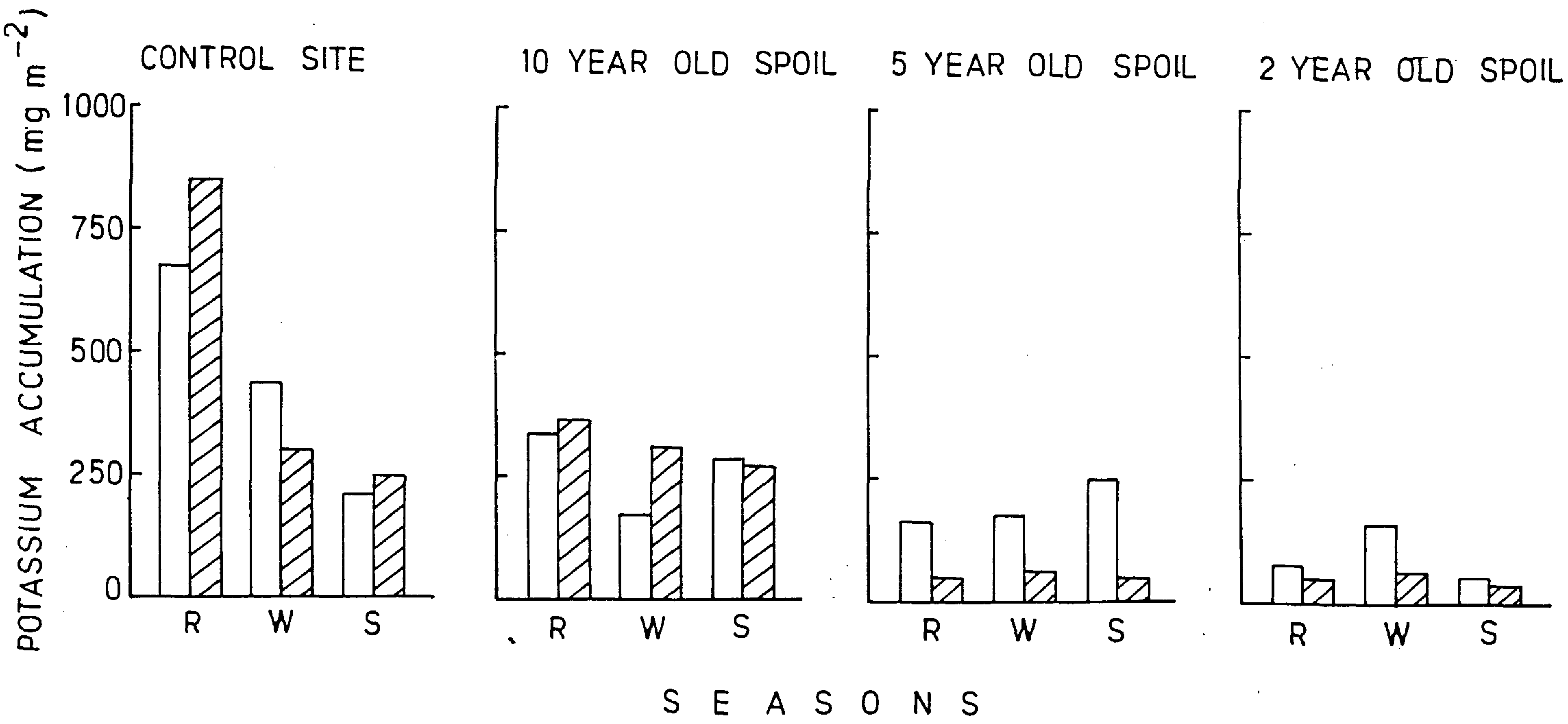


Fig. 7.3 - Seasonal variation in potassium accumulation (mg m^{-2}) in the below-ground compartment of vegetation growing on coal mine spoils of different ages and the control site. ☐ Root; ▨ Rhizome; R Rainy; W Winter; S Spring.

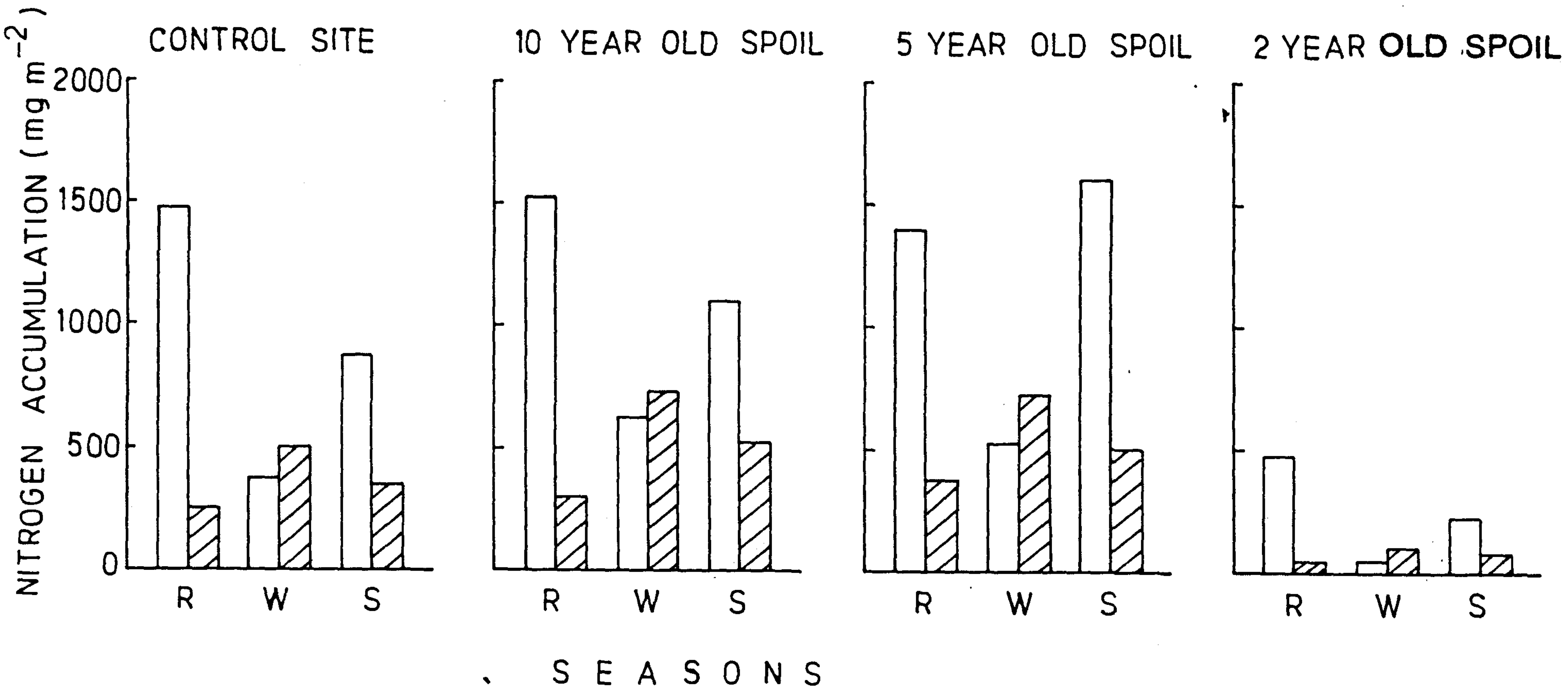


Fig. 7.4 - Seasonal variation in nitrogen accumulation (mg m^{-2}) in the live and standing dead parts of the aboveground compartment of vegetation growing on coal mine spoils of different ages and the control site. ☐ Live; ▨ Standing Dead; R Rainy; W Winter; S Spring.

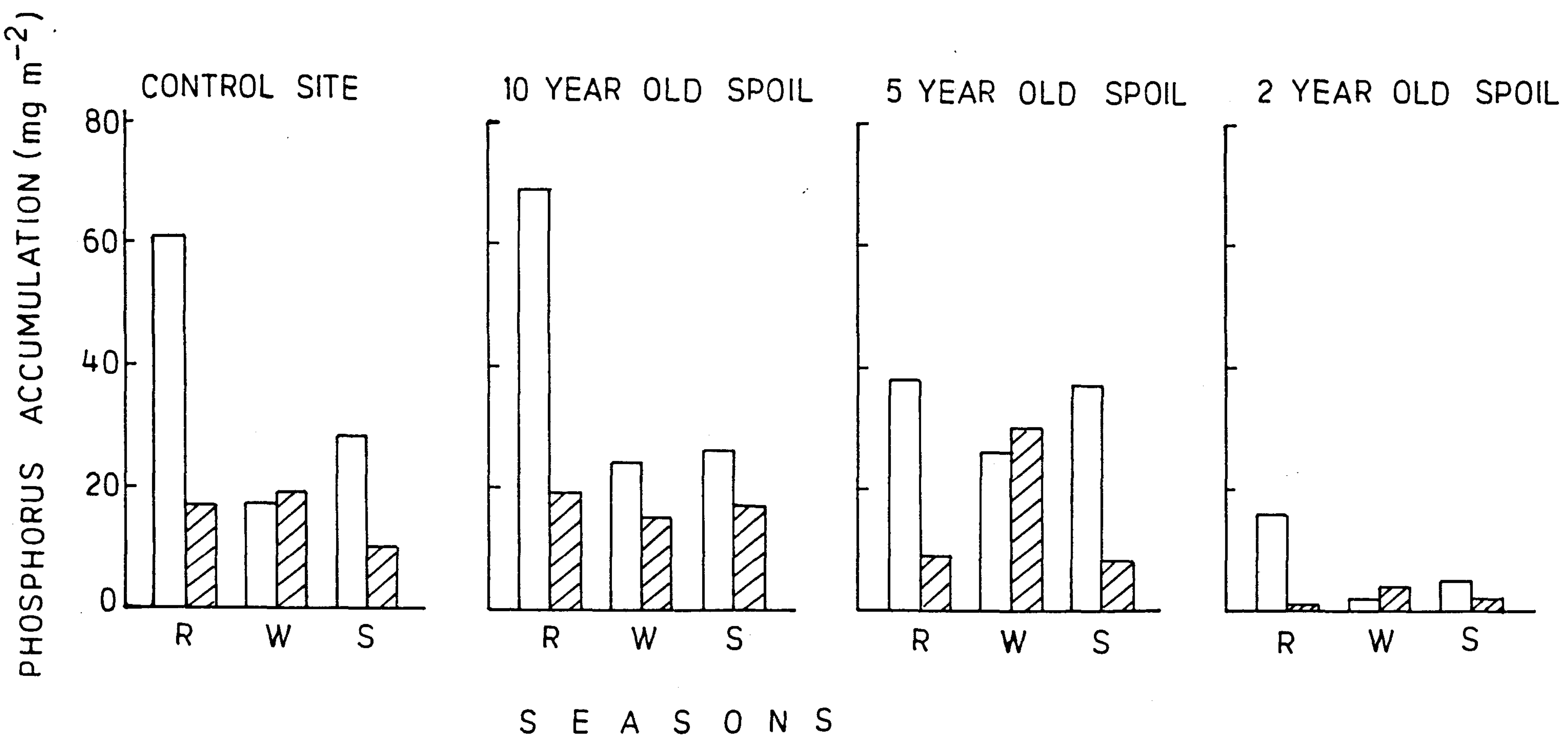


Fig. 7.5 - Seasonal variation in phosphorus accumulation (mg m^{-2}) in the live and standing dead parts of the aboveground compartment of vegetation growing on coal mine spoils of different ages and the control site. ☐ Live; ▨ Standing Dead; R Rainy; W Winter; S Spring.

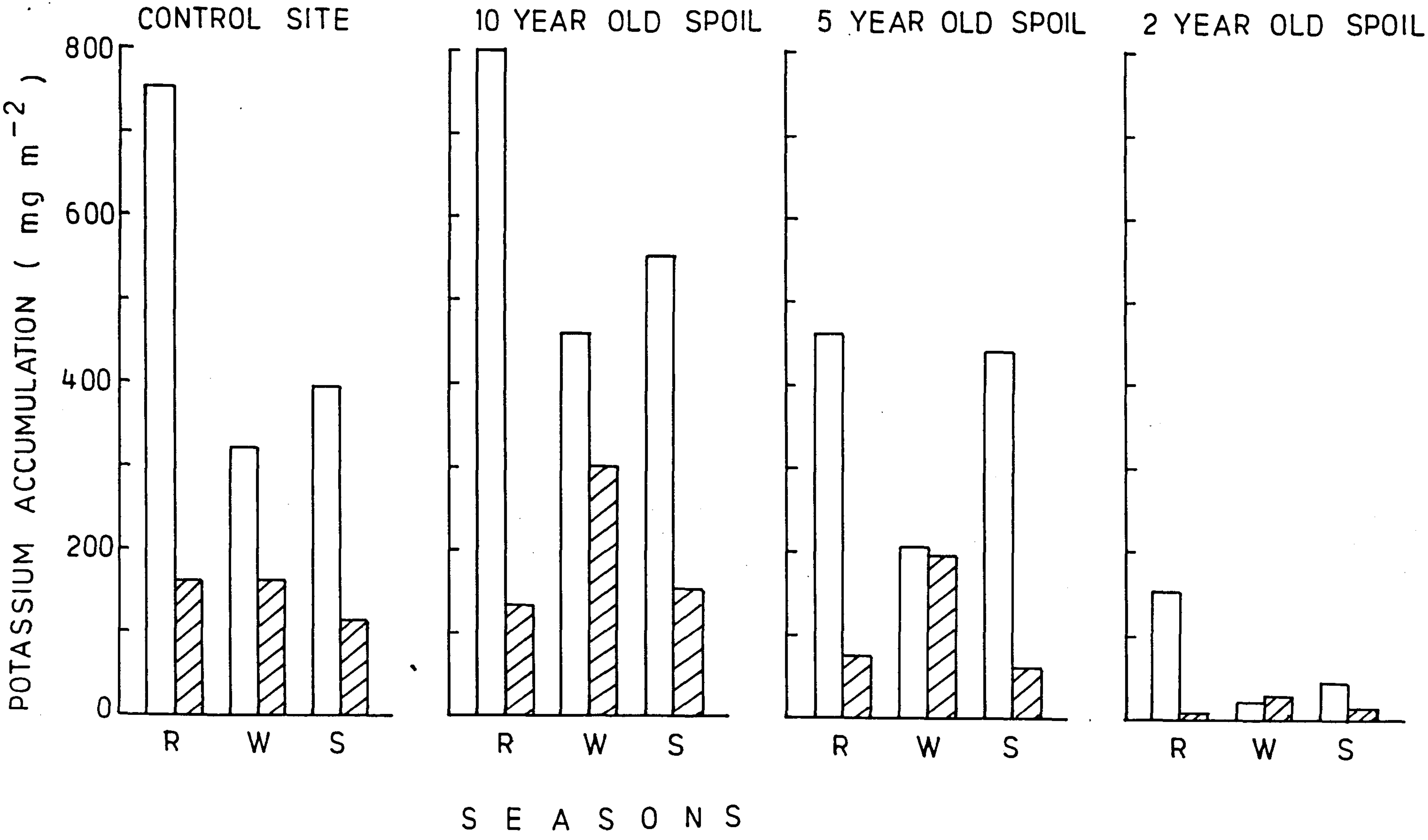


Fig. 7.6 - Seasonal variation in potassium accumulation (mg m^{-2}) in the live and standing dead parts of the aboveground compartment of vegetation growing on coal mine spoils of different ages and the control site.
☐ Live; ▨ Standing Dead; R Rainy; W Winter; S Spring.

