

**STUDIES ON VEGETATIONAL AND MICROBIOLOGICAL
PROCESSES IN COAL MINING AFFECTED AREAS**



By

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**Thesis Submitted
In Fulfilment of The Requirement of The Degree of
Doctor of Philosophy in Botany**

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We certify that the thesis entitled "Studies on vegetational and microbiological processes in coal mining affected areas" submitted by Mr. Subhasish Das Gupta for the degree of **Doctor of Philosophy** of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by him under our supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. The work has not been submitted for any Degree of any other University.



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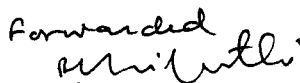
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CHAPTER I

GENERAL INTRODUCTION

Since the dawn of history, human beings have been dependent upon natural resources for food, shelter, clothing and energy. Thus the disturbance to ecosystem has been taking place ever since the use of the landscape commenced. Such disturbances were not perilous as long as human population was low and natural resources were in excess of the requirement. Before the industrial revolution got under way, agriculture and forestry together with the limited use of metals, served all human aspirations. With the advancement of technological knowledge, novel transformations of materials contributed to the enhancement of quality and comfort in life. The industrial development took a myopic view of natural resources and became the symbol of status for different countries.

The progress of mankind depends upon the judicious exploitation of natural resources. Utilization of these resources is of paramount importance in sustaining natural 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 various kinds of fuels for meeting energy requirements, metals for making engines and machines, ores for chemicals and fertilisers, clay for vases, rocks and stones for buildings, bridges and dams, gold, diamonds and precious stones for jewellery.

Coal has remained a vital energy source in the world for over two centuries. Hubbert (1973) noted that "during the eight centuries prior to 1860, it is estimated that cumulative production of coal amounted to 7×10^9 metric tonnes. By 1970, cumulative production reached 140×10^7 metric tonnes on a world's scale. Hence, the coal mined during the 110 year period from 1860 to 1970 was approximately 19 times that of the preceding eight centuries".

Though the world wide production of coal was 3.7×10^9 billion metric tonnes in 1977, the trends between 1960 and 1977 showed a gradual rise in production of coal in North-America, a decline in production in Western Europe and Japan and substantial increase in South Africa, Australia and India (Griffith and Clarke 1979). India is one of the fifth largest coal producing countries in the world. The production in India was about 154.30 million tonnes in 1985-86 and it is expected that the production level will reach 417 million tonnes by 2000 A.D. (Coal India 1986).

The Indian sub-continent is replete with minerals and almost every state has its own coal or metal resources. Soon after independence, India witnessed a spurt in the growth of heavy industries that needed a large amount of coal and metals. Mining operations began on a large scale and mine wastes, sewers and belching chimney pumped in large amounts of metals into soil, river channels and atmosphere. Most of the mining areas have been converted into degraded lands and

are regarded as heavy metal hot spots due to the release of chromium, lead and mercury into the environment. Presently, in India, more than 80,000 ha of land are under various types of mining (Valdiya 1988).

Various types of mining activities have been going on in the country since then. Mining activities in Raniganj in West Bengal, Jharia in Bihar and Singrauli in Madhya Pradesh for coal, Bichhri, Khetri and Zawar in Rajasthan, Malanjkhand in Madhya Pradesh and Agnigundala in Andhra Pradesh for lead, zinc, copper and cadmium and in Neyveli in Tamil Nadu for lignite mines have reduced the adjoining areas to a pit-scarred and barren landscape. The fertility of lands in most of the areas has been reduced to the limit that is beyond redemption.

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). By 1830, several coal mines came up in the Raniganj coal area. In North-East, coal mining was initiated by Medlicott (1869, 1874). This was followed by the preliminary excavations by Fox (1935-38) in Garo Hills and some mining works by Arogyaswami and Desikachari (1949-1950) in south Khasi Hills. Coal fields of Garo Hills were reexamined by Arogyaswami, Sen, Rao and Puri in 1949-50. Some coal occurrences in Jaintia Hills were examined by shallow drilling by Dias in 1962-63 and Goswami and Dhara in 1963-64 (Bulletin of Geological Survey of India, 1969).

The state of Meghalaya is rich in mineral resources of which principal ones are coal, limestone and sillimanite. The forested as well as the mining areas are intimately linked. The extent of environmental perturbations due to mining can be gauged from the denudation of the forest cover in all the mine belts especially in the Jaintia Hills. During the past twenty years, the forests in Jaintia Hills have been ravaged by coal mining operations.

Coal deposits occur as seams of the Eocene age (Guha Roy, 1991). These deposits 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 gentle dipping in nature. The coal is found to occur in various places in Meghalaya namely : Laitryngew, Cherrapunjee, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, East Darrangiri, Pynursla, Lyngkyrdem, Mawlong-Shella-Ishamati in Khasi Hills, West Darrangiri, Siju, Pyndengru-Balphakram, Salsella Block in the Garo Hills and Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioski in Jaintia Hills. Out of the total production of 3747000 tonnes of coal in Meghalaya, the largest contribution came from Jaintia Hills having 2786000 tonnes in 1991 (Meghalaya Statistics, 1996).

The prevailing land holding system is the greatest stumbling block in the mining of this precious mineral in Meghalaya. The mines are operated by private owners in a very unscientific and obsolete way by resorting to the "**rat hole**"

method of mining. The "rat hole method" of coal mining employed by the private operators involves manual excavation which is crude, uneconomical and unscientific. In this method, pits ranging from 5 to 100 m² are excavated in to the soil till the coal seam is reached. The coal seam occurs at the depth ranging from 2 to 10 meters. Coal is then removed from this pit. Tunnels are made into the seam sideways and coal is brought into pits by wheel-barrows. From the pit, coal is taken outside in conical baskets. The columns of coal are left intact here and there 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 pieces of soil rocks above the coal seams are thrown haphazardly outside the pit creating coal mine spoils which cause large scale destruction to the surrounding land and vegetation often beyond replenishment.

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 by dint of shale breaking down along its laminations thereby making fragments like slate in shape. Due to the occasional formation of mud and sand stone pieces within, the spoil becomes much more noticeable as weathering continues.

Coal mine spoils represent extremely rigid substrata for plant growth and development. Colonization, establishment and maintenance of vegetation on these spoils are enormously difficult. Among the factors which hinder the growth of plant species on these spoils, acidity merits special mention. Extreme acidity is caused due to the oxidation of iron pyrites (FeS_2) (Chadwick 1973, Caruccio 1975). So, colonization of spoils depends only on those species which have the tolerance to grow in nutrient-deficient habitats. The number of species colonizing them increases with the increase in pH of the substratum (Bradshaw and Chadwick 1980). Continued acidification for many years may lead to die back of well established vegetation (Costigan *et al.* 1981). Besides acids, 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 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 a major factor regulating plant growth. The two limiting nutrients on coal mine spoils are nitrogen and phosphorus (William 1975, Whittwer *et al.* 1981). The shortage of organic matter is attributed to the absence of litter. Organic matter is often found in the upper few centimetres of mine spoils (Schafer *et al.* 1980).

Ecology of mined lands has been the subject of extensive study the world

over (Bradshaw *et.al.* 1986, Brenner *et.al.*1994). In India, Banerjee (1981), Singh and Jha (1987), Valdiya (1988), Saxena (1979), Mann and Chatterjee (1979), Prasad (1989), Jha (1989, 1990, 1992), Jha and Singh (1990, 1991) and Soni *et.al.* (1990) have made pioneering contribution to our understanding of the ecology of Indian mine spoils. In the context of Meghalaya , studies by Lyngdoh *et.al* (1992) and Lyngdoh (1995), Uma Shanker *et.al.* (1993) and Tiwari (1996) have proved to be precursors for future studies in this direction. An in-depth scanning of the literature available on various facets of coal mine spoil ecology and subsequent rehabilitation measures brought to the fore, the inadequacy of information pertaining to the coal mine spoil reclamation in Meghalaya. A review of existing literature revealed that no integrated study aimed at understanding the ecological and microbiological aspects of coal mine spoil has been undertaken. So far, coal mining in Meghalaya has been synonymous with the complete absence of any rehabilitation measures and tackling of environmental hazards by the societal segment engaged in this activity. It is with this objective in mind that a **study on vegetational and microbiological processes in coal mining affected areas** was undertaken in the Bapung coal mine belt of Jaintia Hills district encompassing the aspects viz.,

(i) edaphic changes in coal mine spoils undergoing natural recovery, (ii) vegetational changes on coal mine spoils of different ages, (iii) plant biomass, production and nutrient dynamics on coal mine spoils of different ages, (iv)

microbial community changes on coal mine spoils undergoing natural recovery and (v) growth of a few selected plant species on mine spoils after chemical amendments.

The data collected on the above-mentioned aspects have been dealt with in detail in chapters 4-8. The objective of the present study has been spelt out in this chapter which is also the "**General Introduction**". The "**Review of Literature**" (chapter -2) gives an overview of researches done on the aspects related to the present study, such as characteristics of mine spoil habitat, species diversity, plant successional pattern, plant species phenology, biomass and primary production, nutrient build up, physico-chemical features of spoils, reclamation of these nutrient starved habitats. In addition to these aspects, the researches on the pivotal role played by microbial groups through functions such as respiration, mineralization, population dynamics, enzymatic activity and microbial biomass accumulation etc. have also been reviewed. A brief description of climate, soil and vegetation of the study area apart from the distribution and growth behaviour of three plant species under simulated conditions have been given in chapter -3. The critical discussion follows the results given in chapters 4-8. Major findings of the entire work have been discussed in an integrated manner in chapter-9 (**General Discussion**).

CHAPTER II

REVIEW OF LITERATURE

Ecosystem disturbance may be defined as an event or series of events that alters the relationship of organisms and their habitat in time and space. Ecosystem disturbance by mining is an inevitable fall out of industrialization and modern civilization. With accelerating demand for fuel energy the world over, coal is certainly going to retain its place of primacy well in to the middle of the next century. Surface mining of coal causes enormous damage to the flora, fauna, hydrological relations and soil biological systems. Destruction of the vegetal cover during surface mining is invariably accompanied by an extensive damage and loss to the system. The disturbed and haphazardly mixed infertile, consolidated and unconsolidated materials overlying a coal seam are known as **overburdens**. These overburdens when dumped in unmined areas in the vicinity of the coal mines create **mine spoils**. Nutrient deficient sandy spoils are generally hostile to plant growth and the revegetation and reclamation strategies other than natural colonization on mine spoils are a very tardy process. Some important researches on the mine spoil ecology relevant to the present study are being reviewed here.

FLORISTIC STUDIES ON COAL MINE SPOILS.

Intensive studies on mine spoil ecology have been undertaken in

different parts of the globe. The development of an ecosystem on china-clay wastes was studied by Dancer *et al.*(1980, 1981) . Studies on reclamation of China-clay wastes were undertaken by Marrs and Bradshaw (1982). Iron mine tailings were studied in detail by Leisman (1957), Shetron and Duffek (1970) and Martinik (1977) who found that the tailings represented adverse site for plant growth but proved excellent for some herbaceous species upon fertilizer application. They further demonstrated that the herbaceous cover capable of vegetative stabilization proved to be economically sound, self-perpetuating and fast in establishment. Schuman *et al.* (1987) made an in-depth study on bentonite mine spoils. The vegetation establishment on asbestos waste was studied by Moore and Zimmermann (1977).Saxena (1979) has provided a list of plant species for revegetation of gypsum, bentonite and fuller's earth mined areas in Rajasthan. For maintaining water balance and water table, Mann and Chatterjee (1979) have recommended the plantation of some "phreatophytes" in mica mining areas of Dungarpur, limestone mining in Chittaur and Nagpur districts, granite mining areas of Jalore district and sandstone mining areas of Jodhpur. Prasad (1989) succeeded in growing *Eucalyptus teretecornis* and *Pongamia pinnata* on Dolomite mine spoils. Prasad and Shukla (1985 b) developed a planting technique for revegetating a bauxite mine spoil in Madhya Pradesh. Revegetation of iron-ore mine areas of Madhya Pradesh was studied by Prasad in 1989 who observed better growth performance of

Dalbergia sissoo, *Albizia procera*, *Pongamia pinnata* etc. in manured pits. Soni et al. (1989 a) undertook revegetation efforts on a rock phosphate mine at Dehra Dun followed by similar studies by Soni et al. (1990) on limestone overburdens in the same area.

The factors contributing to the early colonization of mine dumps have been given considerable attention by various workers. Bradshaw (1983), Chadwick (1973), Byrnes et al. (1973) found natural succession on coal mine spoils a slow process due to surface mining altering physico-chemical properties of soil. Alvarez et al. (1974) reported the prevalence of Asteraceae, Poaceae and Fabaceae on mine spoils. Armiger et al. (1976), Doubleday (1974), Arnold et al. (1984) and Farmer et al. (1974) found alkalinity, salinity, higher rates of litter accumulation, damages by insects and pathogens adversely influencing the reclamation of mine spoils. Banerjee (1987) reported successful conversion of derelict land in to a natural sanctuary for wildlife and birds in the abandoned stone quarries in Gujarat.

Studies pertaining to the reclamation technique of spoils, floristic composition of the reclaimed spoils were made by Gemmell (1973,1977), Fitter et al. (1974), Glover et al. (1975), Power et al. (1978b), Powell et al. (1981), Johnson and Bradshaw (1979), Bloomfield et al. (1981), Rimmer (1982), Bradshaw (1983,1984, 1987), Brenner (1984), Palmer and Chadwick (1985), Brenner and Steiner (1987), Brenner et al. (1994) and Lal (1994) who found that succession of native and

herbaceous plant species increased the density and community diversity on mined lands. Bradshaw and Chadwick (1980) found acid-tolerant species as being capable of colonising the mine spoils.

Physico-chemical properties of mine spoils:

Power (1978) considers soil physico-chemical characters like texture, pH, electrical conductivity, soluble Ca, Mg, Na, B, cation exchange capacity, exchangeable cations, gypsum and calcium carbonate equivalents as being crucial to the prediction of plant growth potential of mine overburdens with water holding capacity and infiltration rate as the other important variables. Richardson (1958), Richardson and Greenwood (1967), Bradshaw *et al.* (1975) and Bell and Ungar (1981) found high temperature and low moisture of surface coal mine spoils to be important factors limiting plant growth.

Soil structure and texture:

The colonisation of plant species on coal mine spoils is influenced by the particle size of the soil derived from the overburden and coal mine wastes. This was conclusively proved by Byrnes and Miller (1973) and Down (1974). Richardson *et al.* (1971) reported that with high clay content, the soils become water-logged, whereas with high silt content, the soils become compact forming crusts which often restrict seedling growth and entry of water and air into the soil system. Dollhopf (1981) also reported similar results. He further reported that water movement,

unfavourable root growth and dispersed clay are noticeable with high sodium and low soluble salt contents. This causes an increase in nutrient loss. Power *et al.* (1978a) found the bulk density of Northern Great Plain to be 10-30% lower than the original soil, whereas Pederson *et al.* (1980) reported that soils with high bulk density and low porosity had low infiltration rates. Several workers have reported lower clay content, lack of structure, low water holding capacity and generally inhospitable physical condition of the mine spoils even after several years of revegetation (Richardson, 1975, Schafer and Nielson 1979, Rimmer 1982, Russel and Lari 1986). Lyngdoh (1995) reported lower bulk density in spoils in comparison to the unmined control site. Uma Shankar *et al.* (1993) reported higher proportion of sand in the affected mine sites in relation to the unaffected control site.

The slopy topography of the coal mine spoils makes the dumps vulnerable to erosion (Johnson and Bradshaw 1979). Curtis (1973) believes that severe erosion from the mine spoils increases silting and acidity of the streams flowing nearby. Archibold (1980) noted that seeds and clay particles move along with the spoil material during rains.

Water supply:

Due to the adverse conditions ingrained in coal mine spoils, water supply to plants becomes scarce. This is evident from the fact that the coal mine spoils have a coarse texture, low water holding capacity. Ludeke (1973) believes that a light

loam may hold more available water than a heavy clay and an uniform fine sand mine tailings more than the silty-clay overburden. Though the availability of water is a serious problem at the soil surface, its effect on plants depends upon their tolerance to moisture stress (Bell and Ungar, 1981).

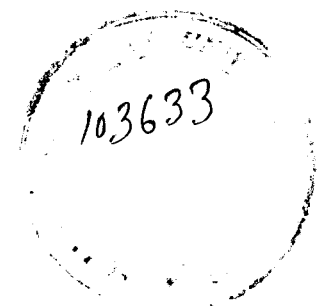
pH :

pH is a major determinant in controlling plant growth on impoverished lands such as mine spoils. Acute acidity acts as a severe constraint on sward development (Johnson and Bradshaw 1977). The pH of coal mine spoils ranges from 1.5-8.0, the commonest being 3.5. Exposure, abundance and neutralising properties of minerals along with their combustion bring about such a variation in pH (Gemmell, 1977). Bradshaw and Chadwick (1980) have opined that alkaline pH is generally exhibited by freshly formed coal mine spoils. A drastic drop in pH is a certainty when iron pyrites (FeS_2 called Fool's Gold) get exposed to air and converted into acids. The pyritic exposure and subsequent conversion to acids is a microbe-mediated process and iron-oxidising bacteria called *Thiobacillus ferro-oxidans* are known to aid the process (Johnson and Bradshaw 1979). Inhibition of root growth, reduced nutrient availability and poor soil structure are found to be associated with extreme acidity (Johnson and Bradshaw 1979; Iverson and Wali 1982 and Marschner 1991). Caruccio (1975) and Chadwick (1975) summarised the complex weathering process in the form of a chemical equation: $4\text{FeS}_2 + 15\text{O}_2 + 14\text{H}_2\text{O} = 4\text{Fe}(\text{OH})_3 + 8\text{H}_2\text{SO}_4$. High

availability of ferrous, copper, zinc, aluminium and manganese is associated along with a low supply of magnesium, calcium, potassium, nitrogen and phosphorus (Black,1968; Barnhisel and Massey, 1969; Reley,1973 and Havill *et al.* 1974).

Temperature:

Temperature of a coal mine spoil gets drastically altered due to the absence of ground vegetal cover. As a result of this, the substrate behaves differently due to excess radiation. The absence of a ground vegetation also amplifies the magnitude of seasonal and diurnal variation in temperature. Soil and surface temperatures play an important role in the establishment of vegetation. Black (1968) reported high soil water evaporation rate and poor water availability due to altered temperature conditions in coal mine spoils. Barren spoils especially the dark shales, common on mine sites lose little heat through convection and evaporation with a consequential rise in soil temperature. As the barren soil dries, evaporation decreases and surface temperature continues to rise. Temperatures as high as 67°C have been recorded in dark mine wastes (Deely and Borden, 1973). High temperature and low moisture of surface mine spoils limit plant growth (Richardson,1958; Richardson and Greenwood, 1967; Bradshaw *et al.*1975 and Bell and Ungar,1981) and reduce decomposer activity (Wieder *et al.* 1983).



Toxicity:

During mining or excavation of coal from the earth, many metals are seen to gain access to both terrestrial and aquatic ecosystems. Sometimes the contents of elements at the spoil surface increases to a potentially hazardous level. Water soluble B, Cu, Fe, Ni, Sr and Zn contents were found to be greater in mine spoils compared to unmined sites in Northern Dakota (Wali and Freeman,1973). According to Severson and Gouch(1983), boron deficiency and toxicity are the major problems hindering the efforts at rebuilding the mine in the arid western United States. Kimber et al.(1978) also found Fe, Al, Cu, Mn ,Ni, Zn and Pb at toxically high concentration. The toxic levels of Fe, Al and Mn (Berg and Vogel,1973) and Cu, Ni and Zn (Massey and Barnhisel,1972) can be found on different coal mine spoils. Reclaimed mine sites also suffer from toxicity (Rimmer,1982).However, some coal mine spoils can be non-toxic and support plant growth. These spoils can easily be revegetated e.g. Jhingurda coal mine spoils of India (Singh and Jha,1978;Jha and Singh,1992). Many workers viz.Nordgren et al.(1985), Dave (1994) found biosorption of heavy metals by soil microfungi.

Cooney and Pettibone (1986) demonstrated the usefulness of microbes in testing of metal toxicity.Barghighiani et al. (1987) attempted to estimate the nature of mercury uptake by plants in a mining area and found it to be quite high even ten years after the stoppage of mining operations. Pratt *et al.*(1988) evaluated soluble

toxicant in contaminated soils and suggested short-term chronic bioassays for evaluation of waste site soils. Abbasi and Soni (1990) studied the level of cobalt and nickel in the environment and found it to inhibit both aquatic and terrestrial life. Barghigiani *et al.*(1991) used **Pinus** as an atmospheric biomonitor of mercury. Pillai (1996) found industrial application of microorganisms for metal mining and treatment of toxic wastes rich in metals as an useful tool in providing new insights in the transport process. Brookes *et al.*(1992) studied the impact of Cr (IV and VI) on plants and soil microorganisms and found the impairment of soil microbial respiration, biomass and mineralization by it.

Organic matter and nutrients :

Any conceivable land bereft of its natural flora and fauna is sure to be starved of nutrients. This assumes further significance when it comes to the degraded mined lands. Johnson and Bradshaw (1979) reported that nitrogen and phosphorus are the two principal limiting nutrients though potassium, calcium and magnesium contents may also become critical for growth of plants in lands affected by mining.

Litter layer which is an exchange site for nutrients is lost from the slopy spoils due to water and wind erosion, thereby greatly reducing the nutrient holding capacity of the system (Jha and Singh 1990, 1992). In mine spoil environment , soil though a living system is a skeleton and soil forming processes are confined to a few centimetres only (Down 1975, Anderson 1977, Schafer *et al.* 1980, and

Rimmer 1982). Down (1957) found 0.79, 1.52 and 1.81% organic matter on 0, 5 and 12 year old mine spoils at Somerset coal field. There was however, no significant difference in organic matter between natural soil and the mine spoil in Northern Great Plains (Toy and Shay 1987).

The deficiency of nitrogen acts as limiting factor for plant growth on spoils (Davison and Jefferies 1966, Fitter and Bradshaw 1974, Handley *et al.* 1978 and Bradshaw and Chadwick 1980). Leaching contributes to nitrogen deficiency in spoils (Richardson and Dicker 1972, and Gemmell 1973) and could lead to non-availability of nitrogen to plants growing on spoils (Cornwell and Stone 1968, 1973, Palmer *et al.* 1985). Wittwer *et al.* (1981) found nitrogen and phosphorus to be the limiting factors for plant growth in southern Kentucky mine spoils. Iverson and Wali (1982) observed phosphorus as a major limiting nutrient during colonization and early succession process on surface mined land in North Dakota. Sim (1993), Yli-Halla *et al.* (1995) and Obserson (1966) studied the level of phosphorus and its subsequent runoff from mine spoils.

Biomass and productivity

The green plants assimilate and transform light energy into potential chemical energy which is stored in the organic molecules. A part of this potential energy is utilized by the plant for respiration and the balance contributes to increase in biomass. The net ecological production is manifested in the biomass. Estimation

of biomass and production rates are useful tools in understanding the ecosystem function. Johnson *et al.* (1982) found higher calcium and nitrogen contents in the biomass of undisturbed sites than the spoil areas. Biomass and productivity have been estimated extensively in different ecosystems all over the world. Whittaker (1961) estimated the net production of forest and shrub communities. Pandey and Singh (1992) studied the influence of rainfall and grazing on belowground biomass dynamics in a dry tropical savanna. Singh *et al.* (1992) have carried out detailed work on biomass, productivity and nutrient cycling in Indian forest ecosystems. However, relatively less work has been carried out on the biomass and productivity of the coal mine spoils (Naylor 1974, Singh and Yadava 1974, Barclay *et al.* 1986, Deshmukh 1986, Messier *et al.* 1991). A significant increase in the total biomass of plant communities with spoil age with the control site registering much greater biomass than the spoils was observed by Lyngdoh (1995) while studying the natural recovery pattern in coal mine spoils in Meghalaya. Uma Shankar (1991) reported greater accumulation of phytomass in the belowground compartment rather than the aboveground compartment in a degraded grassland ecosystem in Meghalaya.