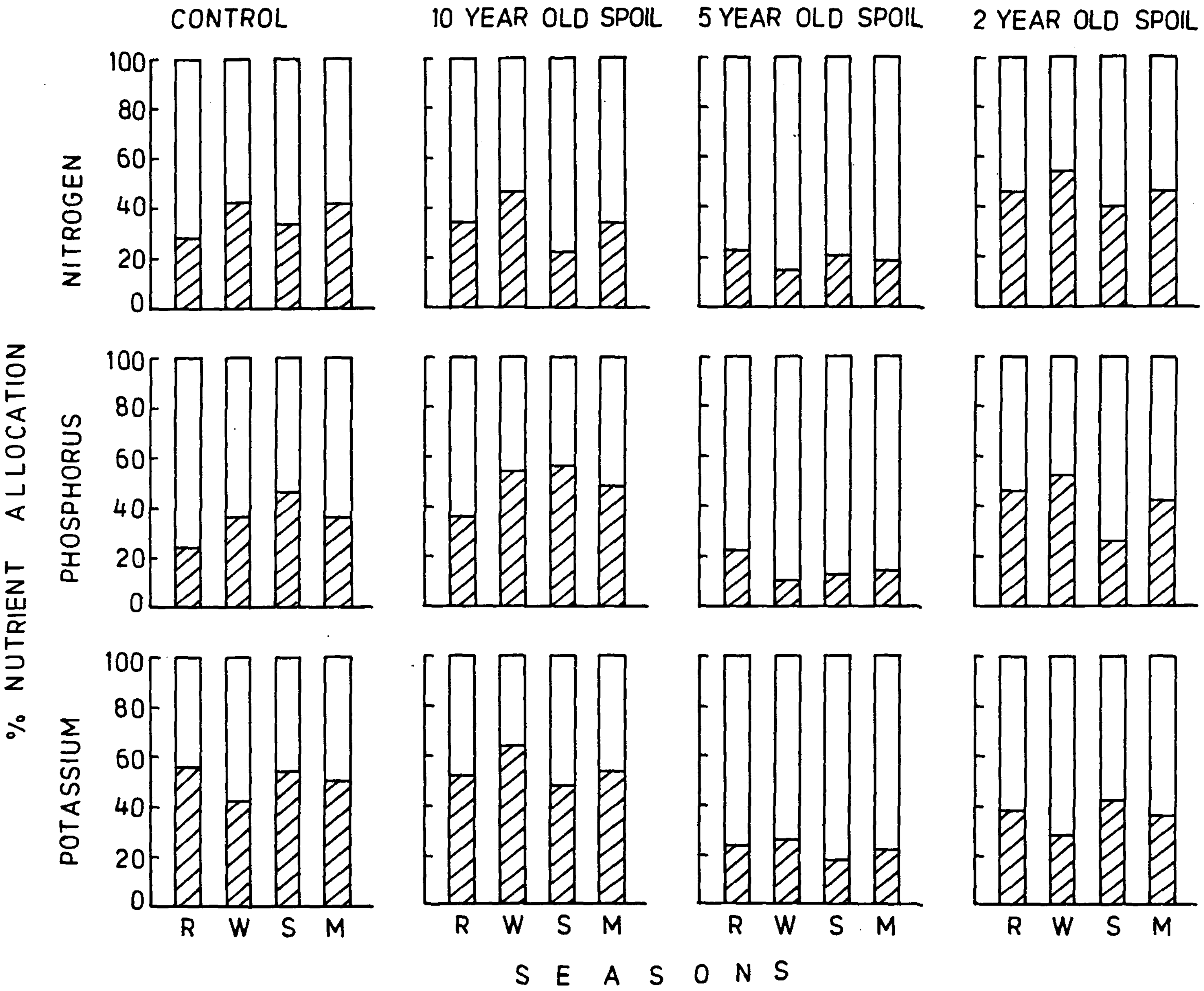


Fig. 7.7 - Seasonal variation in proportional allocation of nutrients to root and rhizome parts of the belowground compartment of vegetation growing on coal mine spoils of different ages and the control site. ☐ Root; ▨ Rhizome; R Rainy; W Winter; S Spring; M Seasonal Mean.

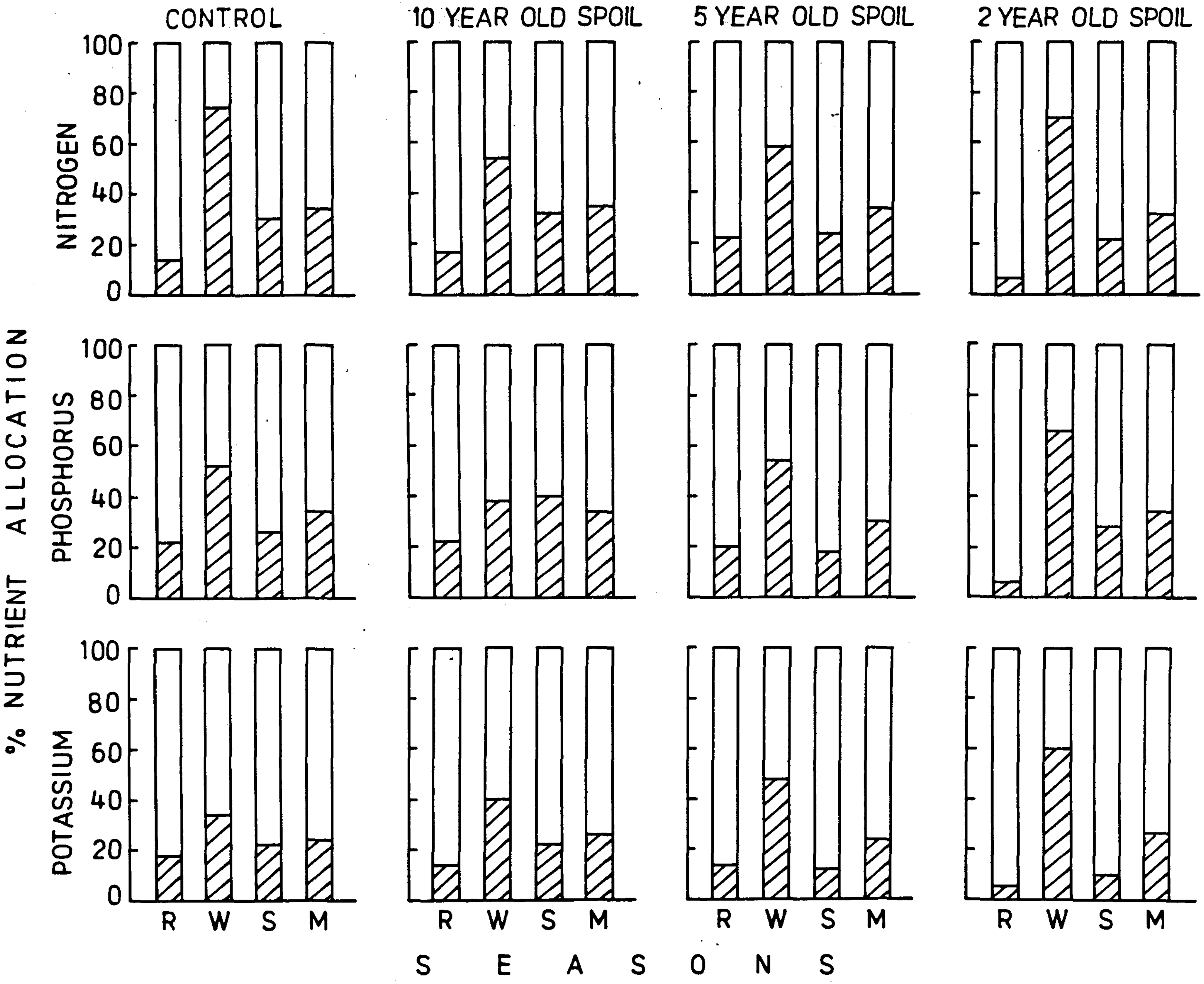


Fig. 7.8 - Seasonal variation in proportional allocation of nutrients to live and standing dead parts of the aboveground compartment of vegetation growing on coal mine spoils of different ages and the control site. □ Live; ▨ Standing Dead; R Rainy; W Winter; S Spring; M Seasonal Mean

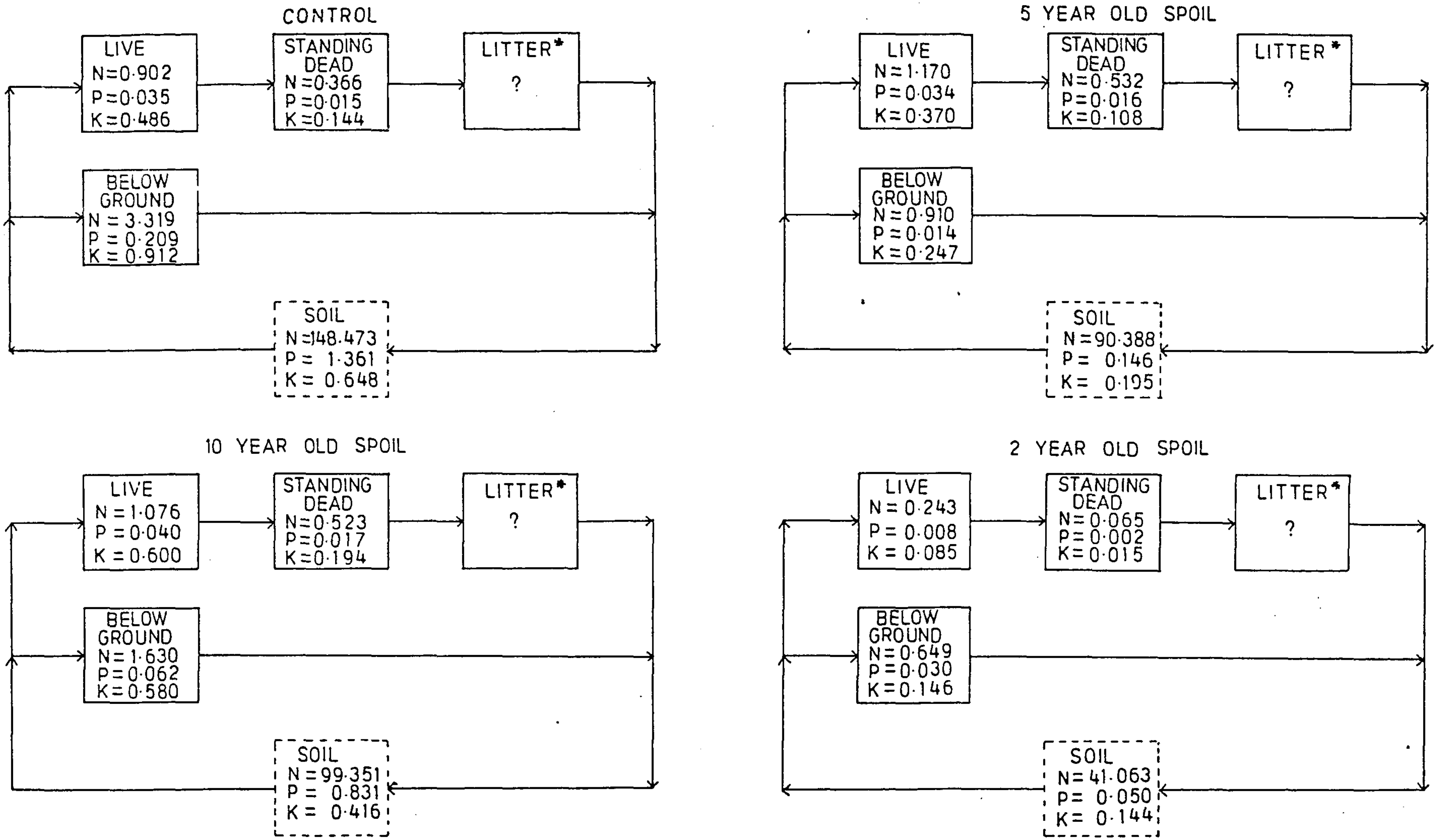


Fig. 7.9 - Mean standing state of nutrients (g m^{-2}) in the different ecosystem compartments of coal mine spoils of different ages and the control site. * Litter not available for sampling.

CHAPTER 8

GROWTH OF A FEW SELECTED SPECIES ON SOILS FROM UNMINED SITE AND COAL MINE SPOILS

INTRODUCTION

Lands disturbed due to mining activity present rigorous habitats where conditions are extremely unfavourable for plant growth. These lands should be restored to their original condition. If this is not possible, at least they should be reclaimed to an ecologically improved (compared to their present state) and aesthetically pleasing conditions. One of the important means of bringing about this kind of improvement is to introduce such plants on these degraded lands that are specially adapted to grow there.

The successful and economic restoration of vegetation on derelict or degraded land depends on overcoming the environmental factors limiting or restricting plant growth. Hence, it is important to know the species which are able to overcome the exacting environmental conditions and establish themselves successfully, otherwise both money and effort are likely to be wasted. Several species of legumes and grasses have been established and maintained for various uses within surface mined land reclamation programmes (POWELL *et al.* 1983, BARNHISEL *et al.* 1985). But these species, while they might have been successful in some parts of the world, may not be suitable for reclamation in this part.

Suitability of different plant species to a particular environmental conditions can be determined by analysing their growth and resource allocation pattern. HARPER & OGDEN (1970) emphasized the importance of studies on resource allocation (proportion of total dry matter stored in each plant part) in the identification of distinct ecological strategies. Most of the studies of resource allocation in plants are concerned with biomass allocation exclusively, although in many situations, plant growth is typically limited by water or nutrients rather than carbon (CHAPIN III 1980). In conditions with limited nutrient supply, allocation of nutrients is as important as the allocation of biomass (VAN ANDEL & VERA 1977). Several workers have also pointed out that mineral elements and biomass are frequently not allocated similarly (ABRAHAMSON & CASWELL 1982) and it has been known that nutrient concentration varies greatly between plant organs and at different growth stages.

The field observations indicated that *Axonopus compressus* (Poaceae) can grow on mine spoils. But *Eragrostiella leioptera* (Poaceae), though dominant on the control site, was not found on the spoils. Similarly *Erosaema chinense* (Fabaceae), the only legume frequently found on the control site was not recorded on the coal mine spoils. It is felt that perhaps these two species have not had the chance of reaching the spoils and once they reach there they might grow quite successfully. Hence an experiment was designed to study the growth response of all the above three species when grown on soils from the unmined (control) site and from the coal mine spoils of ages 5 and 10 years. Informations relating to this aspect may have implications for the restoration of mine spoils if an attempt is made to revegetate them using these plant species.

MATERIALS AND METHODS

In March 1992, soil samples were collected from the upper 15 cm layer of 15 1 m x 1 m quadrat from each mine spoil of ages 5 and 10 years and from the unmined grassland (control) of Jarain in Jaintia Hills district of Meghalaya. Samples from a given site were pooled together to make a composite sample and these were transported to Jowai. The soil samples were seived with a 2mm mesh sieve. Earthern pots of about 21 cm internal diameter and 19 cm depth having a basal drainage hole were numbered serially, and approximately 1.5 kg of sieved soil was put in each pot. The experimental design consisted of 3 soil types x 3 species x 3 harvests x 5 replicates thus involving a total of 135 pots. Seedlings of 2-3 leaf stage of *Axonopus compressus* and *Eragrostiella leioptera* and tubers of *Eriosaema chinense* which had just started sprouting were selected from the natural populations to serve as the propagules for raising plants in the experimental pots. The mean dry weight per seedling was 55 mg for *Axonopus compressus* and 64 mg for *Eragrostiella leioptera* and mean dry weight of tubers was 674 mg. A constant density of 4 plants per pot was maintained in the experimental pots. Planting of tubers and seedlings was done on the 10th of April 1992. Pots were completely randomized and kept in a polythene roofed net house.

Harvesting was done at two months interval corresponding to 60, 120 and 180 days after planting *i.e.* on 10th June, 10th August and 10th October 1992. At each harvest root length, plant height, leaf area and biomass of each component organ was determined for each species. For biomass estimation roots were throughly washed to remove adhering soil particles and the component plant parts were then separated, ovendried to constant weight at 80°C and weighed. From these data, three growth functions namely relative growh rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) (HUGHES & FREEMAN 1967, RADFORD 1967) were calculated as follows:

$$\mathrm{RGR} = \frac{\ln W_2 - \ln W_1}{(t_2 - t_1)}$$

$$\mathrm{NAR} = \frac{(W_2 - W_1)\ (\ln A_2 - \ln A_1)}{(A_2 - A_1)\ (t_2 - t_1)}$$

$$\mathrm{LAR} = \frac{(A_2 - A_1)\ (\ln W_2 - \ln W_1)}{(\ln A_2 - \ln A_1)\ (W_2 - W_1)}$$

where W_1 and A_1 are biomass and leaf area at time t_1 and W_2 and A_2 are the same at time t_2.

Total kjeldahl nitrogen (TKN) concentration of each component organ was determined by microKjeldahl procedure using Tecator Kjeltec Auto 1030 nitrogen analyser. Total nitrogen content of each organ was obtained by multiplying the N concentration in that organ with the corresponding biomass value. Analysis of nitrogen was performed in triplicates.

RESULTS

1. *Erisaema chinense* (Plate 8.1)

Biomass (Table 8.1). There was a significant difference ($P<0.05$) in total biomass of *E. chinense* grown on different soils at H_1. There was an increase in biomass from H_1 to H_2 in the case of the control soil, while no significant increase was observed in the case of the two mine spoils. But from H_2 to H_3 there was a slight decrease in the control soil and a drastic decrease in soil from the 5 year old spoil. At H_1, the biomass in the control soil was much lower than that in the mine spoils while at the subsequent harvests, lowest biomass was recorded when the plants grew on soil from the 5 year old spoil and highest when they were grown in the control soil.

Belowground/aboveground biomass ratio (Table 8.1) decreased drastically from H_1 to H_3.

Dry matter allocation. Percentage dry matter allocation to the different component organs of *E. chinense* is presented in Fig. 8.1. Major part of the dry matter was diverted towards the belowground parts on both control soil and mine spoils. Among the belowground parts, only a small percentage was allocated to the roots while the major part was allocated to the tuber. Allocation to the tuber decreased from H_1 to H_2, but it increased at H_3 in the control soil and 10 year old spoil. Allocation to the tubers was maximum when the plants were grown in soil from the 5 year old spoil. Allocation to the roots was low at H_1 on all the soils but it increased considerably at H_2 attaining the maximum value. Among the aboveground components, allocation was more to the leaves at H_1 and H_2 but it was more to the stem at H_3 on all the soils. Allocation to the stem increased from H_1 to H_3 and was maximum on the soil from the control site and minimum on the 5 year old spoil. Allocation to the reproductive parts was maximum when the plants were grown in soil from the control site.

Growth functions. The different growth functions namely RGR, NAR and LAR of *E. chinense* as affected by different soils are presented in Table 8.2. RGR in the control soil increased significantly from H_1 (0.004 g/g/day) to H_2 (0.007 g/g/day) but decreased drastically at H_3 (-0.0019 g/g/day). In the case of 5 year and 10 year old spoils, there was much decrease in RGR from H_1 to H_2. But while there was an increase from H_2 to H_3 on the 10 year old spoil, there was further decrease on the case of the 5 year old spoil.

Much increase was observed in the NAR from H_1 to H_2 and the increase being much greater on the control soil than on the two mine spoils. But from H_2 to H_3 there was a drastic decrease in the case of the control soil and 5 year old spoil resulting in negative values, while there was only a slight decrease in the case of the 10 year old spoil.

The LAR also increased tremendously from H_1 to H_2 and increased further at H_3. At H_2, highest LAR was observed in the control soil and lowest in the 5 year old spoil, while at H_3 highest value was observed in the 10 year old spoil.

Total Nitrogen Concentration (Table 8.3). At H_1 concentration of total nitrogen was maximum in the leaves and minimum in the tuber on all the three soils and there was no significant variation due to soil types. At H_2, concentration decreased in all the organs and in all the three soils except in root in the case of the mine spoils where concentration was observed to increase. At H_2 variation in concentration due to soil types was not significant except in the reproductive parts where significant variation ($P<0.01$) was observed due to soil types, minimum value being in the case of 5 year old spoil and maximum in the control soil. At H_3 concentration in the root increased in the 5 year old spoil and the control soil.

Total Nitrogen Content (Table 8.4). Nitrogen content varied widely in the different component organs of *Eriosaema chinense*. Maximum amount of nitrogen was observed in the tuber and minimum in the stem at all harvests and in all the three soils.

Nitrogen allocation (Fig 8.2). In *E. chinense*, major part of total nitrogen was allocated towards the tuber. But this allocation was much lower in the control soil compared to the mine spoils at all harvests. Maximum percentage of nitrogen was observed in the tuber at H_1, which decreased drastically at H_2 but increased again at H_3. Allocation to the roots was much greater on the control soil than on the mine spoils. In case of the stem, there was an increase in allocation with harvests, but variation due to different soils was not significant. Allocation towards leaves and reproductive parts was much higher on the soil from the control site than on the mine spoils. But percentage of the standing dead was maximum in soil from the 10 year old spoil.

2. *Axonopus compressus* (Plate 8.2)

Biomass (Table 8.5). Total biomass of *Axonopus compressus* increased tremendously from H_1 to H_3 in all the three soils. At

H_1, total biomass was found to be maximum on the soil from the control site and minimum on the 5 year old spoil. But no significant variation due to the soils was observed at subsequent harvests.

There was a decrease in belowground/aboveground biomass ratio from H_1 to H_3. At H_1, this ratio was least in the 10 year old spoil, at H_2 in the 5 year old spoil, while at H_3 it was least in the control soil (Table 8.5).

Dry matter allocation. Percentage dry matter allocation to the different organs of *Axonopus compressus* is presented in Fig. 8.3. Major part of the dry matter was allocated to the roots on all the soils and at all the three harvests. On the control soil, allocation to the root was maximum at H_1 while at the subsequent harvests it decreased considerably. A similar trend was observed on the 5 year old spoil. But on the 10 year old spoil, there was no significant difference in the allocation towards the roots between the three harvests. Allocation to the rhizome was very low at all the harvests and on all the soils. Allocation towards the green leaves was maximum at H_2. Further, it was maximum in the 10 year old spoil. The percentage of dry matter as standing dead was maximum on the 10 year old mine spoil at H_1 and H_3. Maximum percentage of standing dead was observed at H_3 on the control soil, while on both the mine spoils, it was maximum at H_1. Maximum allocation to the reproductive part was observed in soil from the 5 year old spoil and minimum in soil from the 10 year old spoil at H_2, while at H_3 minimum value was observed on the 5 year old spoil. The reproductive allocation did not differ significantly between the 10 year old spoil and the control soil.

Growth functions. The different growth functions namely RGR, NAR and LAR of *Axonopus compressus* are presented in Table 8.6. RGR of *A. compressus* was quite high at H_1 but it decreased at subsequent harvests in the case of the control soil and 10 year old spoil. At H_1, highest RGR value was observed on the control soil and lowest on the 5 year old spoil, however, at H_2, a reverse trend was observed. At H_3, on the other hand, the lowest value was observed on the 10 year old spoil. The NAR, was initially quite high but at H_2 and H_3 it decreased considerably. At H_1 and H_2, highest value was observed in the 5 year old spoil while at H_3, highest value was observed in control soil. LAR did not vary significantly with harvests in the case of the control soil, but it varied significantly when the plants grew on soils from the mine spoils. At H_1, it was quite low, but it increased tremendously at H_2. There was a decrease in LAR from H_2 to H_3 except on the 5 year old spoil where there was an increase in LAR.

Nitrogen Concentration (Table 8.7). Variation in nitrogen concentration in the different component organs of *Axonopus compressus* due to different harvests and soil types was not large except during the first harvest in the case of leaves where the N concentration was significantly ($P<0.01$) higher in comparison to the other organs.

Total Nitrogen Content (Table 8.8). Total nitrogen content in the different component organs of *A. compressus* varied widely with soils and with harvests. At H_1 and H_3 maximum amount of nitrogen was present in the roots and leaves and minimum in the rhizomes. At H_2 maximum value was observed in the leaves and minimum in the standing dead. Nitrogen content increased in all the organs of the plant from H_1 to H_2 except for standing dead, which did not all the soils. Nitogen content per plant increased from H_1 to H_3 in all the soils and also it was much higher when the plants were grown on the control soil than when they were grown on the mine spoils .

Total Nitrogen Allocation (Fig 8.4). In *Axonopus compressus*, in the control soil and 5 year old spoil allocation of nitrogen was highest to the root, but on the 10 year old spoil it was highest in the leaves. The amount allocated to the root was highest at H_1, but it decreased at H_2 and increased again at H_3 in all the soils. The amount allocated to the standing dead was highest at H_1 and lowest at H_2 on all the soils. In the control soil and on the 5 year old spoil, the amount allocated to the reproductive part was highest at H_2. Minimum amount of nitrogen was allocated to the rhizome in all the soils and at all the harvests.

3. *Eragrostiella leioptera* (Plate 8.3)

Biomass (Table 8.9). At H_1, there was no significant variation between the biomass on the control soil and 5 year old spoil, but biomass on the 10 year old spoil was much lower than that on the other two soils. At H_2, biomass on the control soil was much higher than on the mine spoils, and the lowest biomass was recorded on the 5 year old spoil. At H_3, biomass on the 5 year old spoil was much lower than on the other two soils.

Belowground/aboveground ratio (Table 8.9). At H_1, the ratio was less than unity, and highest value was observed on the 5 year old spoil and lowest on the 10 year old spoil. At H_2, highest and lowest values were observed on the 5 year and 10 year old spoils respectively. At H_3, this ratio was greater than unity on all soils and highest and lowest values were observed on the control soil and 5 year old spoil, respectively.

Dry matter allocation (Fig 8.5). At H_1 and H_2, maximum percentage of dry matter was allocated towards the leaves except on the 5 year old spoil where it was maximum towards the standing dead. At H_3, allocation was slightly higher to the root than to the leaves except on the 5 year old spoil. Allocation towards the leaves decreased from H_1 to H_3 in soil from the control site and 10 year old spoil, while on the 5 year old spoil, there was an increase from H_1 to H_2 and no significant difference was observed between the values recorded at H_2 and H_3. On the control soil, allocation towards the roots was lower at H_2 compared to the other two harvests. On the 10 year old spoil, there was no significant difference in allocation to the roots between H_1 and H_2, but there was a marked increase in the allocation at H_3. On the 5 year old spoil, there was an increase in allocation to the roots and rhizomes from H_1 to H_3. The standing dead (%) was highest at H_1 on all the soils. The maximum value for standing dead was recorded on the 5 year old spoil and minimum on the control soil at H_1 and H_2 while at H_3 maximum value was observed on the 10 year old spoil.