Wyatt *et al.* (1980) found three times greater root biomass in old spoils than in new spoils especially in the case of plants with tap roots. Fyles *et al.* (1985) and Fyles and McGill (1987) found higher root biomass in fertilized mine spoils than in

naturally revegetated spoils. Jha (1989) found that 65% to 85% of the total root biomass was in the upper 0-15 cm soil depth. He also found an increase in root biomass with increase in spoil age.

Bacterial and fungal population:

Microbial population constitutes one of the most important components of the soil. Though a dynamic equilibrium is maintained, there are numerous varieties of microbes which colonise the spoils and undergo continual changes in their population and activity. Such a dynamic microbial equilibrium in the soil system is synchronous with the changes in their habitat. Apart from this, the success of any microbial community in a given situation is also determined by its ability to coexist with other organisms. It is now well known that every vegetational community harbours a characteristic microbial population. The microbes are principal agents which participate and regulate organic matter breakdown, nutrient release, mineral cycling, soil fertility status and growth and development of plants.

Adamez (1886) was the first person to isolate fungi from soil. Waksman (1916) reviewed the early literature on soil fungi. He observed that each soil habitat has a distinct fungal flora influenced by the abundance and nature of organic matter in soil. Jensen (1931) found that *Penicillium* and *Trichoderma* species were common in acidic soil and *Mycogone niger* and *Cercospora agricola* were common in alkaline soils. Based on these studies, he suggested that the soil

reaction governs the structure of fungal community.

Ghatak and Roy (1939) studied the fungi of the paddy fields and reported that the cultivated soil microflora was distinctly different from virgin soils. Warcup (1951) found acidity and temperature as the two important factors influencing the distribution of soil fungi. In India, pioneering work on the ecological factors governing fungal distribution was carried out by Saksena (1955) who observed a direct correlation between fungal population and soil phosphate and nitrate contents. Dwivedi (1966a & b) and Mishra (1965, 1966a, b, & c) carried out extensive ecological studies on soil fungi at Varanasi. Latter *et al.* (1967) found markedly different fungal flora on moorland soils. They reported that the structure of fungal community was governed by pH, temperature, water-logging and oxygenation in soils. Prakash and Khan (1971) opined that the variation in soil moisture was one of the principal factors responsible for seasonal fluctuations in microbial population. Similar view was also expressed by Allison (1973) in case of bacterial population. Tiwari *et al.* (1986) found that CO₂ evolution was not related to fungal and bacterial population and it was maximum during the periods when microbial population was minimum.

Tate (1979) found increased aerobic and facultative bacterial populations in flooded soils. Upadhyay and Rai (1979) reported the frequent occurrence of *Trichoderma* in forest soils with high organic matter and low pH. Terry and Tate

(1980) studied the denitrifying bacterial activity in flooded soils and found it to be enhanced just after flooding. Lynch and Panting (1980) found clay soils with more bacterial biomass than loams. Stermann and McLaren (1959) also reported similar results. The delay in biodegradation because of organic matter adsorbed on clay has been corroborated by Gordon and Millero (1985), Marshman and Marshall (1981) and Stermann *et al.* (1959). But Stotzky (1966) and Stotzky and Rem (1966) held that clay inactivated microbial inhibitors, increased ion-exchange capacity, buffered pH and maintained humidity. This was further illustrated by Acea and Carballas (1990). They found that moisture was the main factor controlling microbial population. The role of cation saturation and Mg in bacterial metabolism has been emphasised by Jasper and Silver (1977), Alexander (1967) and Jenson (1965) reported that both Ca and Mg favoured microbial population by increasing the pH. Acea and Carballas (1990) studied the relationship among microbial groups in various humid zone soils and the factors controlling their growth and development. Principal components analysis of the soil microbial population and factors affecting them was done by Acea and Carballas (1990). They reported that the soil depth, time and nitrification potential were the most important factors affecting the proliferation of microbes in soil. The application of lime to a forest soil evoked a positive microbiological response in the form of enhanced nitrifying and denitrifying bacterial population at pH 6.5 (Acea *et al.* 1992). Verstraete *et al.*

(1994) worked on the effect of manuring practices and increased copper concentration on soil microbial population. Abdel Sater *et al.* (1994) dealt with the growth and enzyme activities of fungi and bacteria in sodium chloride salinized soil. Changes in the soil fungal-bacterial biomass ratios following reduction in the intensity of management of an upland grassland were observed by Bardgett *et al.* (1996). Niemela (1966) put forth a semi-empirical precision control criterion for duplicate microbial colony counts. Pankhurst *et al.* (1996) studied the biodiversity of soil microbial community and the application of microbial products for agricultural purposes in China.

Wilson (1965) observed that actinomycetes and bacterial numbers increased in mine spoils with established vegetation. Swift *et al.* (1979) and Miller and May (1981) reported lower microbial abundance and activity in mine spoils than the native grassland soils. Hershman and Temple (1978) measured ATP as a parameter for characterising the microbial status of ATP in mine spoils. Jurgensen (1978) and Cundell (1977) emphasised the importance of soil microflora in enhancing satisfactory plant growth and subsequent formation of soil organic matter during revegetation of a strip-mined land. Microbial activity reflects the critical genetic process of organic matter and nutrient accumulation (Schafer *et al.* 1980). Recognition of the importance of the microbial community in managing reclamation of mine spoils has led to a number of studies in different mine wastes (Zak *et al.*

1990). Microbial abundance and activity have been determined in kaoline spoil (Otrosina *et al.* 1984), coal ash (Klubek *et. al* 1992) , coal refuse site (Lawrey 1977, Lindemann *et. al* 1984) and oil shale (Elkins *et al.* 1984). Chapin *et al.* (1994), del Morl and Bliss (1993) and Marrs and Bradshaw (1994) found that the successional advance of a vegetative community is driven by the gradual accumulation of soil organic matter that provides energy and essential resources for the growth of microbial population.

Dehydrogenase activity (DHA) :

Nutrient cycling in soil involves biochemical, chemical and physico-chemical reactions. Biochemical processes are mediated by microorganisms and plant root-soil system. All biochemical reactions are catalysed by enzymes having high catalytic property and denaturation due to elevated temperature and extreme pH (Tabatabai 1982). Biological oxidation of organic compounds is generally a dehydrogenation process and there are many dehydrogenase enzymes catalysing dehydrogenation.

Drobnik (1955) pointed out non-suitability of quantitative microbial activity estimation done by population counts in preference to quantitative estimation of various soil processes like enzyme activities. Lenhard (1956) introduced the method for measuring dehydrogenase activity (DHA) using the reduction of 2-3-5 triphenyl tetrazolium chloride (TTC) to triphenyl formazan. Stevenson (1958) modified the

modified the Lenhard's technique and presented evidence for the reliability of the dehydrogenase as a measure of estimating total microbial activity in soils though he did not find any correlation between DHA and bacterial numbers. Casida *et al.* (1964) detected relatively uniform DHA regardless of the small fluctuations in microbial numbers. Skujin and McLaren (1968) compared DHA of geologically preserved soils with that of freshly collected desert sand cultivated soils and found measurable DHA in fresh soil though it reflected only the overall metabolism and not microbial numbers. Ross (1971) reported a lower concentration of formazan in incubated aerobic systems. Dehydrogenase activity showed a downward trend after soil is stored at -4°C for 15-30 days unlike urease and invertase. Casida (1977) modified the dehydrogenase activity estimation technique making it more suitable for measuring the metabolic activity of microorganisms. Schinner and Gurschler (1978) reported higher values for enzyme activity, soil organic matter and moisture with decreasing depth. Smith and Pugh (1979) proved the utility of dehydrogenase assay in indicating soil microbial activity. Enzyme activity has also been studied by Nannipieri (1966), Mohanty (1992) and Dick (1996). Tabatabai and Bremner (1973) have shown that added Fe_2O_3 , MnO_2 , SO_4^{-2} and PO_4^{-3} stimulated soil DHA, whereas NO_3^- , NO_2^- , Fe^{-3} seemed to inhibit this activity. Tate and Terry (1980) reported an increased DHA with increase in soil depth. Stroo and Jencks (1982) determined the microbial respiration and soil enzyme activities on mine spoils in the

early stages of soil formation and compared it with those of native soils. They found low respiratory activity in barren mine spoils than in the native soils. As organic matter and nitrogen accumulated in the mine spoils, the microbial activity slowly recovered. They emphasised the importance of the link between vegetation and the development of microbial activity in mine spoils. Tiwari and DasGupta (1993) found reduced rates of dehydrogenase, esterase and phosphatase activity in mining affected rice field soils in comparison to the unaffected sites.

Soil respiration :

The rate of soil respiration is taken as a measure of soil metabolic activity. Smith and Brown (1932) attributed 90% of all soil respiration to the activity of microorganisms. According to Stotzky (1960) soil respiration is closely related to microbial number and nitrogen transformation. Nannipieri *et al.* (1978) noted a relation between CO₂ evolution and urease on one hand and bacterial and fungal biomass on the other. Seto *et al.* (1978) recorded significant differences in CO₂ evolution from the floor of coniferous and broad leaved forests. Gupta and Singh (1977) studied the transformation of organic matter into CO₂. Ross and Cairns (1978), Seto (1980, 1981) and Gupta and Singh (1981) reported that soil respiration is a good measure of soil metabolic activity. Kursar (1989) studied the interrelation between the rate of soil respiration and soil CO₂ concentration in a low land moist forest in Panama. Medina *et al.* (1972, 1980, 1986) and Rajvanshi

(1986) have studied soil respiration in various types of forest soils. Singh and Gupta (1977) worked on the plant litter decomposition and soil respiration in terrestrial ecosystems. Freijer (1991) critically studied the accuracy and effectiveness of using the dynamic CO₂ absorption method for measuring soil respiration. Amador *et al.* (1993) determined the effect of nutrient limitations on microbial respiration in peat soils with different total phosphorus contents. Brookes and McGrath (1984) and Brookes *et al.* (1984) have reported unhindered microbial respiration at heavy metal concentration at around EU mandatory limits. Only at very large concentration of metals, the rate of CO₂ evolution declined. Tyler (1981) reported decreased microbial respiration at 100 ug/g Cu or Zn. Similarly Bardgett (1994) reported a linear decline in respiration at about 1500 ug Cr/g soil.

Mineralization :

The availability of nitrogen to plants is determined by both external inputs (atmospheric deposition, fertilizer application) and by internal recycling within the system (mineralization). Nitrogen mineralization is strongly dependent upon temperature, moisture and substrate (Swift *et al.* 1979). The dependence on substrate makes the mineralization rate not only a determinant of the species composition of the vegetation, but also dependent upon this factor. This occurs mainly because the amount and chemical composition of the plant organic matter differ widely between the plant species (Vitousek and Walker 1987, Berendse *et*

al. 1989, Wedin and Tilman 1990).

Disturbance to vegetation is known to result in enhanced concentration of N in the soil, presumably because of a reduction in plant uptake of NH_4^+ and NO_3^- ions (Vitousek and Melillo 1979, Vitousek *et al.* 1982). Any activity that stimulates mineralization while concurrently failing to stimulate plant uptake should increase inorganic-N in soil water. Hayes and Seastedt (1988) intensively studied the factors influencing nitrogen concentration in soil water in a North-America tall grass prairie and found the concentration of organic-N higher in soil water. Crouse *et al.* (1994) evaluated the effect of preservation methods on inorganic nitrogen content in soil. Mineralization of C and N has been studied in great detail by many workers viz. Macduff *et al.* (1985), Wood *et al.* (1990, 1991 a & b), Klemmedson *et al.* (1992), Ando *et al.* (1991), Van Gestel *et al.* (1991), Ambus *et al.* (1992), Hassink *et al.* (1993), Grant *et al.* (1994), Persson *et al.* 1993, 1994), Grant (1994), Juma (1994) and Gnanamani *et al.* (1994). Very few researches have been carried out on the pattern of nitrogen mineralization in soils of mined areas. Johnson and Williamson (1994) made a laboratory assessment of nitrogen losses from the restored top soils at opencast mine sites at Cumbria. Robertson *et. al* (1995) studied the mineralization of C and N in organic compost and derived positive residual effect of amendments on the total soil N at Frankston.

Microbial biomass:

Soil microbial biomass, which generally comprise 2-3% of the total organic carbon in soil has been recognised as an important source of nutrients because of its fast turnover (Jenkinson and Ladd 1981). Microbial biomass, a labile fraction of soil organic matter is a major sink (when immobilized as well as a source when mineralized) of plant available nutrients (Singh *et al.* 1989). Microbial biomass and activity have been widely measured as indicators of ecosystem functioning by many workers like Singh *et al.* (1991), Parkinson *et al.* (1991), Beeby *et al.* (1993), Perrott *et al.* (1992), Hassink (1993) and Anderson *et al.* (1989), Grant *et al.* (1993).

Microbial biomass carbon and nitrogen were determined by Jenkinson (1988), Vance *et al.* (1987), Brookes *et al.* (1985), Vance *et al.* (1983), Diaz-Ravina *et al.* (1989), Wu *et al.* (1990, 1994 a) , Bosatta *et al.* (1994) , Singh *et al.* (1994), Grant *et al.* (1993), VanGinkel *et al.* (1994), Nicolardot *et al.* (1994), Lovell *et al.* (1995), Dick *et al.* (1995) and Lovahun *et al.* (1996). These studies proved that microbial biomass is the most reliable quantitative assessment of microbes in soil. Mazzarino *et al.* (1996) studied the dynamics of soil total C and N in microbial biomass and water soluble C in tropical agroecosystems and found that microbial biomass content is affected by crop phenology, soil moisture and water soluble C. Acea *et al.* (1993) investigated the pattern of variation in microbial biomass and

found it to be positively related to the soil productivity. Tripathi *et al.* (1997) studied the seasonal dynamics of microbial biomass C, N and P in a subtropical forest in North-East India and reported them to increase with increased age of the forest regrowth. They also observed a higher level of microbial biomass C, N and P in the surface layer than the sub-surface layer. Significant changes in soil microbial biomass, enzyme activity and respiration were reported by Lovell *et al.* (1995) in grasslands subjected to long and short term management changes. The effect of vegetation removal on microbial biomass was studied by Henrot and Robertson (1994). Chander and Brookes (1991b) reported the effect of heavy metals on microbial biomass. Brookes *et al.* (1997) reported that soil microbial biomass can be used as a good measure for assessment of soil ecosystem health. An extensive survey of literature pertaining to various microbial aspects of coal mine spoil revealed the paucity of information in this field.

Legumes as agents for reclamation :

Degraded ecosystems are of worldwide occurrence and their revegetation is hindered due to the deficiency of vital nutrients among which the deficiency of N is an important factor limiting plant growth. In such cases, it is futile and uneconomical to provide the plant with N in the form of fertilizers every year because it is quickly leached away. Legumes by virtue of their N₂ fixing ability are

pivotal in land restoration practices., for example ,*Trifolium repens* has been found suitable for reclaiming derelict lands (Bradshaw and Chadwick 1980). Several reports are also available on the exploitation of the symbiotic legume *Rhizobium* for the reclamation of the degraded system (Ashton *et al.* 1997). Bradshaw and Chadwick (1988) have reported the high rate of N-availability for companion grasses from *Trifolium repens* while yielding protein and mineral rich herbage for itself.

Legumes are also vital in restoration of mine spoils and swards established on colliery spoils which were found to deteriorate quickly without a legume component (Bradshaw and Chadwick 1988). The use of legumes for N-accumulation in china-clay waste was emphasised by Dancer *et al.* (1977) and Lanning and Williams (1980). Skeffington and Bradshaw (1980) have studied the effectiveness of various legumes and non-legumes associations in fixing of nitrogen . Nitrogen fixation rates in legumes like *T. repens* were at least ten times greater than those of non-legumes . Thus legumes could be recommended as the most valuable means of promoting N-accumulation. Legume growth, N-accumulation and N-transfer to companion species were compared amongst different legumes species established on colliery spoils and on sand wastes. N-accumulation of 295 kg ha⁻¹yr⁻¹ and 76 kg ha⁻¹ yr⁻¹ from the legume to companion grasses was recorded within 2 years of sowing (Jefferies *et al.* 1981). Among

different legumes, *Trifolium* was found to be the most effective source of N with N₂-fixation rates estimated to be 70% higher than the maximum rates estimated for other legumes like *Ulex* (Dancer *et al.* 1977).

Bradshaw and Chadwick (1988) found that degraded areas in Minnesota were colonised by two legumes viz. *Trifolium repens* and *Melilotus alba*. They argued that both species grew successfully under stressed conditions due to their N₂-fixing ability. In another spoil, they found *T. repens* to be a pioneer species, appearing within 2 years and after 13 years the species had a frequency of 95% from the initial 5%. Under such conditions, the rate of N-accumulation was reported to increase from 45 kg ha⁻¹ to 258 kg ha⁻¹ within a short span of one year (Bradshaw and Chadwick 1988).

Pulverised fuel ash spoils provide another example of a poor substrate on which only certain species can grow. *T. repens* was found to colonise this substrate at seral stage 3. Once established on such barren areas, *T. repens* exhibits excellent growth of fixation, steadily building up the N-status of the substratum and making it more hospitable to colonization by other seral species.

There are a number of reports on the factors affecting the establishment and growth of these legumes during reclamation (Szabo *et al.* 1974, Fail and Wochok 1977, Bennet *et al.* 1978, Palmer *et al.* 1979). Palmer (1982) reported a greater accumulation of mineralizable and total- N under swards dominated by

T. repens, compared to swards without clover. Jefferies *et al.* (1981b) reported similar findings from naturally occurring patches of white clover. *Agrostis castellana* was found to have higher N-concentration when grown with white clover on colliery spoils and china-clay waste compared to when it was grown in monoculture (Jefferies *et al.* 1981b). Palmer and Iverson (1983) have attempted to elucidate the factors affecting N₂ - fixation by *T. repens* on colliery spoils. Residual soil phosphate level affected fixation, the rates being higher under high residual phosphate levels. They also found that sunshine hours, spoil temperature and substrate moisture level affected N₂ -fixation the most.

Over the years, white clover has emerged as the legume of choice for the purpose of reclamation of degraded ecosystems on account of its remarkable N₂ - fixation ability and reproducibility from both stolons and seeds. The prostrating stolons also impart an appreciable ground cover. Lyngdoh (1995) while working on the) reported that the production of reproductive shoots, aboveground biomass and total leaf area of *T. repens* showed pronounced increase in disturbed plot in comparison to the protected plot. It was also evident from the study that *T. repens* owes its luxuriant growth to biotic disturbance like grazing, cutting and trampling in grasslands.

In India, the suitability and efficiency of leguminous species viz., *Trifolium repens* in reclamation of mine spoils and the benefits accrued therein has engaged

very little attention of the workers. The work of Pradhan and Tripathi (1980) on the growth and co-existence of *Trifolium repens* and *Paspalum dilatatum* in the grassland of Shillong, Meghalaya merits a mention.

CHAPTER III

STUDY AREA AND METHODS

Study sites

The study was conducted in Bapung (latitude 25°25'N, longitude 92°8' E, altitude 1200 m asl) in Jaintia Hills, ca. 87 km away from Shillong (Fig. 3.2). The landscape of the area is characterised by round topped hillocks and undulating topography. Coal mine spoils of 0-2 years, 6-8 years and 12-14 years of age with replicates were selected for the study. Under each age group, three heaps measuring 50m² in area and 6 metre in height were selected for the detailed study. All the sites were located within half a kilometre horizontal distance from each other. For making a comparative analysis of vegetational and microbial parameters, an adjacent unmined land measuring about 1 ha was chosen to serve as a control. A basic assumption of the research is that the members of the sequence were originally identical and only time is a variable proposition. The study sites were carefully chosen ensuring that they satisfy the above assumption.

Geology and soil

The Jaintia Hills plateau is the continuation of the Shillong plateau of the Khasi Hills. The region is predominantly composed of metamorphic rocks and consists of thick series of quartzites and schists with intrusions of granites, dolerites and perodites and embedded bands of argillites. The southern slope

(Bapung) of Jaintia series consists of pre-tertiary and tertiary rocks of limestones. The soil is mostly sandy, reddish brown to yellow brown in colour, acidic in reaction with low water holding capacity and has poor contents of organic matter and nutrients.

Climate

The climate of the study area is subtropical monsoonic. The mean annual maximum and minimum temperatures recorded during the study period were 28°C and 5°C respectively (Fig.3.3). The place registered rather heavy rainfall of about 7912.2 and 4331.35 mm during 1995 and 1996 respectively. The year can be divided into four seasons : (i) summer (March-mid-May), (ii) rainy (mid-May-September), (iii) autumn (October-November), and (iv) winter (December-February). The summer season is characterised by occasional showers and gradual increase in temperature over the preceding winter months and a high velocity wind. The rainy season commences with the setting up of south-west monsoon in mid-May and lasts up to September. This is the wettest period of the year and about three-fourth of the annual rainfall is received during this period. The rainy season is followed by a brief autumn during which a sharp decline in rainfall and lowering of temperature takes place. It is a transitory period between rainy and winter seasons. The winter season extends from December to February. Intermittent showers and dry weather are the characteristic features of this season. The relative humidity (RH)

was maximum (100%) during the rainy season and minimum (40%) during the winter.

Vegetation

The natural vegetation of this region is subtropical (Chauhan and Singh 1992). The large scale unscientific land use practices have resulted in the depletion of primary forest and colonisation of the degraded sites by *Pinus kesiya*, which grows well to develop into secondary forests. Besides, the forest floor is covered with grasses, mosses, *Impatiens* sp., *Lycopodium* sp., *Dicranopteris* sp. and *Houttuynia* sp. etc. The presence of isolated patches of degraded forests amidst the grassland imparts a savanna like appearance to the landscape of the region. The acidic and highly impoverished shallow soil layer is neither conducive for regeneration through seeds nor for healthy plant growth.

Methods

Community analysis

Three coal mine spoils of varying ages, viz. 0-2 years, 6-8 years and 12-14 years and an unmined control were selected for the present study. A detailed analysis of community structure at the ground level was undertaken in all the three replicates of the mine spoils and control site. For this purpose, five 50 x 50 cm quadrats were randomly laid in each stand at least once during each of the four seasons in annual cycle over a two-year period (1995-1996). The vegetational

characteristics such as density, frequency, abundance, importance value index (IVI), sociability, cover value, relative performance index (RPI), index of floristic similarity (IFS), growth form, seed production and vegetative propagation were determined by following Misra (1968) and Ellenberg and Muller-Dombois (1974). The identification of plant species collected from the study sites was done according to Hooker's (1872-1897) flora.

Above and belowground biomass and production

The plant biomass and primary productivity on the mine spoils and the unmined control site were determined by harvest method. This comprised the determination of above and belowground biomass separately taking samples on seasonal basis. The above ground parts of the plant species from the five randomly laid 50 cm² quadrats were clipped close to the ground level with the help of sharp scissors. The harvested material was collected species-wise in polythene bags for further laboratory analysis. Such a harvesting of aboveground parts was done in each season. The harvested plant materials were later sorted out into live green and standing dead fractions. The plant litter was also collected from five randomly laid quadrats of 50 cm² area. The samples were separated into pine, non-pine (both dicot and monocot) plant parts and miscellaneous fragments in the laboratory. The samples were oven-dried at 80⁰ C for 48 hours and their final weight was taken.