Growth functions (Table 8.10). On the control soil, RGR of *Eragrostiella leioptera* increased only slightly from H_1 to H_2, but it decreased sharply at H_3 registering a negative value. On the 10 year old spoil RGR increased significantly from H_1 to H_2, but on the 5 year old spoil, RGR decreased from H_1 to H_2 and increased again at H_3. At H_1, minimum RGR was observed on the 10 year old spoil. The RGR values were equal on the control soil and 5 year old spoil. At H_2, minimum value for RGR was recorded on the 5 year old spoil and maximum in soil from the control. At H_3, however, maximum RGR was recorded on the 10 year old spoil, and minimum on the control soil.

NAR on the control soil decreased from H_1 to H_3 on the 10 year old spoil it increased slightly from H_1 to H_2, but there was a sharp increase from H_2 to H_3. On the 5 year old spoil NAR decreased sharply from H_1 to H_2, but it increased again at H_3. At H_1, maximum and minimum values were recorded on the 5 year and 10 year old spoils respectively. At H_2, maximum and minimum values were recorded on the control soil and 5 year old spoil respectively. At H_3, maximum value was recorded on the 10 year old spoil and minimum on the control soil. LAR on the control soil and 5 year old spoil increased from H_1 to H_3, but on the 10 year old spoil it increased from H_1 to H_2, whilst from H_2 to H_3 it decreased. At each harvest minimum value for LAR was recorded on the 5 year old spoil and maximum on the control soil.

Total Nitrogen Concentration (Table 8.11): Variations in nitrogen concentration in the different component organs of *E. leioptera* due to soils and at different harvests were not significant. But there was a wide variation in the concentration of nitrogen in the different organs. On all the soils, and at all harvests maximum concentration was observed in the rhizome and minimum in the standing dead.

Total Nitrogen Content (Table 8.12): Nitrogen content in all the component organs of *E. leioptera* was extremely low, but in each organ there was an increase in the content from H_1 to H_3 on all soils. Total nitrogen content per plant was significantly higher on the control soil than on the mine spoils.

Total Nitrogen Allocation (Fig 8.6): Major portion of nitrogen on the control soil was shared more or less equally among the root, rhizome and leaves and very little percentage was present in the standing dead. On the 10 year old spoil, at H_1 about 50% of the total plant nitrogen was allocated to the leaves while the rest was shared equally among the root, rhizome and the standing dead compartments. At H_2 and H_3, nitrogen was distributed more or less equally among the root, stem and leaves. On the 5 year old spoil, major portion was allocated more or less equally towards the rhizome and leaves at H_2 and H_3, however, at H_1, quite a high proportion of the plant N was present in the standing dead.

Analysis of variance shows that variation due to species at different harvests and soils was highly significant for biomass ($P<0.01$), RGR ($P<0.01$), NAR ($P<0.01$), LAR ($P<0.01$) and total nitrogen content ($P<0.01$). Biomass and nitrogen accumulation were greater in *E. chinense* and *A. compressus* than in *E. leioptera*. The values for the various growth functions were relatively greater for *A. compressus* than for the other two species, indicating its potential for better growth on the mine spoils.

DISCUSSION

Despite the large variation in the standing state of nutrients in the three different soils (as evident from data presented in Chapter 4 & 7), the effect of soils on growth of any of the three species namely *Eriosaema chinense, Axonopus compressus* and *Eragrostiella leioptera*, was not very strong. Total biomass of *E. chinense* increased from H_1 to H_2, but at H_3 there was a decline in total biomass which was due to the decrease in the aboveground biomass attributable to senescence and shedding of leaves. An important feature of biomass allocation pattern in *E. chinense* is the allocation of a high proportion of energy towards the belowground parts particularly the tuber, and extremely reduced allocation to sexual reproductive organs, which suggests that this species is least dependent on sexual reproduction for its population growth and it relies more on vegetative mode of propagation. An increase in the aboveground biomass allocation accompanied by a decrease in the belowground biomass on all the three soils indicates rapid transfer of resources from below to aboveground organs to maximize photosynthesis. However at H_3, there was an increase in the allocation towards the tuber. In the mine spoils, the transfer of resources was not as rapid as in the case of the control soil. Allocation towards the roots was much lower on the mine spoils compared to that on the control soil. This is probably related to high acidity of the mine spoils, which inhibits root growth (MARSCHNER 1991). The greater allocation towards the stem and the leaves may be related to the need of the plant to grow taller and develop photosynthetic apparatus for efficient photosynthesis. However at H_3, allocation to the leaves decreased and the proportion of the standing dead increased probably because of senescence due to advancing age.

The tremendous increase in the biomass of *Axonopus compressus* through the harvests is probably because of better growth of its root system coupled with the efficient photosynthetic activity due to larger leaf area. This also probably accounts for a higher belowground/aboveground biomass ratio which was usually greater than one except on the 10 year old spoil where it was slightly lesser than one.

Unlike *Eriosaema chinense*, allocation of dry matter in *A. compressus* was more towards the roots at all harvests and on all the three soils. This is a mechanism to maximize nutrient intake through a larger root system (CHAPIN III 1980) rather than through a high nutrient absorbing capacity (NYE 1977, NYE & TINKER 1977). Among the aboveground parts, more biomass was allocated towards the leaves. On the mine spoils relatively greater proportion of the biomass was present in the standing dead. This is probably related to the nutrient deficiency of mine spoils which enhances senescence of leaves. In *A. compressus*, a good proportion of biomass was allocated towards the reproductive organ, which indicates that this species, in contrast to *E. chinense*, lays more emphasis on sexual reproduction.

Though biomass accumulation in *Eragrostiella leioptera* also increased through the harvests, the increase was not to that extent as was observed in the case of *Axonopus compressus*. Belowground/aboveground biomass ratio increased at the later harvests and it was generally greater than one indicating that in this species more emphasis is laid on the belowground biomass accumulation.

Allocation of dry matter in *E. leioptera* at H_1 and H_2 was more towards the leaves suggesting that the plants under stress condition develops a strategy to increase the photosynthetic area for greater assimilation efficiency. On the mine spoils a good percentage of biomass was allocated towards the standing dead at H_1 which is probably related to the poor absorption of essential nutrients leading to premature dying of plant parts. A very low allocation to the sexual reproductive parts and high allocation to the rhizome in *Eragrostiella leioptera* suggest that this species lays more emphasis on the vegetative reproduction than sexual reproduction. This is in agreement with RAM & RAMAKRISHNAN (1988).

Relative growth rate (RGR) is usually highest in the early vegetative phase and lowest at maturity when leaves become senescent (BLACKMAN 1968). *Axonopus compressus* showed better RGR compared to *Eriosaema chinense* and *Eragrostiella leioptera* and this confers on it an advantage over the other two species. The decline in RGR in all the three species during the H_3 could be attributed to the progressive fall of leaves. This is supported by the findings of PANDEY & SINHA (1977) and PRADHAN (1990). *Eriosaema chinense* and *Eragrostiella leioptera* showed negative growth rate at H_3 - a consequence of negative net assimilation rate (NAR), which indicates a greater loss of carbon during respiration compared to the photosynthetic gains during this period. This was largely due to abscission and shedding of leaves. RGR in plants is dependent upon net assimilation rate

(NAR) and leaf area ratio (LAR). The NAR and LAR values for *Axonopus compressus* being higher during the first two harvests, its RGR was also high during this period. Increase in NAR of *Eriosaema chinense* at H_2 is due to expansion of leaves during this period. Under favourable conditions for growth, the rate of increase in dry weight is mainly determined by carbon assimilation rate which is directly related to the activity of leaves. A large LAR of *Axonopus compressus* is an important attribute in enabling it to grow successfully under stress condition.

Despite the large variation in the standing state of nitrogn in the soil (Chapter 4 & 7), nitrogen concentration in a given plant part of any of the three species did not differ significantly due to soil type. However, concentration in different organs of each species varied widely. In all the three species, maximum nitrogen concentration was observed in the leaves on all the three soils. This is probably related to their various metabolic activities, e.g. chlorophyll synthesis, protein synthesis etc. Nitrogen concentration was maximum in the leaves of *Eriosaema chinense* and *Axonopus compressus* at H_1 and in *Eragrostiella leioptera* at H_2. This is probably due to the flush of newgrowths as also reported by SARMA (1985) and UMA SHANKAR 1991. However, with the increasing plant growth, the plant nitrogen concentration decreased, which may be attributed to depletion of nitrogen during rapid growth phase (VAN ANDEL & VERA 1977, BORAL 1993). Nitrogen concentration drastically decreased in leaves of *Eriosaema chinense* and *Axonopus compressus* at H_3 indicating a large withdrawal of nitrogen from leaves before abscission (MORTON 1977, CHATURVEDI *et al.* 1988, UMA SHANKAR 1991). In *Eriosaema chinense* and *Axonopus compressus*, nitrogen concentration was higher in the root than in the tuber/rhizome. This is probably related to higher metabolic activity of the former (UMA SHANKAR 1991). But in the case of *Eragrostiella leioptera* concentration was more in the rhizome than in the roots. *Eragrostiella leioptera* being a tussock perennial grass, there could be a withdrawal of nitrogen from the leaves for storage in the living tussock materials as was reported by MORTON (1977) in *Molinea caerulea.*

A very significant variation in nitrogen accumulation was observed in the three species. The amount of nitrogen per plant was quite high in *Eriosaema chinense* followed by *Axonopus compressus* and then by *Eragrostiella leioptera.* This could be attributed to comparatively much greater biomass accumulation in *E. chinense* and high concentration of nitrogen in some of its organs. *Eragrostiella leioptera*, on the other hand, had the least amount of nitrogen due to its very low biomass and low nitrogen concentration.

The analysis of allocation strategy on the basis of biomass alone (HARPER 1977) does not give a complete picture. Studies of SAXENA & RAMAKRISHNAN (1983), SHARMA (1985) suggest that nutrient allocation strategy is equally important particularly for reproductive growth.

In *Eriosaema chinense*, major part of nitrogen was allocated towards the tuber at all the three harvests. This is a mechanism to store organic food and nutrients in the tuber in order to bring about efficient vegetative reproduction using the food resources. The larger allocation of available resources to the belowground organs of regeneration indicates that this species lays more emphasis on vegetative reproduction (KEELY & KEELY 1977). Allocation towards the tuber declined drastically at H_2 and increased at H_3, indicating thereby a rapid transfer of nitrogen from the tuber to the aboveground organs such as leaves and reproductive organs, and from the leaves back to the tuber prior to abscission. A good percentage was also allocated towards sexual reproductive organs during the second harvest indicating that *Eriosaema chinense* also lays some emphasis on sexual reproduction.

In *Axonopus compressus* there was very low allocation towards the rhizome and a good percentage was allocated towards the sexual reproductive organs indicating that the plant lays emphasis on sexual reproduction. *Eragrostiella leioptera*, on the other hand, lays more emphasis on the vegetative reproduction as indicated by high percentage allocation of nitrogen towards the rhizome.

It may be concluded that *Axonopus compressus* and *Eriosaema chinense* are better suited for reclamation of mined land than *Eragrostiella leioptera* by virtue of their higher growth rate, more efficient absorbing and photosynthetic systems and their capacity to reproduce by both sexual and vegetative means.

Table 8.1 - Total biomass per plant (g) and belowground/above ground biomass ratio of *Eriosaema chinense* as affected by soil from the mined and unmined (control) sites. ±SE of means.

Harvests	Biomass	Control	10 year old spoil	5 year old spoil
H_1	Total Biomass	0.848 ±0.08	0.994 ±0.12	0.964 ±0.13
	Bg/Ag biomass ratio	5.19	8.47	8.54
H_2	Total Biomass	1.314 ±0.13	1.019 ±0.11	0.988 ±0.10
	Bg/Ag biomass ratio	1.67	1.89	3.37
H_3	Total Biomass	1.206 ±0.09	1.056 ±0.13	0.614 ±0.07
	Bg/Ag biomass ratio	2.27	1.88	2.68

Bg-Belowground, Ag-Aboveground

Table 8.2 - Growth functions of *Eriosaema chinense* as affected by soil from the mined and unmined (control) sites

Soil source	Relative Growth Rate (RGR) g/g/day			Net Assimilation Rate (NAR) mg/cm^2/day			Leaf Area Ratio (LAR) cm^2/g		
	60 Days	120 Days	180 Days	60 Days	120 Days	180 Days	60 Days	120 Days	180 Days
control	0.004	0.007	-0.001	0.000	0.400	-0.060	0.000	18.427	21.981
10 year old spoil	0.007	0.000	0.001	0.000	0.030	0.020	0.000	15.819	20.298
5 year old spoil	0.006	0.000	-0.008	0.000	0.030	-0.360	0.000	12.973	22.082

Table 8.3 - Nitrogen concentration (%) in different component organs (and standing dead parts) of *Eriosaema chinense* as affected by soil from the mined and unmined sites.

	After 60 days growth			After 120 days growth			After 180 days growth		
Organs	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil
Root	1.902 ±0.04	1.921 ±0.01	2.045 ±0.04	1.521 ±0.15	2.133 ±0.04	2.057 ±0.03	1.962 ±0.008	1.884 ±0.01	2.198 ±0.04
Tuber	1.222 ±0.03	1.273 ±0.01	1.370 ±0.00	1.159 ±0.05	1.124 ±0.02	1.247 ±0.00	1.330 ±0.05	1.311 ±0.01	1.422 ±0.00
Stem	1.730 ±0.03	1.722 ±0.03	1.642 ±0.01	1.163 ±0.03	1.419 ±0.02	1.186 ±0.05	1.088 ±0.02	1.002 ±0.05	1.182 ±0.00
Green leaves	2.353 ±0.04	2.361 ±0.03	2.479 ±0.04	2.079 ±0.01	2.396 ±0.10	2.104 ±0.13	1.282 ±0.01	1.536 ±0.01	2.002 ±0.02
Standing dead	-	-	-	-	-	-	2.015 ±0.04	1.106 ±0.11	1.417 ±0.02
Reproductive part	-	-	-	2.043 ±0.06	1.817 ±0.19	1.673 ±0.02	1.737 ±0.00	1.126 ±0.14	0.837 ±0.02

- No biomass
± SE of means

Table 8.4 – Nitrogen content (mg/plant) in different component organs (and standing dead parts) of *Eriosaema chinense* as affected by soil from the mined and unmined (control) sites.