On each sampling date, belowground biomass was also determined by

collecting the soil from three randomly laid soil cores measuring 45 cm long with a inner diameter of 6.3 cm down to 20 cm depth using a soil corer. The soil samples were kept in polythene bags and stored at -20°C in a deep freeze until separation. The roots were extracted from the soil cores by wet sieving method as outlined by Bohm (1979). The root samples were oven-dried at 80°C for 48 hours and their final weight was taken in an electronic balance to determine the dry matter content. Seasonal and depth-wise variation in root biomass was also recorded. Production in all the three components was calculated by taking the positive increment in biomass with seasons being taken into consideration. Nutrient accumulation was calculated by multiplying the mean drymass with their corresponding concentration. Similarly, nutrient input was obtained by multiplying production values with mean concentration.

Plant nutrient analysis

Oven-dried samples of the aboveground plant parts, litter and belowground parts were powdered in a grinding mill (Cyclotec-Tecator) and used for the estimation of total Kjeldahl nitrogen, total phosphorus and exchangeable potassium concentrations. Total phosphorus was determined by digesting the oven-dried samples using tri acid ($1\text{ ml HClO}_4 + 5\text{ ml HNO}_3 + 0.5\text{ ml H}_2\text{SO}_4$) in a block digester and subsequently analysing the digested material by molybdenum blue method (Anderson and Ingram, 1993). Total Kjeldahl nitrogen was estimated by

digesting the oven-dried powdered plant samples with concentrated H_2SO_4 acid in a block digester using Kjeltab as a catalyst. Distillation was carried out in a semi-microdistillation set and the distillate was collected in boric acid indicator. The distillate was titrated with N/140 HCl (Allen *et al.* 1974). Exchangeable potassium was estimated by flame photometer method as described by Allen *et al.* (1974).

Soil

Soil samples were collected randomly from all the three mine spoil sites and the control area on a seasonal basis over a period of two years (1995-1996) using a steel corer of 6.3 cm diameter and 45 cm length. The soil core thus obtained was divided into two layers viz. 0-10cm and 10-20 cm soil depth. The soil samples were mixed to obtain a homogeneous soil mixture, air dried and sieved through a 2 mm sieve and stored for analysis.

A digital pH meter was used to determine soil pH in 1:2.5 suspension of soil and distilled water (Anderson and Ingram 1993). Soil moisture content (SMC) was gravimetrically determined by drying 10 g of freshly sieved soil at $105^{\circ}C$ for 24 hours in a hot air oven (Allen *et al.* 1974).

Soil bulk density (BD) was gravimetrically determined and soil texture was analysed by Bouyoucos hydrometer method (Allen *et al.* 1974). Soil water holding capacity (WHC) was determined by Keen's box method by using copper cups having an internal diameter of 7 cm and 1.2 cm height (Piper 1942). Cation

exchange capacity (CEC) was determined by extracting the soil with 1 M ammonium acetate solution (pH 7.00) followed by dispersion of $\text{NH}_4\text{-N}$ with KCl and distillation with MgO (Allen *et al.* 1974).

Air-dried and sieved (0.5 mm) soils were used for total Kjeldahl nitrogen (TKN), available-P and exchangeable-K. TKN was determined by digesting the soil sample with concentrated H_2SO_4 using Kjeltab as catalyst in a block digester. Distillate obtained from semi-microdistillation set was titrated with N/140 HCl (Allen *et al.* 1974). Available-P was determined by molybdenum blue method after extracting the soil-P in 0.5 M sodium bicarbonate (Anderson and Ingram 1993). Soil exchangeable potassium was determined by flame photometer using ammonium acetate method as outlined by Jackson (1973).

Microbial community in soil

The temporal variation in microbial population and activity in soil was estimated by collecting soil samples on a seasonal basis. Fungal population in soil was estimated by the soil plate method (Warcup 1950) using rose bengal agar medium (Martin 1950), wherein, 0.02 g of soil was transferred to the sterilised petridishes with the help of a spatula. A few drops of sterilised distilled water were poured at the bottom of the petridish to disperse the soil aggregate uniformly. Approximately, 15 ml of molten and cooled (below 45°C) rose bengal agar supplemented with streptomycin sulphate was poured into petridishes and incubated

at $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for 5 days. Bacterial population was enumerated by employing the dilution plate method (Waksman 1922) on nutrient agar medium (Johnson and Curl, 1972). The dishes were incubated at $30^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for 24 hours.

The soil microbial-C was estimated by chloroform-fumigation incubation (FI) method of Jenkinson and Powlson (1976) with a minor modification as suggested by Srivastava and Singh (1988). The soils were pre-incubated for 7 days at room temperature for conditioning and to settle down the microbial activity. 100g of field moist soil samples were fumigated with chloroform for 24 hours and then evacuated to remove the chloroform vapours. The soil samples were then adjusted to 60% of water holding capacity and transferred to rectangular glass jars along with two beakers, one containing 20 ml deionised water to prevent soil drying during incubation and another containing 50 ml 1N NaOH. 1g of unfumigated soil was then added to each jar. The jars were incubated at $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for 10 days. After 10 days, the residual alkali was titrated against 1N HCl to find the amount of CO_2 evolved from the fumigated soil samples (FC). The same soils were further incubated for next 10 days. The titrated values for the next 10 days of incubation were treated as control (C) as suggested by Merckx *et al.* (1985). The flush of CO_2 during fumigation was calculated by subtracting the UFC from FC, and microbial biomass C was calculated by dividing the flush of CO_2 by a factor (Kc) of 0.45 (Jenkinson and Ladd, 1981).

Microbial biomass C = FC-UFC/Kc.

Where Kc is the fraction of carbon mineralized during the first 10 days.

The soil respiration was measured by determining CO₂ evolution by absorption and titration method using phenolphthalein indicator and 0.1N KOH as absorbent (Macfadyen 1970).

2-3-5 triphenyl tetrazolium chloride (TTC) reduction technique was adopted for the assessment of the dehydrogenase enzyme activity (DHA) in soil (Casida 1977). 10 g of fresh soil was taken in a test tube and treated with 0.1 g of CaCO₃ and 1 ml of 1% TTC solution. The plugged test tube containing the sample was then shaken to ensure proper mixing. The sample was then incubated at 30°C for 24 hours. A blank was also run simultaneously. After 24 hours, the incubated sample was extracted with methanol aliquots and filtered through Whatman filter paper No.1. The final volume was made up to 50 ml. The optical density of the pink coloured extract was read at 485 nm and expressed as mg formazan/g dry wt /24 hours. N-mineralisation was estimated by following the method as outlined by Burke *et al.* (1980).

Growth of plants for reclamation measures

The enrichment of soil nitrogen by leguminous species is quite well known. In order to ascertain the suitability of plant species for reclaiming the degraded mine spoils, one legume (*Trifolium repens*), grass (*Arundinella khasiana*) and one hardy

forb (*Borreria hispida*) were grown in polypacks containing 500 g soil from 0-2 year old and of 6-8 year old spoil in replicates and treated with the required doses of amendments like murate of potash (MOP), lime (Calcium hydroxide) and diammonium phosphate (DAP). Moisture level was raised to a uniform level with light intensity and temperature being monitored. The plants were harvested thrice from April, 1997 after 45, 90 and 135 days designated as H₁, H₂, and H₃ respectively. At the time of each harvest, fresh weight and dry weight of leaf, stem and roots were measured. The dried plant material from each harvest was powdered for nutrient estimation. Total Kjeldahl nitrogen contents of plant materials were determined as outlined by Allen et al. (1974).

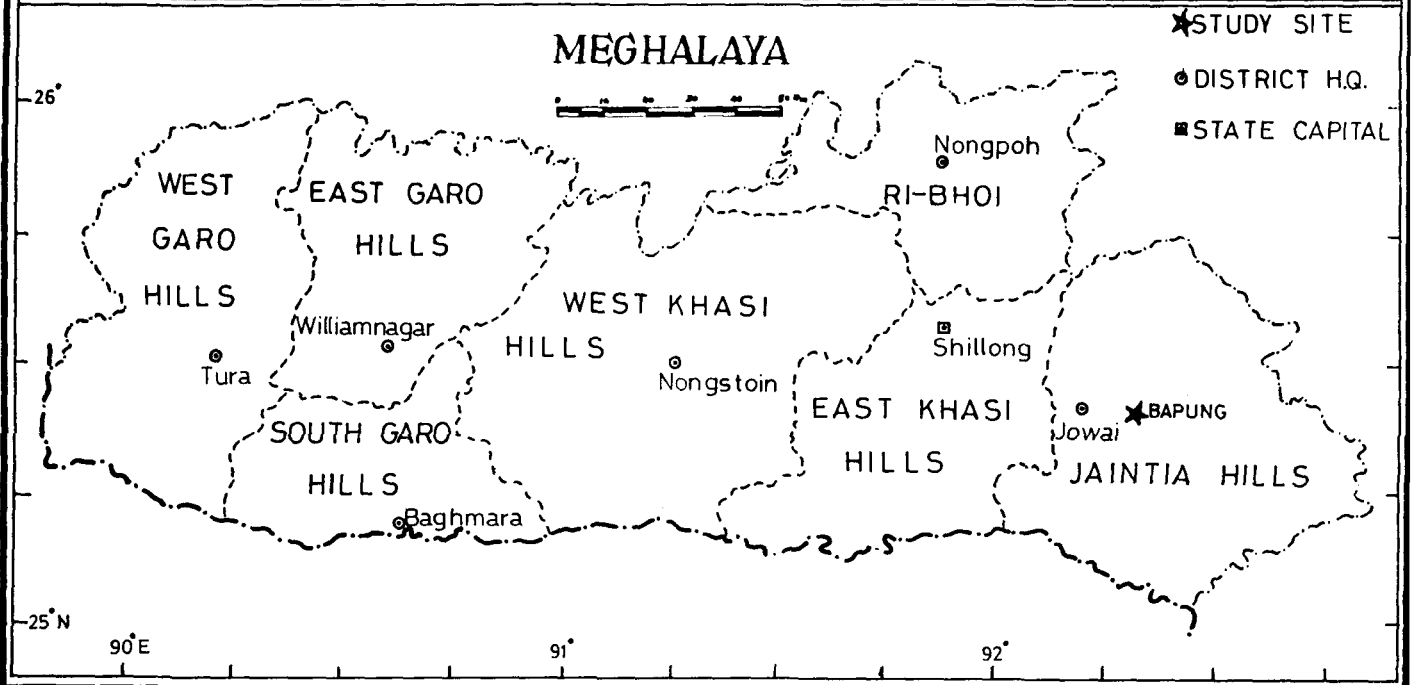
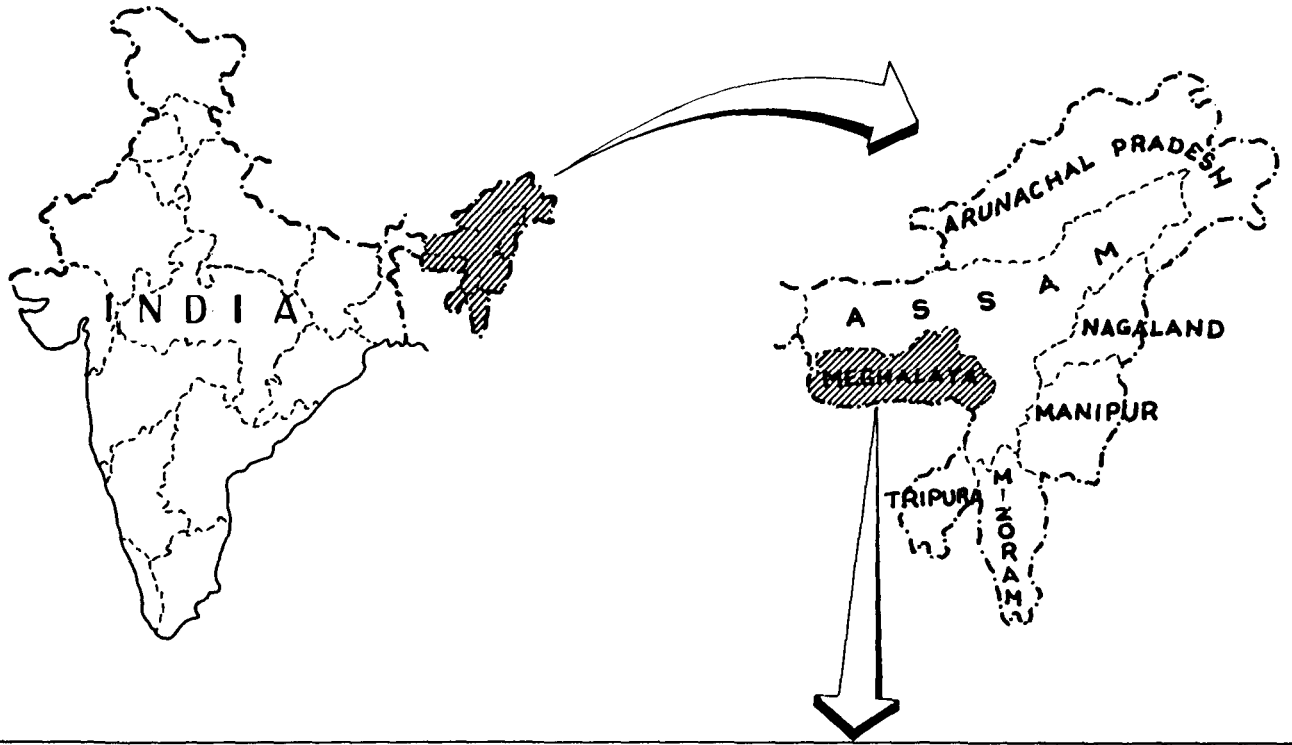
Statistical analysis