Organs	After 60 days growth			After 120 days growth			After 180 days growth		
	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil
Root	1.0 ±0.2	0.8 ±0.1	0.7 ±0.1	2.9 ±0.5	1.9 ±0.2	1.3 ±0.3	2.6 ±0.4	1.7 ±0.3	0.8 ±0.1
Tuber	8.0 ±0.3	9.5 ±0.5	11.4 ±0.3	7.3 ±0.5	6.5 ±0.7	8.7 ±0.4	9.4 ±0.5	7.8 ±0.3	5.8 ±0.2
Green leaves	2.4 ±0.4	1.6 ±0.3	1.8 ±0.4	4.7 ±0.6	4.6 ±0.4	3.2 ±0.3	1.9 ±0.2	1.3 ±0.4	1.3 ±0.2
Stem	0.6 ±0.1	0.6 ±0.2	0.5 ±0.0	1.7 ±0.13	1.3 ±0.2	0.7 ±0.2	1.7 ±0.3	1.4 ±0.3	0.8 ±0.1
Standing dead	-	-	-	-	-	-	0.3 ±0.0	1.2 ±0.1	0.3 ±0.0
Reproductive part	-	-	-	2.5 ±0.2	1.3 ±0.2	0.2 ±0.0	0.8 ±0.1	0.4 ±0.1	0.1 ±0.0
Total/plant	12.0 ±1.0	12.5 ±1.1	14.4 ±0.8	19.1 ±1.9	15.6 ±1.7	14.1 ±1.2	16.7 ±1.5	13.8 ±1.5	9.1 ±0.6

± SE of means

Table 8.5 - Total biomass per plant (g) and belowground/above ground biomass ratio of *Axonopus compressus* as affected by soil from the mined and unmined (control) sites.

Harvests	Biomass	Control site	10 year old spoil	5 year old spoil
H_1	Total Biomass	0.272 ±0.03	0.225 ±0.03	0.175 ±0.02
	Bg/Ag biomass ratio	1.37	0.88	1.22
H_2	Total Biomass	0.576 ±0.09	0.576 ±0.05	0.533 ±0.06
	Bg/Ag biomass ratio	0.82	0.87	0.70
H_3	Total Biomass	0.941 ±0.22	0.814 ±0.04	0.896 ±0.18
	Bg/Ag biomass ratio	0.71	0.77	0.78

Bg-Belowground, Ag-Aboveground
± SE of means

Table 8.6 - Growth functions of *Axonopus compressus* as affected by soil from the mined and unmined (control) sites

Soil source	Relative Growth Rate (RGR) g/g/day			Net Assimilation Rate (NAR) mg/cm^2/day			Leaf Area Ratio (LAR) cm^2/g		
	60 Days	120 Days	180 Days	60 Days	120 Days	180 Days	60 Days	120 Days	180 Days
Control site	0.027	0.013	0.008	0.370	0.170	0.120	71.413	72.809	68.354
10 year old spoil	0.023	0.016	0.006	0.370	0.160	0.070	48.695	96.091	85.483
5 year old spoil	0.019	0.019	0.009	0.400	0.240	0.100	36.342	78.669	84.557

Table 8.7 - Nitrogen concentration (%) in different component organs of *Axonopus compressus* as affected by soil from the mined and unmined sites.

Organs	After 60 days growth			After 120 days growth			After 180 days growth		
	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil
Root	1.105 ±0.01	1.056 ±0.03	1.042 ±0.01	0.879 ±0.04	0.656 ±0.01	0.923 ±0.01	1.008 ±0.01	0.798 ±0.01	0.885 ±0.00
Rhizome	0.868 ±0.04	0.792 ±0.07	0.700 ±0.03	1.087 ±0.08	0.962 ±0.02	0.876 ±0.03	0.831 ±0.08	0.545 ±0.01	0.801 ±0.07
Green leaves	1.895 ±0.00	1.679 ±0.07	1.843 ±0.09	1.552 ±0.05	1.255 ±0.02	1.510 ±0.01	1.500 ±0.09	1.308 ±0.09	1.597 ±0.00
Standing dead	0.801 ±0.07	0.845 ±0.00	0.979 ±0.04	0.657 ±0.03	0.562 ±0.03	0.707 ±0.08	0.627 ±0.02	0.500 ±0.01	0.586 ±0.01
Reproductive part	-	-	-	1.510 ±0.08	1.227 ±0.11	1.210 ±0.02	0.685 ±0.02	0.633 ±0.00	0.769 ±0.02

- No biomass
± SE of means

Table 8.8 - Nitrogen content (mg/plant) in different component organs of *Axonopus compressus* as affected by soil from the mined and unmined (control) sites.

Organs	After 60 days growth			After 120 days growth			After 180 days growth		
	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil
Root	1.3 ±0.3	0.8 ±0.1	0.7 ±0.1	1.7 ±0.2	1.4 ±0.1	1.6 ±0.1	3.0 ±0.3	2.0 ±0.2	2.9 ±0.2
Rhizome	0.3 ±0.1	0.3 ±0.1	0.2 ±0.1	0.7 ±0.1	0.5 ±0.0	0.4 ±0.0	0.7 ±0.2	0.5 ±0.1	0.5 ±0.1
Green leave	1.1 ±0.1	0.9 ±0.2	0.6 ±0.2	2.4 ±0.3	2.3 ±0.2	2.3 ±0.2	2.5 ±0.1	1.2 ±0.3	3.2 ±0.4
Standing dead	0.5 ±0.2	0.6 ±0.2	0.4 ±0.1	0.4 ±0.1	0.4 ±0.1	0.4 ±0.1	1.4 ±0.1	1.1 ±0.1	1.0 ±0.1
Reproductive part	-	-	-	1.4 ±0.08	0.8 ±0.11	1.2 ±0.20	1.1 ±0.18	0.9 ±0.10	1.0 ±0.12
Total/Plant	3.2 ±0.6	2.6 ±0.5	1.9 ±0.8	6.6 ±0.7	5.4 ±0.5	5.9 ±0.6	8.7 ±0.9	5.7 ±0.8	8.6 ±0.8

- No biomass
± SE of means

Table 8.9 - Total biomass per plant (g) and belowground/above ground biomass ratio of *Eragrostiella leioptera* as affected by soil from mined and unmined (control) sites.

Harvests	Biomass	Control site	10 year old spoil	5 year old spoil
H_1	Total Biomass	0.118 ±0.01	0.080 ±0.01	0.120 ±0.01
	Bg/Ag biomass ratio	0.84	0.54	0.91
H_2	Total Biomass	0.273 ±0.02	0.136 ±0.03	0.166 ±0.03
	Bg/Ag biomass ratio	0.87	1.00	1.05
H_3	Total Biomass	0.523 ±0.03	0.512 ±0.13	0.305 ±0.06
	Bg/Ag biomass ratio	1.20	1.17	1.02

Bg-Belowground, Ag-Aboveground
± SE of the mean

Table 8.10 - Growth functions of *Eragrostiella leioptera* as affected by soil from the mined and unmined (control) sites

Soil source	Relative Growth Rate (RGR) g/g/day			Net Assimilation Rate (NAR) $mg/cm^2/day$			Leaf Area Ratio (LAR) cm^2/g		
	60 days	120 days	180 days	60 days	120 days	180 days	60 days	120 days	180 days
Control site	0.011	0.014	-0.002	0.470	0.360	-0.040	23.681	38.390	51.822
10 year old spoil	0.004	0.009	0.022	0.210	0.290	0.780	20.789	31.273	28.285
5 year old spoil	0.011	0.005	0.010	0.740	0.240	0.380	15.255	22.846	26.789

Table 8.11 – Nitrogen concentration (%) in different component organs of *Eragrostiella leioptera* as affected by soil from mined and unmined (control) sites.

Organs	After 60 days growth			After 120 days growth			After 180 days growth		
	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil	Control site	10 year old spoil	5 year old spoil
Root	0.794 ±0.02	0.558 ±0.07	0.482 ±0.03	0.915 ±0.03	0.763 ±0.12	0.825 ±0.01	0.854 ±0.04	0.900 ±0.04	0.711 ±0.03
Rhizome	3.126 ±0.05	1.070 ±0.00	1.110 ±0.11	1.362 ±0.04	1.246 ±0.11	1.224 ±0.04	1.007 ±0.10	1.171 ±0.13	1.289 ±0.01
Stem	-	-	-	0.887 ±0.12	0.872 ±0.04	1.030 ±0.03	0.946 ±0.10	0.892 ±0.02	0.847 ±0.09
Green leaves	0.910 ±0.09	0.843 ±0.08	0.964 ±0.05	1.024 ±0.00	0.902 ±0.08	1.000 ±0.03	0.931 ±0.01	0.968 ±0.02	0.885 ±0.04
Standing dead	0.388 ±0.02	0.545 ±0.02	0.482 ±0.00	0.476 ±0.01	0.287 ±0.06	0.488 ±0.07	0.477 ±0.00	0.449 ±0.01	0.446 ±0.04
Reproductive part	-	-	-	-	-	-	0.758 ±0.06	0.057 ±0.00	ND

- No biomass, ND Not detectable
± SE of the mean

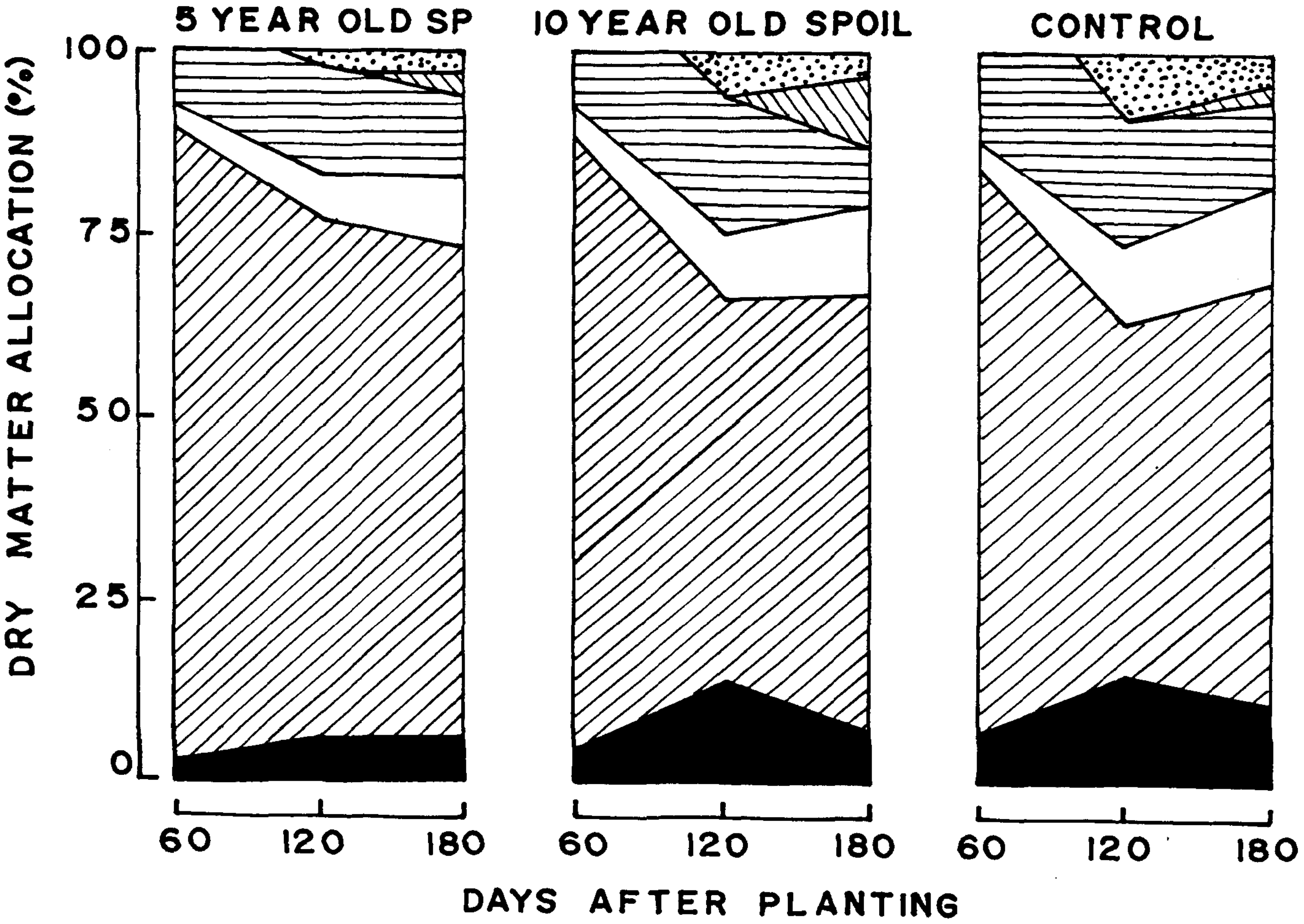


Fig. 8.1- Percentage dry matter allocation to different component organs of *Eriosaema chinense* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Tuber; □ Stem; ☰ Leaves; ▧ Standing Dead; ░ Reproductive parts.