Data were statistically analysed using one, two, and three way ANOVA (fixed effect model) to test whether the sampling periods and age of mine spoils had significant effects on biomass, production, nutrient concentration of different plant parts, soil characters and microbial parameters. Simple and multiple regression analysis were carried out on roots, litters and aboveground plant parts considering them as dependent variables and climate (rainfall, mean monthly minimum and maximum air temperature) and edaphic (soil moisture, pH, SOM, TKN and available-P) characteristics as independent variables.

FIG. 3.1. AREAS AFFECTED BY MINING ACTIVITIES IN INDIA



FIG. 3.2 MAP OF THE STUDY AREA



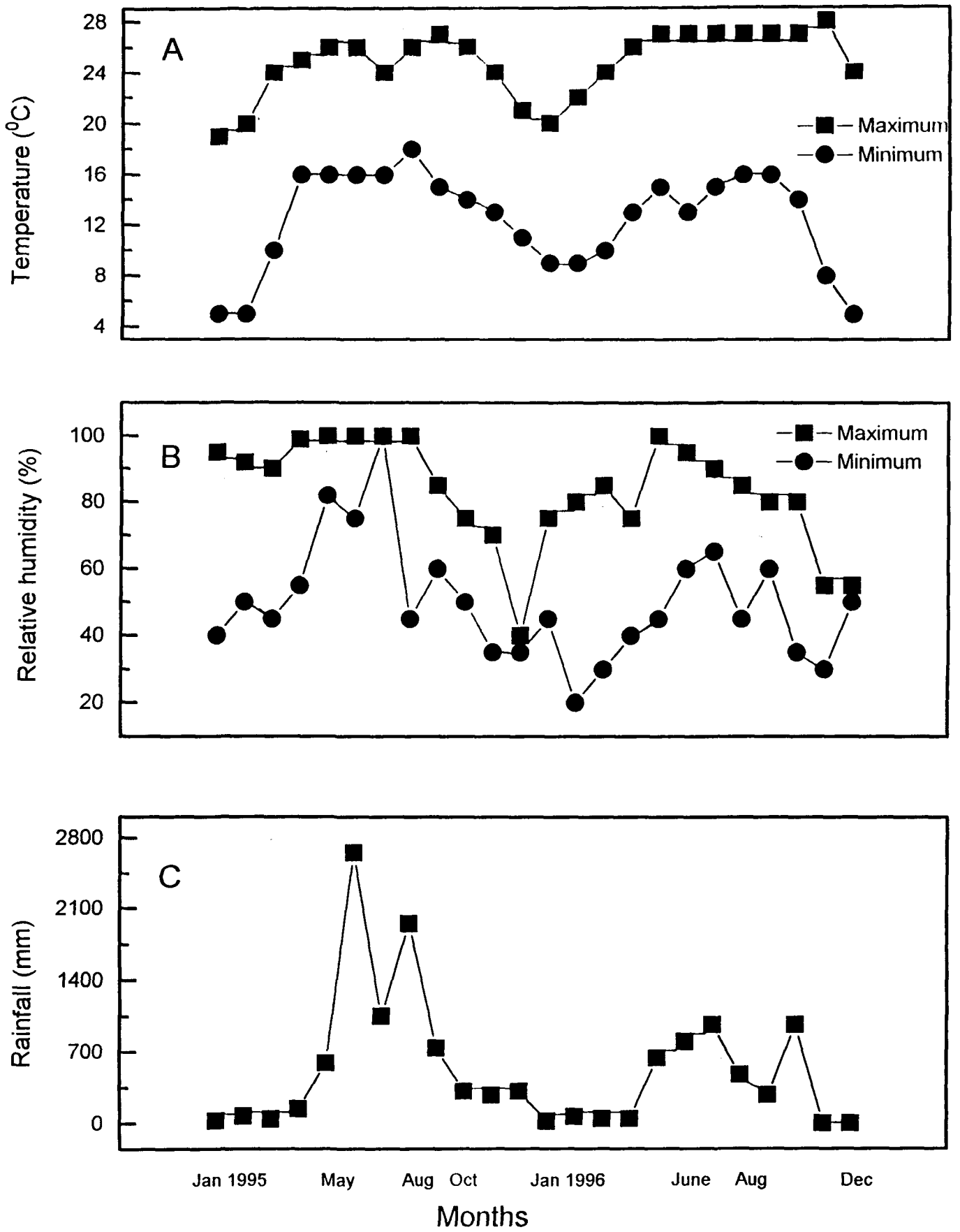


Fig.3.3. Temperature (A), relative humidity (B) and rainfall (C) of the area during the study period.

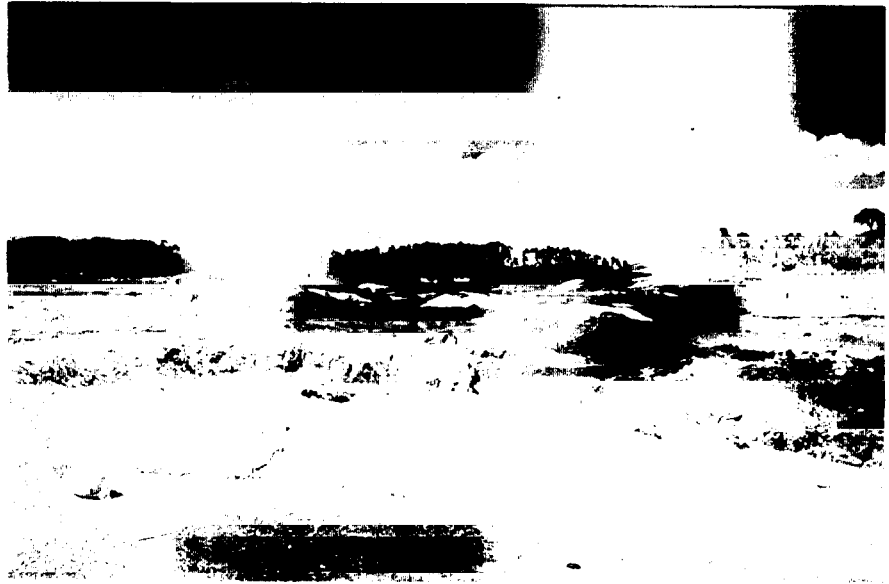


Plate- 1

**Landscape of the study area showing
fresh mine spoils and subsidence**



Plate- 2

**Unmined forest stand adjacent to the
coal mines**



Plate- 3

A view of 12-14 year old mine spoil

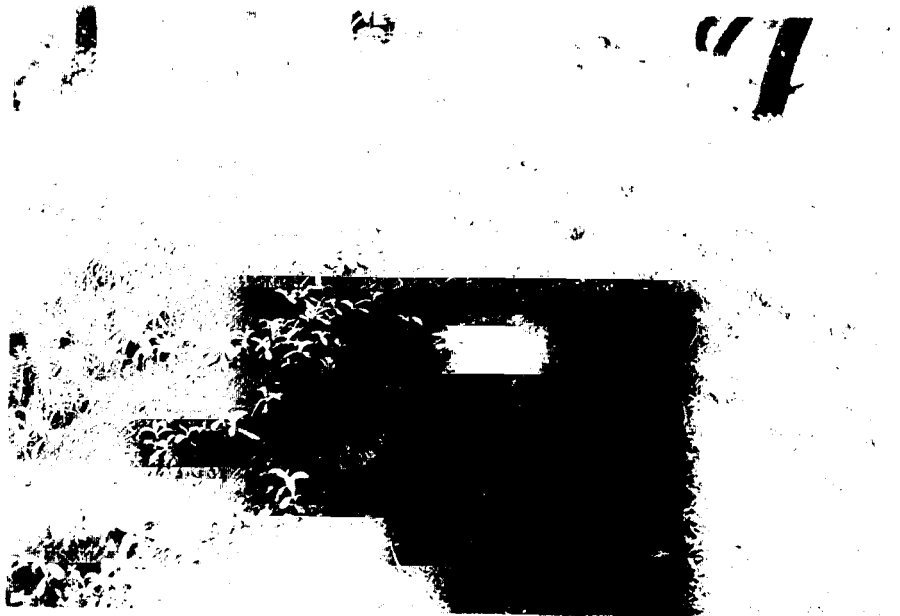


Plate- 4

**A close view of 12-14 year old coal
mine spoil surface**



Plate- 5

A view of 6-8 year old coal mine spoil



Plate- 6

**A surface view of 0-2 year old coal
mine spoil**

CHAPTER IV

EDAPHIC CHANGES IN COAL MINE SPOILS UNDERGOING NATURAL RECOVERY

Introduction

Surface mining of coal inevitably brings about degradation of natural soils. The physico-chemical properties of soil undergo a drastic upheaval influencing plant growth and vegetation characteristics, notwithstanding the impoverishment of nutrients from the system. Mine spoils suffer from impediments like low organic matter contents, low pH, lack of soil structure, low water holding capacity, low infiltration rates, low bulk density, nutrient deficiency and moisture retention stress. Mining process inflicts incalculable damage to the land surface irrespective of the mode of extraction employed. Coal mine belt presents a mosaic of mine spoils spread over a vast stretch of land across the globe. Such mine spoils are of common occurrence in various places in the Jaintia Hills district of Meghalaya. In fact, the colonization and establishment of vegetation on coal mine spoils are quite slow. High acidity due to oxidation of iron pyrites (FeS_2) is an important factor limiting plant growth in several mine spoils (Chadwick 1973, Doubleday 1974, Caruccio 1975, Armiger *et al.* 1976, Bennett *et al.* 1976). High rainfall permits more pyritic oxidation thereby exhibiting excessively acidic soil pH. High acidity in mine spoils causes dysfunction in plant growth, impaired absorption of P, Ca, Mg and K and

increased availability of aluminium (Al), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and nickel (Ni), often in toxic proportions. The acidity also creates unfavourable biotic conditions like reduced N-fixation and mycorrhizal activity, and increase in fungal pathogens (Black 1968, Tucker *et al.* 1987).

Paucity of essential plant nutrients particularly nitrogen (Handley *et al.* 1978, Bradshaw and Chadwick 1980) and phosphorus (Iverson and 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 nucleic acids and hence of all protoplasm. It is generally absorbed by the plants as ammonium or as nitrate ions. Lack of mineralizable organic-N and lower mineralization rates affect the availability of N to plants in mine spoils (Reeder and Berg 1977). Phosphorus as orthophosphate plays a fundamental role in a very large number of enzymic reactions that depend on phosphorylation. It is a constituent of cell nucleus and is essential for cell division and for the development of meristematic tissues. Plants take up phosphorus almost exclusively as inorganic phosphate ions. Prasad and Shukla (1985) reported N, P and K deficiency in coal mine spoils at Dhanpuri, Madhya Pradesh. Deficiency of nitrogen and phosphorus is due to their unavailability in acidic condition and their susceptibility to leaching processes (Richardson and Dicker 1972, Gemmell 1973, Iverson and Wali 1982).

The mine spoils present a rigorous habitat, generally characterised by high

temperature, moisture stress and surface instability, which favour soil erosion. The steep slope as well as barren conditions pave the way for low water storage in soil. Evaporation and continuous run-off also result in water loss. Insufficient availability of water for plant growth is also encountered on the mine spoils due to preponderance of sand.

The physico-chemical properties of coal mine spoils have engaged the attention of a number of workers viz. Kimber *et al.* (1978), Schafer and Nielsen (1979), Pederson *et al.* (1980), Bell and Ungar (1981), Fyles *et al.* (1985), Toy and Shay (1987), Power (1978), Dollhopf *et al.* (1981). In India, studies have been conducted by Mathur *et al.* (1982-1985), Soni *et al.* (1989a, 1990), Jha and Singh (1991) and Pandey *et al.* (1993). The studies on edaphic aspects of coal mine spoils are few and far between in Meghalaya (Uma Shankar *et al.* 1993 and Lyngdoh, 1995). The present chapter deals with the edaphic changes in coal mine spoils undergoing natural recovery.

Results

pH : pH value did not exhibit any seasonal trend. There was as such no depth-wise or site-wise trend of variation as the values fluctuated. The youngest spoil (0-2 year old) however, registered higher pH values in the lower soil layer (10-20 cm) than the surface soil layer (0-10 cm). The pH values of the mine spoils and unmined control site ranged from 3.64 to 6.10. The lowest pH value (3.64)

was recorded in the 12-14 year old spoil during the winter season in the 10-20 cm soil layer and the highest value (6.10) was recorded in the 10-20 cm soil layer of the control site during spring season (Fig. 4.1).

Soil texture : The percentage of sand was overwhelmingly higher in the mine spoils and the control site. Maximum (97%) was recorded in the control site in both the soil layers (0-10 and 10-20 cm) as well in the youngest spoil in the sub-surface soil layer. In other sites, it ranged from 82.3-89%. In 12-14 and 6-8 year old spoil, the texture was sandy loam. The percentage of clay was least in the control site and the sub-surface soil layer in the youngest spoil. However, in the 12-14 and 6-8 year old spoils it was maximum in both the soil layers. In other cases, the clay percentage ranged from 6.5-9.2%. In the case of silt also a similar trend was observed (Table 4.1).

Water holding capacity : Water holding capacity showed a definite decreasing trend with increasing depth and decreasing age of the spoils. The water holding capacity was maximum (66%) in the control site in the surface layer and minimum in the 0-2 year old spoil in the sub-surface layer (Fig. 4.2).

Bulk density: Bulk density of the mine spoils and the soils of the control site showed a trend similar to WHC. It was found to be maximum in the upper layer (0-10 cm) of the control site and least in the sub-surface layer of the youngest spoil (Table 4.2). It increased with the increase in mine spoil age.

Porosity : Porosity of mine spoils and control sites increased gradually with increasing depth and decreasing spoil age. As expected, it showed an inverse relationship with the bulk density. The upper soil layer in the control site had the least porosity whereas maximum value was recorded in sub-surface layer of 0-2 year old spoil (Table 4.2).

Cation exchange capacity : The cation exchange capacity of spoils also showed a trend similar to that of bulk density and water holding capacity. The control site recorded the highest value, whereas the youngest spoil and the lowest value. The CEC decreased with increasing depth, it was the upper most soil depth in the 0-2 year old spoil which recorded the lowest (0.29) value (Table 4.2).

Soil moisture content : The moisture content did not show any definite seasonal trend though a depth-wise marginal decrease was observed except in the lower depth of the 6-8 year and the 0-2 year old spoil. It varied widely between the seasons (Fig 4.3). The sub-surface soil layer (10-20 cm) in the case of 6-8 year and 0-2 year old spoil had a slightly higher level of moisture than the surface layer. The mean SMC showed a declining trend with increasing depth and decreasing spoil age. The highest moisture content was recorded during the rainy season in the control site during the first year, while the minimum was recorded in the autumn season of the same year in the 0-2 year old spoil.

Organic carbon : There was a perceptible decline in the organic carbon with

increasing depth and decreasing age of the spoils (Fig. 4.4). But it did not follow any definite seasonal pattern. The soils of the unmined site had the maximum organic carbon (37.9 mg/g) in the surface layer during the rainy season, whereas the least value (1.3 mg/g) was recorded in the sub-surface soil layer of the youngest spoil during the winter season.

TKN : The concentration of TKN showed a definite seasonal trend with spring registering the maximum value in both years. It decreased gradually from spring to winter in both years in all the mine spoil sites. TKN declined significantly with increasing depths as well as with decreasing spoil age. Maximum TKN (3.50 mg/g) was found in the control site during the spring season in the second year and minimum (0.05 mg/g) in the first year during the rainy season in the youngest spoil. There was a definite increase in TKN from the first to the second year of the study (Fig. 4.5).

Available-P : The concentration of available-P showed a marginal variation between the seasons. The autumn season recorded the highest value (0.9 mg/g) in the second year in the control site. The phosphorus level showed a declining trend with increasing depth (Fig. 4.6). The values also increased with increasing age. The maximum values were recorded in the control site in all the seasons. Available-P increased marginally from the first year to the second year of the study.

Exchangeable -K : It showed a pattern similar to TKN and available-P.

Where are the
data??

How could plants
grow without CO₂?

Notwithstanding marginal variations between the seasons and the spoil sites, there was a distinct lowering of its level with increasing soil depth and decreasing spoil age (Fig. 4.7). The unmined control site always recorded the highest value (0.64 mg/g) in the surface layer spread across the seasons. Lowest concentration (0.03 mg/g) was observed in the sub-surface layer of the youngest spoil in all the seasons.

C/N ratio :C/N ratio in mine spoils of different ages and the control site was higher in the lower depth than in the upper. The C/N ratio was lower in the youngest spoil in comparison to other spoils. The maximum (20.60) C/N ratio was found in the lower depth of 6-8 year old spoil and minimum (9.53) in the upper depth of the unmined site.

Heavy metals : Data obtained from Atomic Absorption Spectrophotometric analysis of spoil samples for assessing the level of concentration of metals like Fe, Co, Cd and Cu did not indicate these elements reaching toxic levels in the study site to impair in any way the process of plant species colonization or revegetation. But the preponderance of Fe was clearly observed. The concentration of Co was very minimal, whereas Cd and Cu were not detected.

Discussion

The results revealed that physico-chemical properties of coal mine spoils of different ages varied with the spoil age, spoil depth and season. The bulk density of

the mine spoils was found to be significantly lower than the unmined control. This is in line with the findings of Lyngdoh (1995) who also reported lower bulk density values in coal mine spoils of Jarain. This is also in conformity with the reports of Power *et al.* (1978a) who found low bulk density, *ca.* 10-30% lower value than the original undisturbed soil in Northern Great Plains. He found that the bulk density values of spoil and undisturbed soil ranged from 1.1 to 1.4 and 1.4-1.7 g/cm³ respectively.

The dumping of spoil causes differential packing. Thus the bulk density in the central axis of the piles becomes higher and lower towards outer slopes. This causes uneven subsidence and differences in surface drainage.

Indorante *et al.* (1981) while undertaking reclamation of surface-mined lands in Illinois found that the constructed soil at 15-30 cm and 45-75 cm depth had a higher bulk density than the undisturbed soils. The bulk density of constructed soil ranged from 1.53-1.78 g/cm³ in that depth range, whereas in case of the undisturbed soils, it ranged from 1.42-1.55 g/cm³.

The coal mine spoils under investigation demonstrated a decrease in bulk density with declining spoil age and increasing soil depth. This is due to the fact that no heavy equipments are used during mining operations and the spoil material tends to be loose. Water infiltration and movement decreased with increase in bulk density. Powell *et al.* (1985) reported an increase in bulk density through soil

ripping in prime farmlands in Kentucky. Bulk density showed negative correlation ($P < 0.05$) with clay particles whereas it was significantly correlated ($P < 0.01$) with microbial population and biomass besides organic carbon.

With increase in spoil age, the porosity declined and the control site had the least porosity. This is in conformity with the findings of Pederson *et al.* (1980) who reported that spoils having high bulk density and low porosity had low infiltration rate. Root growth is restricted in soils with a bulk density higher than 1.6 (Russell 1977).

Dollhopf (1981) suggested that when clay content in the spoil was greater than 40%, it caused low permeability, low infiltration rate, structural and compaction problem, and when the sand content was greater than 70%, the mine spoils retained insufficient water for plant growth. In the present study too, the retention of water would be low as all the mine spoils and the soils of the unmined site, irrespective of the soil depth have very high percentage of sand. This is in agreement with the findings of Lyngdoh (1995). There was no pronounced indication to suggest an increase in clay and silt contents with mine spoil age. This is in contrast to the observations made by Uma Shankar *et al.* (1993). Jha and Singh (1991) reported an increase in proportion of the particle size of 0.2-0.1 mm with age of the mine spoils. The control site though not disturbed by mining, was a degraded forest. The soil was very thin and stony and sand was the most

dominant fraction. This condition can be attributed to the sandy nature of the parent rock, heavy soil erosion and absence of any substantial vegetal cover. The low percentage of clay in the upper soil layer could be due to high porosity. It has been established that due to high sodium and low soluble salt contents, clay becomes dispersed, water movement is restricted and unfavourable conditions for root occurs (Russell 1972). The soil from lower soil depths which was least eroded had higher silt and clay contents. Eyre (1968) reported that the loss of finer soil particles, especially clay component increases the proportion of sand in the soil during the early developmental stage after disturbance. This view was corroborated by Maithani *et al.* (1996) in a study on 7-, 13- and 16-year old naturally regenerated forest stands.

pH of the mine spoils and the control soil did not show any conspicuous trend across the seasons. But the mine spoils generally had a lower pH than the control sites. There was an increase in pH, though minimal, in the sub-surface layer of the spoils. Both moisture stress and acidity were severe in all the mine spoils under study. This conforms with the findings of Lyngdoh (1995). pH of the spoil material was highly acidic primarily due to the oxidation of iron pyrites (Caruccio ,1975; Johnson and Bradshaw ,1979). The control site apparently had a higher pH in comparison to the mine spoils as there was no mining activity in the former. This is in accordance with the findings of Lyngdoh (1995). The sub-surface spoil layer

of the oldest spoil recorded the least pH of 3.64 during the winter season. It may be mentioned that pH below 4 is considered to be toxic for the growth of the plants (Sutton 1970). The continual acidification generally results in the die back of well established vegetation. The occasional rise in pH in the lower depths as found in this study, was also recorded by Pandey *et al.* (1993). Species richness is adversely affected by soil pH. Bradshaw and Chadwick (1980) working on the colliery spoils also reported that the number of species colonizing on the spoil was influenced by its pH. Decline in pH in mine spoil is one of the severe problems associated with coal mining activity. Lowering of pH strongly hampers the availability of a number of essential nutrients in the soil. pH as low as 1.5 has also been reported from colliery spoils in the British Isles by Johnson and Bradshaw (1979). There are several reports where increase in pH has also been reported. In North-Dakota area the mine spoils had higher pH, electrical conductivity and silt and clay content (Wali and Freeman 1973). According to Indorante *et al.* (1981) a higher pH in mining site is expected because during mining different horizons are mixed. In the present study, however, increase in pH was never recorded. pH showed positive correlation ($P < 0.05$) with CEC, BD and moisture.