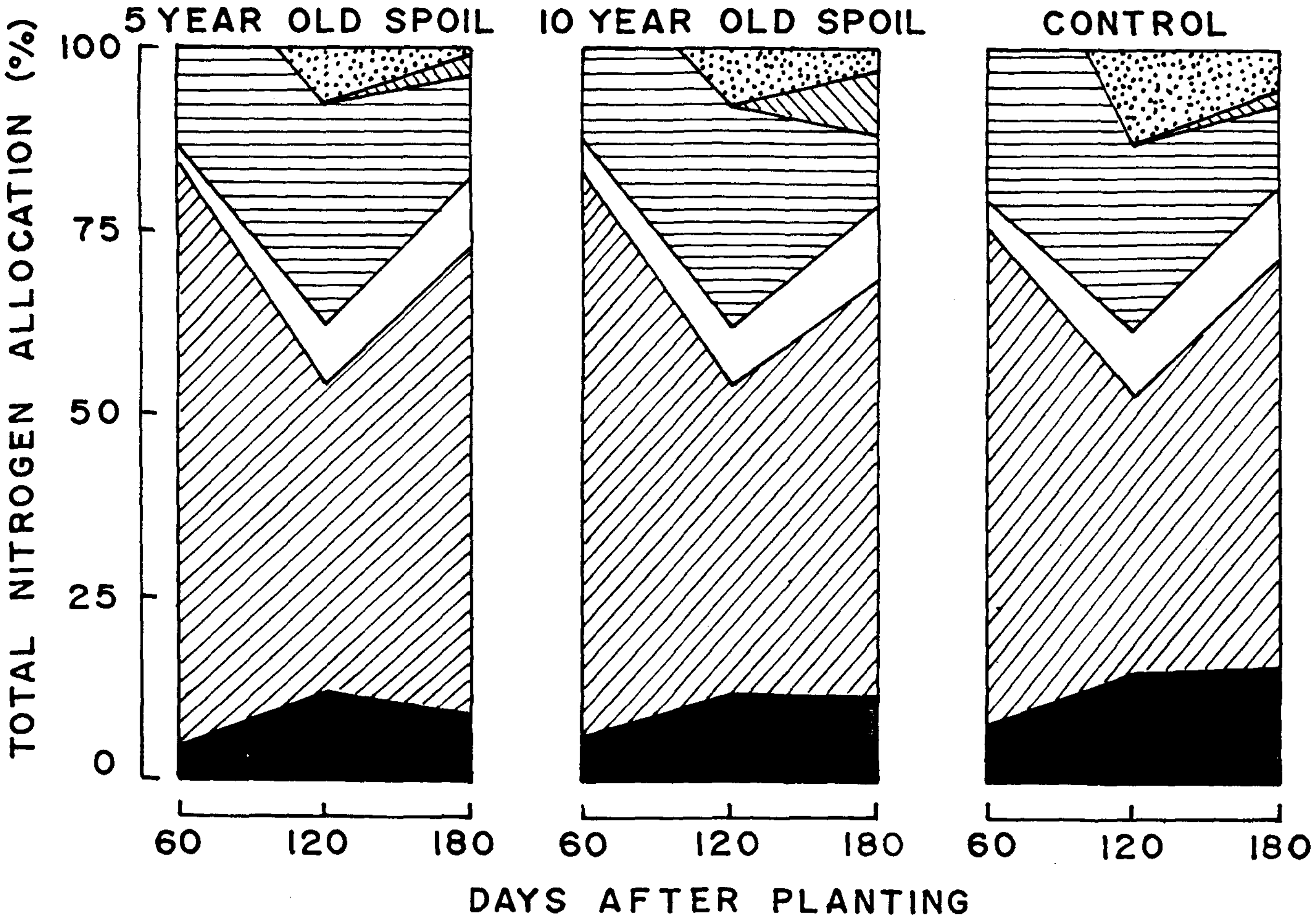


Fig. 8.2- Percentage allocation of total nitrogen to different component organs of *Eriosaema chinense* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Tuber; □ Stem; ☰ Leaves; ▧ Standing Dead; ░ Reproductive parts.

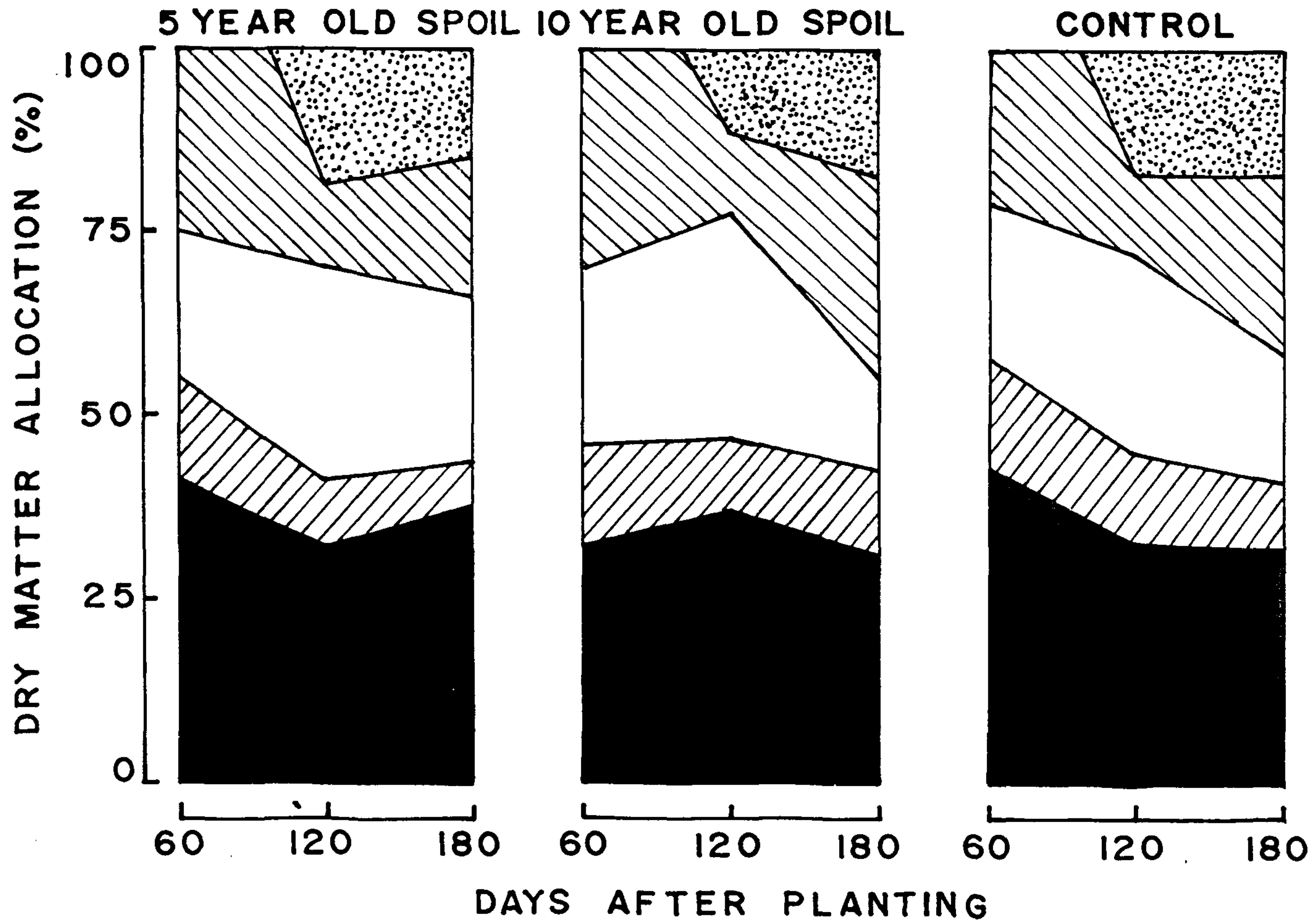


Fig. 8.3- Percentage dry matter allocation to different component organs of *Axonopus compressus* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Rhizome; □ Leaves; ▧ Standing Dead; ⁙ Reproductive parts.

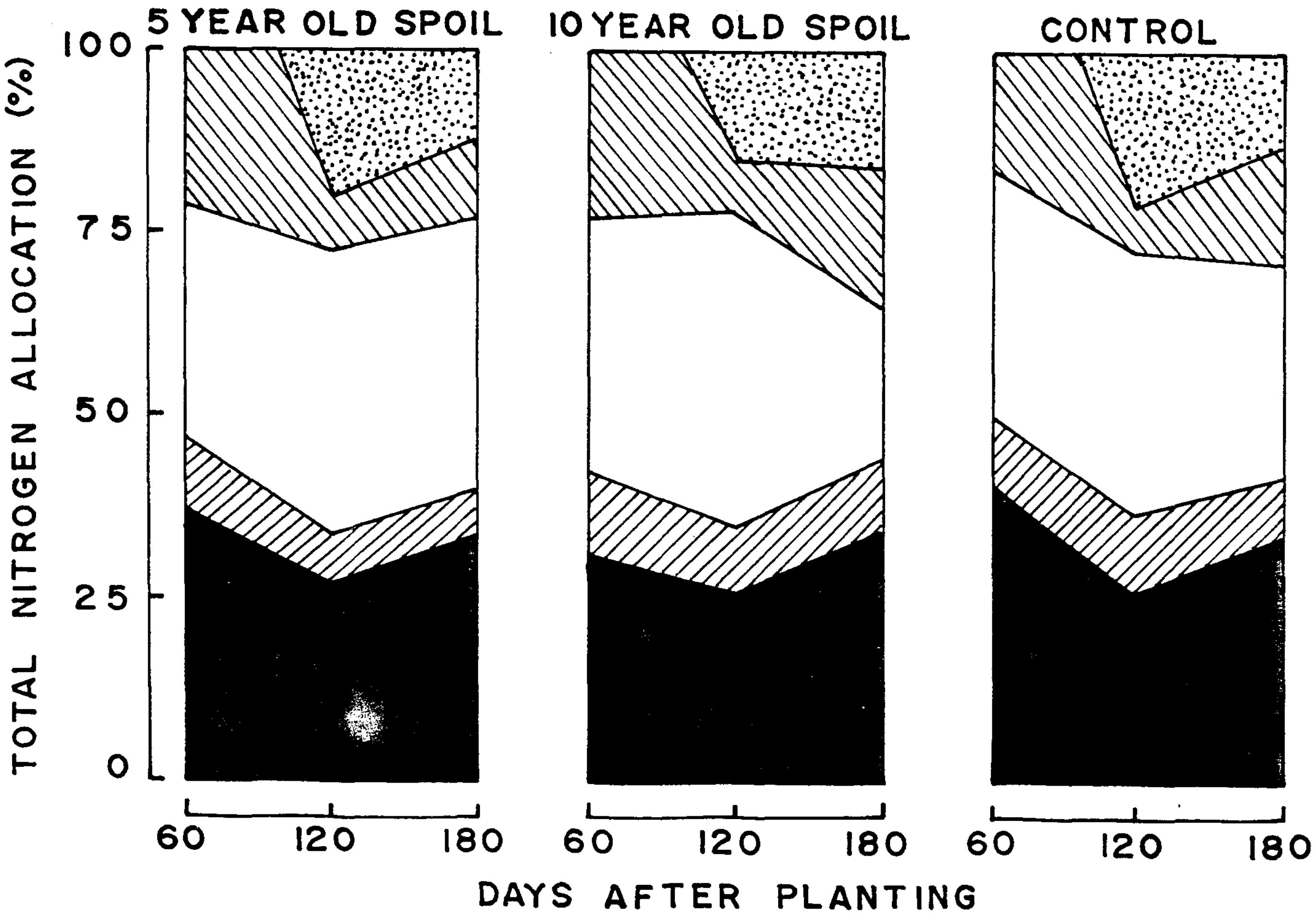


Fig. 8.4- Percentage allocation of total nitrogen to different component organs of *Axonopus compressus* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Rhizome; □ Leaves; ▧ Standing Dead; ░ Reproductive parts.

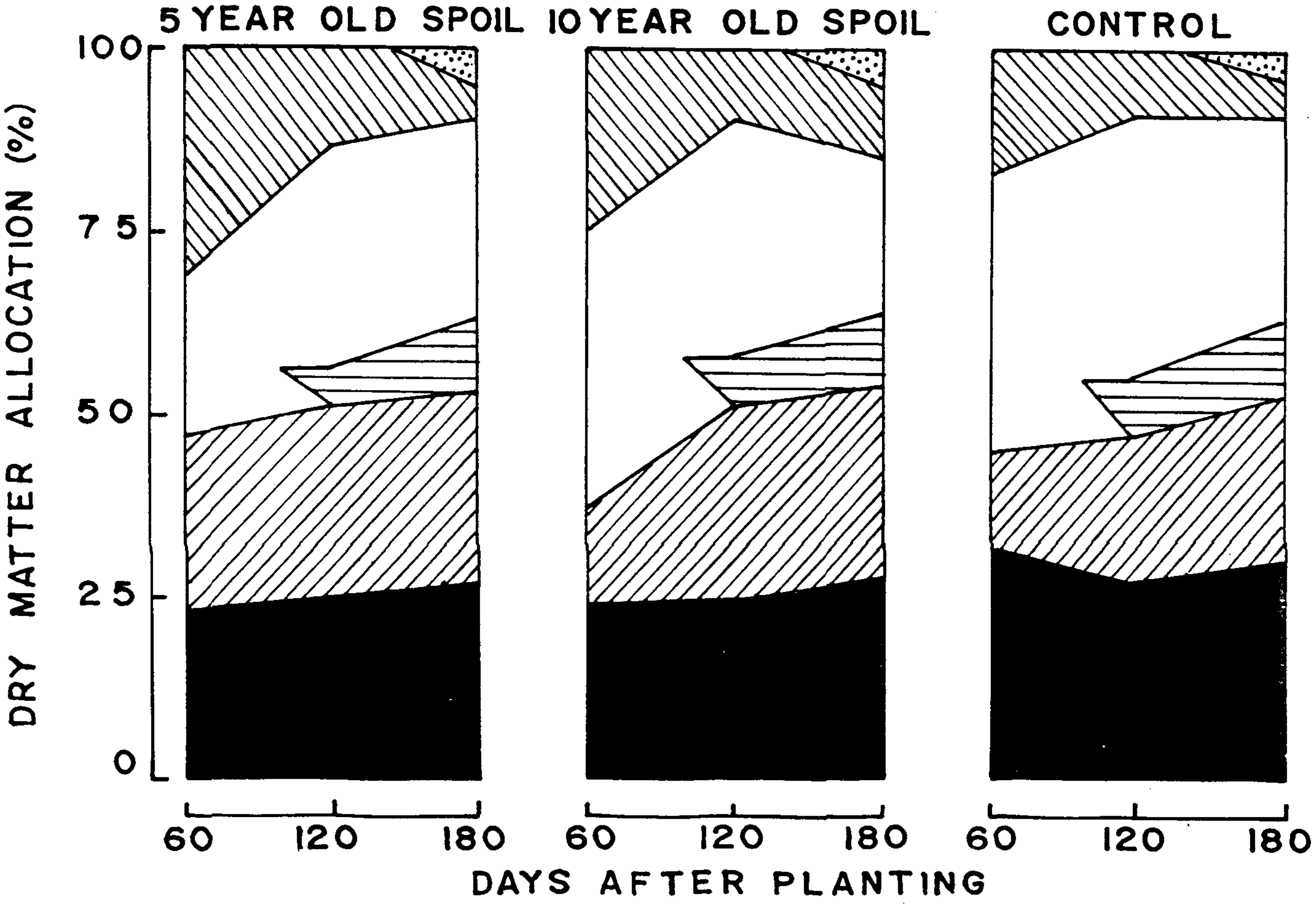


Fig. 8.5- Percentage dry matter allocation to different component organs of *Eragrostiella leioptera* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Rhizome; ▤ Stem; □ Leaves; ▧ Standing Dead; ⬚ Reproductive parts.

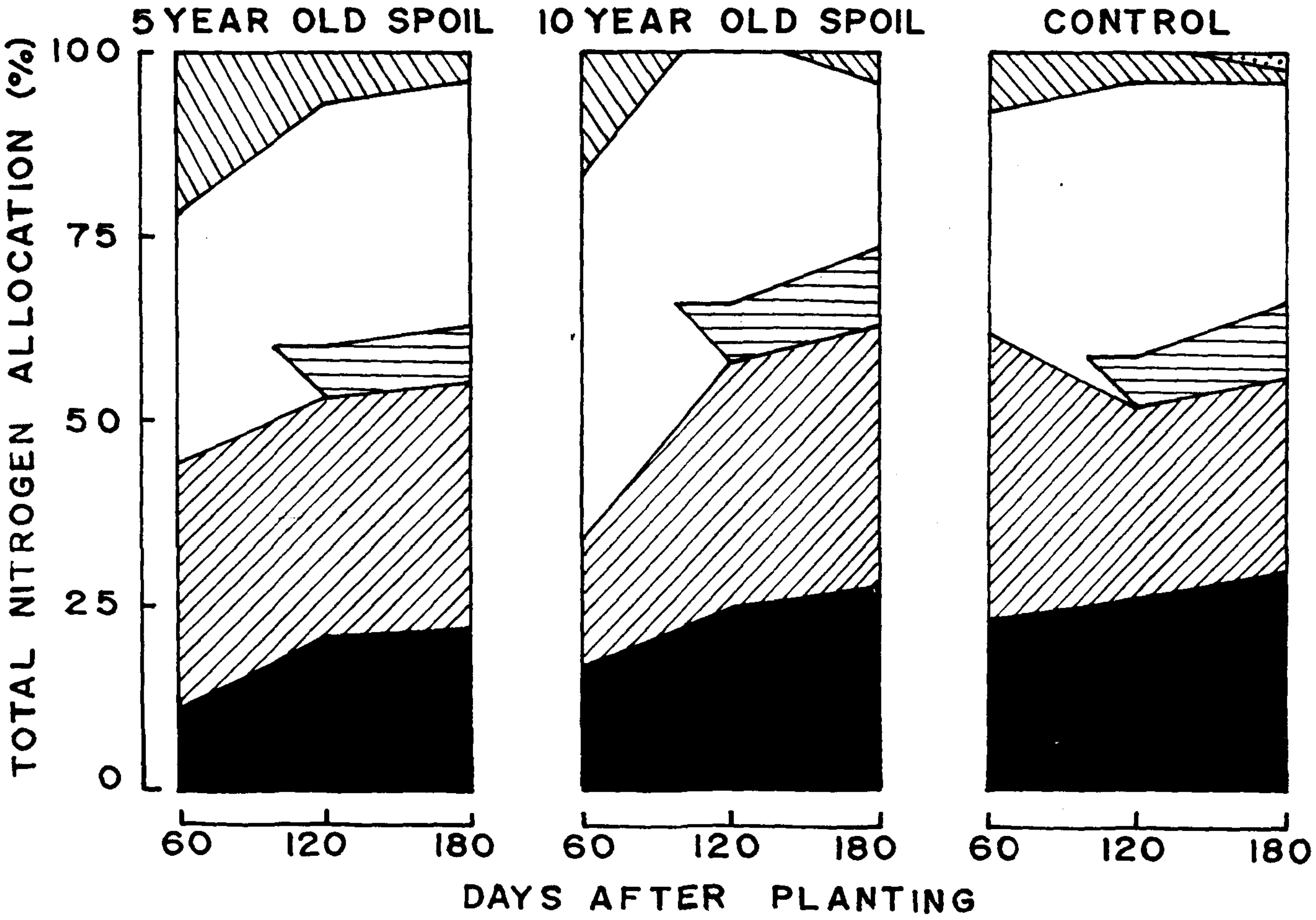


Fig. 8.6- Percentage allocation of total nitrogen to different component organs of *Eragrostiella leioptera* as influenced by soils from the mined and unmined (control) sites. ■ Root; ▨ Rhizome; ☰ Stem; □ Leaves; ▧ Standing Dead; ⬚ Reproductive parts.

Plate 8.1 - *Eriosaema chinense* during H_2. A 5 year old spoil; B 10 year old spoil; C control soil

Plate 8.2 - *Axonopus compressus* during H_2. A 5 year old spoil; B 10 year old spoil; C control soil

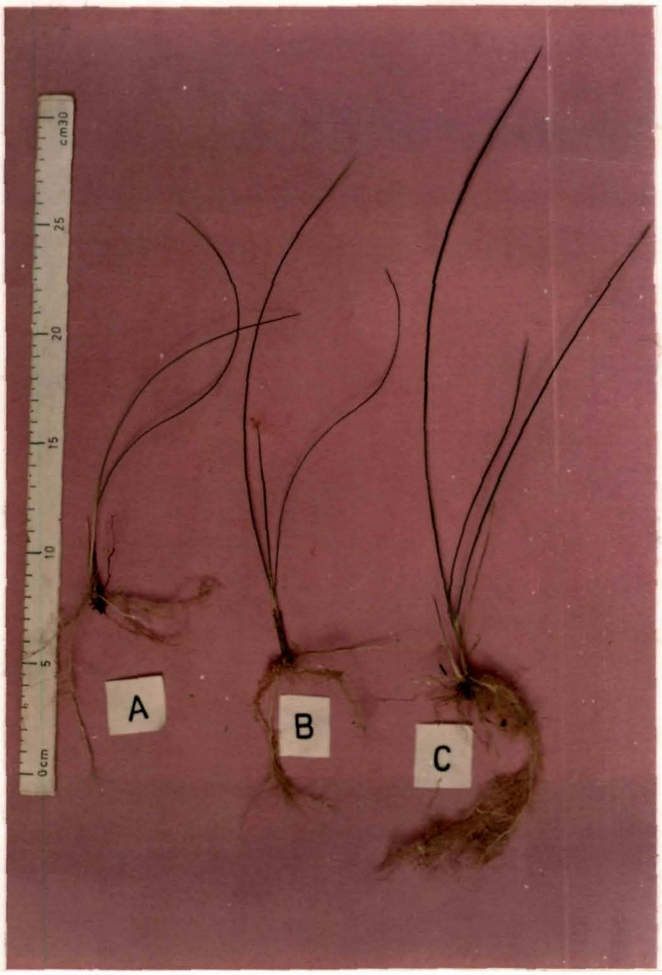


Plate 8.3 - *Eragrostiella leioptera* during H_2. A 5 year old spoil; B 10 year old spoil; C control soil

CHAPTER 9

GENERAL DISCUSSION

Coal mine spoils of Jaintia Hills, Meghalaya represent the extreme stage of degradation of the environment caused by man's exploitation of natural resources. Detailed analysis of these coal mine spoils which are undergoing natural recovery have helped in gaining better insight into the extent of degradation caused by coal mining and also into the edaphic and vegetational changes that take place during their recovery.

The results presented in the foregoing chapters reveal that these coal mine spoils form a veritable habitat where conditions are extremely unfavourable for plant growth and development. The main problems encountered on these spoils are moisture stress, extreme acidity and deficiency of organic matter and nutrients. Many workers have reported similar problems on coal mine spoils (CHADWICK 1973, DOUBLEDAY 1974, CARUCCIO 1975, RICHARDSON 1975, JOHNSON & BRADSHAW 1979, JHA & SINGH 1990, 1992, IVERSON & WALI 1992). Moisture stress could be attributed to steep slope, barren condition and sandy nature of the spoil resulting in very high surface soil temperature which again leads to high evaporation of water from the soil surface (RICHARDSON 1975). Extreme acidity of mine spoils caused due to the oxidation of iron pyrites (FeS_2), as observed in the present study, is in conformity with CHADWICK (1973), DOUBLEDAY (1974), CARUCCIO (1975) and JOHNSON & BRADSHAW (1979). Both moisture stress and acidity were very severe in the young spoils particularly in the 2 year old spoil. But these conditions improved as the spoils grow older as was in the case with the 10 year old spoil.

The concentration of organic matter and nutrients particularly, phosphorus were found to be extremely low in the 2 year old spoil. Concentration of total nitrogen (TKN), potassium, calcium and magnesium were also very low in the 2 year and 5 year old spoils. However, with the exception of phosphorus there was a significant increase in the concentration of organic matter and nutrients with spoil age. Amounts of organic matter and nutrients accumulated in each site varied considerably and except for the organic matter there was a regular trend of increase in accumulation of these nutrients with spoil age. This could be attributed to the growth of an increasing number of plant species on the spoils. The plant growth might have also encouraged weathering of the spoils, resulting in increased release of N and P, whose better availability may favour plant growth and accumulation of nitrogen and phosphorus (CORNWELL & STONE 1968, REEDER & BERG 1977a, FYLES *et al.* 1985, IVERSON & WALI 1992, UMA SHANKAR *et al.* 1993). Accumulation of N, P, and K is also probably related to the soil reaction, water holding capacity and soil moisture content. But as the soil acidity decreased and soil moisture status improved with spoil age, nutrient accumulation (which was least in the 2 year old spoil) also increased.

The unfavourable habitat conditions on coal mine spoils have led to the invasion and growth of only those species which have the ability to evolve tolerance to these conditions. In the present investigation, stoloniferous and rhizomatous hemicryptophytes, particularly *Axonopus compressus*, *Dicranopteris* *linearis*, *Chrysopogon gryllus* and *Ischaemum geobellii* are the important colonizers. The subterranean stolon and fibrous roots of these species have helped them in binding the soil particles, thus making it more stable and in capturing whatever moisture and nutrients that are available in the substratum and thus establish themselves successfully on coal mine spoils. Many workers have also reported the predominance of hemicryptophytes on coal mine spoils (HALL 1957, MOLYNEUX 1963, DOWN 1973). RIES & DEPUIT (1984) also reported that species with fibrous root systems are better suited for the reclamation of coal mine spoils. But development of these communities is very patchy with large bare areas in between. This is probably because the habitat conditions are not uniform. On the bare areas conditions are even harsher compared to some microsites where enough water and nutrients are available for the growth and establishment of plant species. BELL & UNGAR (1981) and GAME *et al.* (1982) also reported patchiness and zonation of vegetation on coal mine spoils. The unfavourable habitat conditions are also responsible for the low species diversity and high dominance on coal mine spoils particularly the young spoils. This is in accordance with ODUM (1985) who reported decreasing diversity and increasing dominance as a result of stress. But as the age of the spoil increased and with the improvement of habitat conditions growth of plant species also increased with spoil age. Species content, total stand density and basal cover increased with age (BRIERLEY 1956, SINDELAR 1979, GAME *et al.* 1982, JHA & SINGH 1990, BAIG 1992). Similarly, biomass and productivity increased with the improvement in habitat conditions as the spoils were undergoing recovery with increasing age. Increase in species content, density and biomass with spoil age has also been reported in other spoils, e.g. lead and zinc mine waste (KIMERRER 1984), china clay wastes (MARRS *et al*. 1980. ROBERTS *et al*. 1981). Increase in species content, species density and biomass with stand age has also been reported in other disturbed ecosystems (TOKY & RAMAKRISHNAN 1983, ARUNACHALAM *et al*. 1995).

Both aboveground net primary productivity (ANP) and belowground net primary productivity (BNP) increased significantly with the age of the spoil. The productivity on the control site was much greater than the productivity on the spoil. The increase in primary productivity with age of the spoils clearly indicates that they have undergone some degree of recovery with passage of time.

The concentration of the three essential nutrients *viz*. N, P and K in the plant tissues varied from site to site presumably due to difference in the species composition of the vegetation growing on them (Chapter 5) and due to the difference in the standing state of nutrients on these sites (Chapter 4). The concentration was also much higher in the live fraction than in the standing dead which could be attributed to the large withdrawal of these nutrients from the senescing organs (MORTON 1977, CHATURVEDI *et al*. 1988, UMA SHANKAR 1991, BORAL 1993). This also accounts for the higher concentration of these nutrients in the live biomass of the dominant species at all sites.

In the belowground compartment of vegetation N, P and K concentration was higher in the rhizome than in the roots at all sites. The rhizomes of most of these species are also used as propagating organs which, generally have a higher concentration of nutrients compared to roots (FITTERS & SETTERS 1988). N, P and K content also varied significantly with organs and with sites. Despite higher concentration of N and K in the rhizomes than in the roots, the total N and K contents were lower in the former. This may be ascribed to a very low biomass of the rhizome compared to the root biomass. P content, however, did not vary significantly between root and rhizome fractions. The higher N, P and K content in the live fraction is clearly due to their higher concentration in the live parts and greater live biomass. The higher N, P and K content in the live parts of the dominant species was also due to similar reasons. Accumulation of N, P and K was more in the belowground than in the aboveground compartment of vegetations on all the sites except 5 year old spoil where *Dicranopteris linearis* was the dominant species. The difference in trend on the 5 year old spoil could be attributed to the growth characteristics of *D. linearis*, which has a rhizome which creeps on the soil surface bearing fibrous roots on its under surface and thus it produces more aboveground biomass.

Of the four ecosystem compartments major amounts of N and P were present in the soil compartment and only a small portion was found in the vegetation compartment. However, K content in the soil was lower than in the vegetation compartment. This is possibly related to the great loss of K from the system (K being much more mobile than N) through rain water as the study area experiences a very heavy rainfall. In addition to this loss, since litter is also lost from the system, potassium that is returned to the system is only through belowground detritus.

The response of *Eriosaema chinense*, *Axonopus compressus* and *Eragrostiella leioptera* to soils from the control site and from mine spoils of ages 5 and 10 years old varied considerably. Biomass of these species differed significantly ($P<0.01$) when grown on soils from the different sites. Significant variations due to species was observed for RGR ($P<0.01$), NAR ($P<0.01$), LAR ($P<0.01$) and total nitrogen content ($P<0.01$). Biomass and nitrogen accumulation were greater in *E. chinense* and *A. compressus* than in *E. leioptera.* The greater accumulation in *E chinense*, could be related to the starting capital of both biomass and nitrogen accumulated in the perennating tuber. On the other hand, the good performance of *A. compressus* may be due to its efficient absorbing system resulting from the better root growth and efficient photosynthetic activity on account of larger leaf area.

Allocation of resources to different component organs also varied widely. In *E. chinense* major part of biomass and total nitrogen were allocated to the tuber, and only a small portion of biomass was allocated to the sexual reproductive organs. However, N allocation to the sexual reproductive parts was much larger compared to the biomass allocation. This species lays more emphasis toward vegetative reproduction for its mode of propagation. In *A. compressus*, allocation was more towards the roots in order to increase the absorbing surface. In this case, a good amount of these resources were allocated to sexual reproductive organs which indicates that this species lays considerable emphasis on the sexual reproduction. *E. leioptera*, on the other hand, lays more emphasis on vegetative mode of reproduction as indicated by a much higher allocation of resources to the rhizomes than to the sexual reproductive organs. *Axonopus compressus* and *Eriosaema chinense* showed better growth and more efficient absorbing and photosynthetic activity and as such, they have the potential to grow better than *Eragrostiella leioptera*. Thus, *E. chinense* and *A. compressus* could be more suitable for reclamation of the mine spoils than *E. leioptera*.

The present study highlights several ecological problems associated with coal mining in the Jaintia Hills district of Meghalaya. The plant community dynamics and edaphic changes on the coal mine spoils undergoing natural recovery have been analysed in detail. Besides, biomass allocation and nutrient compartmentation have also been studied. Three important herbaceous plant species that occur in the study area were grown on the soils brought from the control site and from mine spoils to see their growth response and the data are quite revealing. It is hoped that the information gathered on the above aspects would provide important clues for developing strategies for reclamation and better management of the coal mine spoils of Jaintia Hills.

SUMMARY

The present study deals with the analysis of the changes that take place in the edaphic and community characteristics of naturally recovering coal mine spoils of Jaintia Hills district of Meghalaya. It also deals with the analysis of the growth and resource allocation in three species namely *Eriosaema chinense* (Fabaceae), *Axonopus compressus* and *Eragrostiella leioptera* (Poaceae) when grown on the soils from the mined and unmined sites under controlled conditions. *Axonopus compressus* and *Eragrsotiella leioptera* are the two grass species growing abundantly in the grasslands of the study site. While, *Axonopus compressus* grows on the mine spoils and along the foot paths, *Eragrostiella leioptera* grows only on the unmined site. The third species *Eriosaema chinense*, is the only legume which is found to grow frequently on the unmined site, and by virtue of nodulating profusely, it is likely to play a significant role in nitrogen economy of the soil.

The physico-chemical properties of soils collected from the mine spoils of different ages were determined and attributes of the plant communities developing on these spoils were also analysed with a view to understand the recovery pattern of the mine spoils under natural conditions.

The objective behind analysing the growth of the above plant species when grown on soils collected from the mine spoils of different ages and unmined site under controlled conditions was to determine as to whether they can grow successfully on the

mine spoils and whether they could be planted on the coal mine spoils in order to bring about faster reclamation of these degraded lands.

The experimental sites are located in Jarain (latitude 24°19', longitude 92°8', altitude 1250 m asl) of Jaintia Hills district in Meghalaya. It is a hilly terrain with the average annual rainfall of about 5000 mm per annum, *ca.* 75% of which is received between May and September. The average minimum temperature is about 10°C and the average maximum temperature about 22°C. Mine spoils of different ages (2, 5 and 10 years old) were selected for the study together with an unmined grassland which served as the control. All these sites are sandy in texture having more than 80% of sand.

A brief summary of the work presented in the thesis is given below:

1. Edaphic changes

Bulk density of all the spoils was found to be much lower than that of the control site. Due to predominance of sand, the water holding capacity (WHC) of soils from all sites was very low, but it increased with spoil age and WHC of the oldest spoil approached that of the control site. Soil moisture content increased with spoil age and was maximum in the control site.

The soil was acidic at all sites. pH was very low especially in the young spoils. During winter there was a sharp increase in the pH of the young spoils compared to other seasons. pH of the oldest spoil approached that of the control site. Cation exchange capacity (CEC) was also very low at all sites.

The organic matter content and total Kjeldahl nitrogen (TKN) increased significantly with spoil age and the concentration in the oldest spoil approached that in the control site. Concentration of phosphorus was extremely low in the young spoils, but it increased significantly with the age of the spoil. However, the concentration of the phosphorus in the oldest spoil was still far less compared to the control site. The concentration of exchangeable bases *viz* potassium, calcium and magnesium also increased with spoil age.

The content of organic matter and various nutrients (N, P, K, Ca, Mg) was minimum in the 2 year old spoil and maximum in the control site. Significant increase in content was observed with spoil age.

2. **Community dynamics**

The total number of species recorded on the coal mine spoils (7-21 species) was far less than that (44 species) recorded on the control site. The number of species increased with the age of the spoils, being 7, 9 and 21 on the 2 year, 5 year and 10 year old spoils, respectively.

Osbeckia crinita was the only species which occurred on all the four sites. Eleven species were present exclusively on the coal mine spoils. On all the four site, perennials were more in number than the annuals. On the control site, therophytes (43.2%) were more predominant than the other life forms, while on the mine spoils of all the three ages, hemicryptophytes were more predominant.

Density and importance value index (IVI) of different plant species varied significantly with change of seasons. Total stand density was highest during the rainy season and lowest during winter. Mean stand density also increased with spoil age. The important species growing on the four study sites are as follows:

Control Site:

Eragrostiella leioptera, *Eriocaulon nepalensis*, *Eriosaema chinense*, *Fimbristylis complanata*, *Fimbristylis falcata*, *Ischaemum geobellii* and *Osbeckia crinita*.

10 year old spoil:

Axonopus compressus, *Chrysopogon gryllus* and *Osbeckia crinita*.

5 year old spoil:

Chrysopogon gryllus, *Dicranopteris linearis* and *Osbeckia crinita*.

2 year old spoil:

Axonopus compressus, *Ischaemum geobellii* and *Osbeckia crinita*.

SORENSEN's similarity index between the control site and the mine spoils calculated on the basis of importantce value index (IVI) was very low. SIMPSON's index of dominance (D) decreased with spoil age, while SHANNON's index of general diversity ($\bar{H}$) increased. Margalef's index of species richness also increased with spoil age and was highest on the control site. The dominance-diversity curves for the 2 year and 5 year old spoils showed geometric series of the niche Pre-emption model (POOLE 1974) while those for the 10 year old spoil and the control site approached the log normal model of Preston (*PRESTON 1948*).

3. Biomass and Productivity

There was a significant increase in the total biomass of plant communities with spoil age, and the control site had much greater biomass than any of the spoils. Distinct seasonality was observed in the aboveground biomass, maximum value being recorded during the rainy season on all sites and minimum during winter. However, belowground biomass on the mine spoils did not show any seasonality. Seasonal means of both aboveground and belowground biomass showed significant increase with spoil age.

As expected, the contribution by the dominant species to the total biomass was quite high on all the sites. On the control site, the dominant species *viz.*, *Eragrostiella leioptera*, *Fimbristylis complanata*, *Ischaemum geobellii* and *Osbeckia crinita* contributed more than 37% of the total biomass throughout the year. On the 10 year old spoil, the dominant species (*Ischaemum geobellii*, *Axonopus compressus* and *Dicranopteris linearis*) contributed more than 56% of the total biomass. On the 5 year old spoil, the dominant species (*Dicranopteris linearis* and *Osbeckia crinita*) contributed more than 70% of the total biomass. On the 2 year old spoil, the dominant species *Ischaemum geobellii* and *Osbeckia crinita* contributed more than 16% of the total biomass.

Though total net primary productivity (TNP) increased significantly with the age of the spoil, the TNP of even the oldest spoil was much lower than that of the control site. In the control site, maximum contribution to the total aboveground net primary productivity (ANP) was made by *Eragrostiella leioptera* (19%), in the 10 year old spoil by *Ischaemum geobellii* (36%), in the 5 year old spoil by *Dicranopteris linearis* (64%) and in the 2 year old spoil by *Ischaemum geobellii* (13.8%).

4. Nutrient compartmentation

On the control site, the concentration of nitrogen did not show any distinct seasonality and it was much higher in the rhizome than in the root. But on the mine spoils, during spring there was a significant increase in the N concentration in the root and moderate increase in the rhizome fraction. N concentration in the standing dead fraction of the aboveground compartment was very low on the control site and the mine spoils. In the live fraction significant decrease in N concentration was observed during winter at all sites.

The difference in P concentration in the root and rhizome fraction of the belowground vegetation compartment was not significant, while in the aboveground compartment, concentration in the live fraction was much higher than in the standing dead fraction. Similarly, P concentration in the live fraction was much higher than in the standing dead fraction. During the rainy season, P concentration in both the fractions of the aboveground compartment was very low. Intersite variation in the concentration of N, P, and K in the different vegetation compartments was significant although the concentrations were extremely low.

With the exception of phosphorus in the root and rhizome fraction of the belowground vegetation compartment, accumulation of NPK in the different vegetation compartments varied significantly. Accumulation was much lower in the rhizome than in the root fraction. It was also much lower in the standing dead than in the live fraction. Total accumulation in the vegetation was least in the 2 year old mine spoil, but it increased significantly with the age of the spoil.

Accumulation of N, P and K in the dominant species showed distinct seasonality. In all the dominant species of all sites, accumulation was least in the standing dead fraction. *Ischaemum geobellii* contributed a maximum percentage to the total nutrients accumulated in the aboveground compartment in the case of the 2 year old mine spoil and control site, while *Dicranopteris linearis* and *Axonopus compressus* were the major contributors in the 5 year and 10 year old spoils respectively. Among the vegetation compartments, major accumulation of N, P and K was observed in the belowground compartment on all the sites except the 5 year old mine spoil where major accumulation was in the aboveground compartment. But so far as the ecosystem compartments are concerned, soil was the largest store for both N and P.

5. Growth of *Eriosaema chinense*, *Axonopus compressus* and *Eragrostiella leioptera*

Variations in growth and resource allocation in *E. chinense*, *A. compressus* and *E. leioptera* due to the different soil types *i.e.* soils from the mined and unmined sites were not very remarkable, despite the wide variation in the standing state of nutrients in these soils.

Eriosaema chinense

There was an increase in total biomass of *E. chinense* from H_1 to H_2 on the control soil but when grown on the soils from the mined site there was no significant increase. From H_2 to H_3 there was only a slight decrease in biomass in the control soil while a drastic decrease was observed in the 5 year old mine spoil. Belowground/aboveground biomass ratio was much greater than unity but it decreased drastically from H_1 to H_3.

Both RGR and NAR increased from H_1 to H_2 but decreased at H_3. LAR, however, increased throughout *i.e.* from one harvest to the subsequent ones.

Maximum and minimum N concentration were observed in the leaves and the tuber respectively, but N accumulation was maximum in the tuber and minimum in the stem at all harvests and in all soils.

Resource allocation (allocation of dry matter and nitrogen) was maximum in the tuber in all soils and at all harvests.

Axonopus compressus

Dry matter yield of *Axonopus compressus* increased tremendously from H_1 to H_3 in all the three soils; highest value was observed in the control soil and lowest on the 5 year old spoil. Belowground/aboveground biomass ratio was more than unity in the case of the control soil and 5 year old spoil, althrough it decreased from H_1 to H_3. A major portion of the total dry matter was allocated to the leaves.

RGR was quite high at H_1 but it decreased from H_1 to H_3 in the control soil and 10 year old spoil. NAR was also quite high initially, but it decreased at H_2 and H_3. LAR did not vary much from harvest to harvest in the control soil but on the mine spoils it was low at H_1 increased tremendously at H_2 and decreased at H_3.

N concentration was higher in the leaves at H_1 but in most cases the differences between concentrations in the different organs were not significant.

Nitrogen content was maximum in the leaves at all harvests. N content per plant was much higher when grown in the control soil. In the control soil and 5 year old spoil maximum allocation of nitrogen was towards the root, while in the 10 year old spoil it was maximum in the leaves. Minimum allocation of nitrogen was, however, in the rhizome at all harvests and in all the soils.

Eragrostiella leioptera

Total biomass of *Eragrostiella leioptera* too increased significantly from H_1 to H_3. Belowground/aboveground biomass ratio was less than unity intially, but it increased at the subsequent harvests. At H_1 and H_2 maximum dry matter was allocated to the leaves and at H_3 to the roots. But in the 5 year old spoil maximum dry matter was present in the standing dead at H_1 and H_2 while in all other soils, maximum allocation was towards the leaves.

The growth analysis of the three species revealed that their growth in the control soil was quite different from that in the soils from the mine spoils, and the growth response of the species also differed from each other. The RGR and LAR were much lower in *E. leioptera* than the other two species.

Nitrogen concentration was maximum in the rhizome and minimum in the standing dead at all harvests and in all soils. N content was very low and the major part was shared equally among root, rhizome and leaves.

Biomass and nitrogen accumulation were greater in *E. chinense* and *A. compressus* than in *E. leioptera*.

The study reveals that coal mining in Jaintia Hills of Meghalaya has an adverse effect on land and vegetation. These coal mine spoils represent such habitats where conditions are extremly unfavourable for plant growth and establishment, and as such, only those species which can tolerate the extreme condition can colonise the spoils. The study further reveals that *Axonopus compressus* is suited for reclamation of mine spoils as it can bind the soil particles making the soil more stable and can grow successfully even in extremely poor nutrient conditions as are obtained in the coal mine spoils of Jaintia Hills district of Meghalaya.

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