Brenner *et al.* (1984) reported that organic matter and moisture contents of the spoil are pivotal in determining the ultimate success of reclamation on surface mines. They further observed that the upper layer of a 15-year old surface mine

had 33.7% moisture in comparison to 8.1%, 18.4% and 17.5% in 12, 24 and 26 cm soil depth respectively. The fluctuations of moisture with depth in the present study also showed a similar trend. Baig (1992) reported severe moisture deficiency on spoils during the growing season ranging from 6.3% in 30-55 year to 4.9% in a 2-5 year old coal mine spoils. Barnhisel *et al.* (1969) also reported similar results from Eastern Kentucky coal mine spoils.

Water holding capacity increased significantly with increase in the age of the spoil and spoil depth. The unmined control site had the highest water holding capacity in the surface and sub-surface soil layer due to high organic matter accumulation. This conforms with the findings of Uma Shankar *et al.* (1993) and Lyngdoh (1995). Very low percentage of organic matter, very low level of clay and a high percentage of sand could be the cause of the lowest water holding capacity recorded in the sub-surface layer of the 0-2 year old spoil. There was a recognisable lowering of water holding capacity with depth in all the sites. Coarse and medium textured overburden materials with low water holding capacity when compared, exhibited improvement in water holding capacity as indicated by the increase in WHC with the age of the spoil. WHC showed significant positive ($P < 0.01$) correlation with microbial population and their activities.

The increase in CEC along with the increase in mine spoil age and depth as observed in the present study, is at variance with the findings of Lyngdoh (1995).

The rise culminating in the maximum CEC in the surface soil layer of the unmined control site could be due to the rise in pH level. Furthermore, this rise could be due to the increase in clay particles in the soil of the control site. The lower CEC in the youngest spoils and its increase in the older mine spoils agrees with the findings of Maithani (1996) and Scholes *et al.* (1994) who found a linear relationship between clay particles and CEC both of which increased with increasing age of the sites undergoing recovery.

The mine spoils had inadequate organic carbon. The low organic carbon contents of the spoils further declined with increasing depth. The mean seasonal value of organic matter content declined considerably from the control site to the youngest spoil. Accumulation of litter, maximum biological activity and growth of roots in the surface soil layer might have contributed to the high organic matter and other nutrients in this layer (John, 1998). This observation is in line with Lyngdoh (1995). Williams (1975), Johnson *et al.* (1976), Down and Stocks (1977) and Johnson and Bradshaw (1979) reported that most of the coal mine spoils are deficient in organic matter and nitrogen. Thomas *et al.* (1985) found predictably low percentage of organic carbon in eight Illinois mine spoils. Soni *et al.* (1989) also obtained similar results from a rock phosphate mine spoil in Dehra Dun, India. Low level of organic matter in mine spoils as reported by Lyngdoh (1995), Indorante *et al.* (1981), Brenner (1983) does not augur well for the derelict lands as

this would cause delayed vegetation establishment.

As in the present study, Down (1975) also reported an increase in organic matter content with age of mine spoils at Somerset coal field in U.K. He found 0.79, 1.52, and 1.81 percent organic matter on sites of age 0, 5 and 12 years, respectively. In contrast, Toy and Shay (1987) found that there was no significant difference in organic matter content between the mine spoils and natural soils in Northern Great Plains. The build-up of soil organic matter is an indicator of pedogenic recovery. This shows that with time the edaphic conditions are becoming favourable for plant growth and establishment. There was significant positive correlation ($P < 0.01$) between organic carbon and microbial population, microbial biomass-C and N-mineralisation.

Soil nitrogen showed a clear seasonal trend declining with increasing depth and decrease in mine spoil age. The spring season with its maximum and minimum values recorded during spring and rainy seasons respectively, improved from the first to the second year in all depths and sites. The nitrogen concentration was highest in the control and lowest in the 0-2 year spoil which is in conformity with the findings of Lyngdoh (1995). Very low vegetal cover and minimal recovery may be the reasons for lowest N- concentration on the 0-2 year spoil. Jencks *et al.* (1982) observed an increase in soil nitrogen concentration with increasing age of coal mine spoils of West Virginia. Similar results have been reported by Li and

Danofields (1994), Thomas *et al.* (1983), Jha (1990) and Baig (1992). Anderson (1997), on the other hand, observed that accumulation of large amount of carbon and nitrogen in a 28-year old mine spoil and their concentrations were similar to the native soils in Saskatchewan. Conwell and Stone (1968), Power *et al.* (1974) and Reeder and Berg (1977), however, noted a higher concentration of nitrogen in mine spoils and opined that the increased concentration of nitrogen might be due to its release during partial destruction of the silicate lattices by acids generated during the spoil weathering.

The consistently higher C/N ratio in the sub-surface layer of the mine spoils under study was contrary to the findings of Thomas *et al.* (1985) who obtained relatively higher ratios in the surface layer on coal mine spoils of varying ages. Maithani (1996) reported uneven C/N ratio in the soil depths in degraded forest regrowth. Generally, C/N ratio of 6.4 is considered to be ideal for any soil system and forests. Acea and Carballas (1990) obtained C/N ratio of humid zone soils ranging from 10-19. Similarly, Haron *et al.* (1998) recorded a C/N ratio ranging from 8.8 to 16.0. The C/N ratio in the present study ranged from 9.53 to 20.60.

Most mine wastes are poor in N and P (Barrett *et al.* 1979) due to leaching and the lack of binding power of phosphorus. Phosphorus content was extremely low in all the mine spoils. The unmined control site registered a little higher value compared to the spoils. This supports the findings of Lyngdoh (1995). This also

agrees with the report of Iverson and Wali (1992) who observed that phosphorus was low and a limiting factor during early succession and colonization on surface-mined lands studied by them. Inadequate phosphorus adversely affects plant growth (Safaya and Wali 1979). The findings are also in agreement with the reports of Uma Shankar *et al.* (1993) who reported that N, P and K increased with spoil age. Baig (1992) also found an increase in the concentration of P with increasing age of the spoil.

Like TKN and available- P, exchangeable -K concentration was also very low in all the mine spoils. It increased with increasing spoil age. Jha (1990) also reported increase in the concentration of total nitrogen, extractable phosphorus and exchangeable potassium with the increasing age of spoils in Singrauli coal fields.

The concentration of elements like Fe, Co, Cd and Cu in the mine spoils under study did not attain hazardous proportion. In fact, these elements were in insufficient amounts, often undetectable. This is at variance with the reports of Kimber *et al.* (1978) who reported toxic concentrations of Fe, Al, Cu, Mn, Ni, Zn and Pb in colliery tips in Scotland. Rimmer (1982) observed that metal toxicity in reclaimed mine sites was associated with acidity, nutrient deficiency and physical condition.

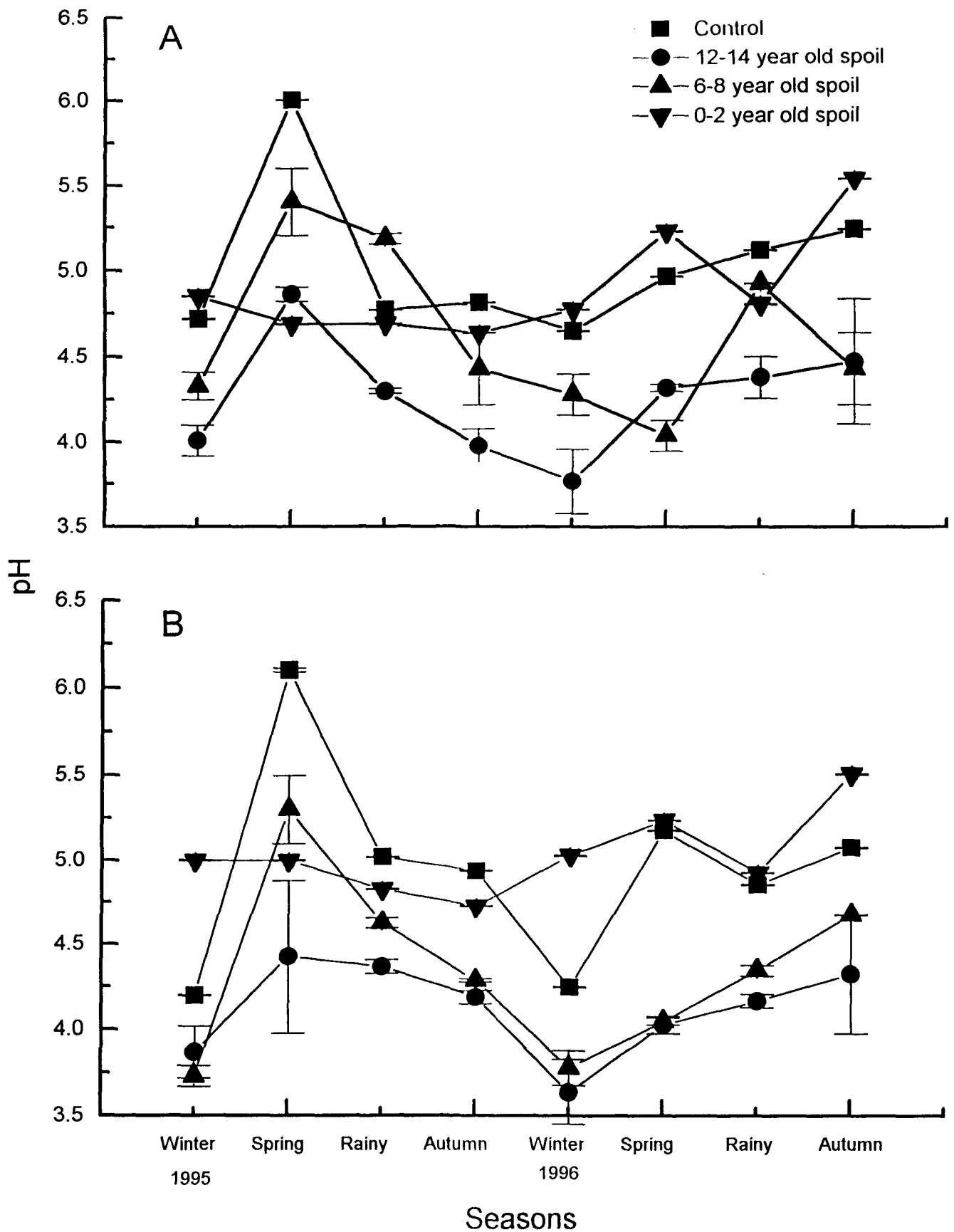


Fig. 4.1. Seasonal variation in pH of mine spoils of different ages and the soil of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

Table 4.1. Proportion of sand, silt and clay in the mine spoils and the control site. (\pm S.E.M.)

Site	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural class
Control	0-10	1 \pm 0.0	2 \pm 0.0	97 \pm 0.0	Sandy
	10-20	1 \pm 0.0	2 \pm 0.0	97 \pm 0.0	Sandy
12-14 year old spoil	0-10	8 \pm 1.0	6 \pm 0.0	86 \pm 1.0	Sandy loam
	10-20	10 \pm 1.0	7.7 \pm 0.0	82.3 \pm 1.0	Sandy loam
6-8 year old spoil	0-10	10 \pm 1.0	7.7 \pm 1.0	82.7 \pm 1.0	Sandy loam
	10-20	9.2 \pm 1.0	7.3 \pm 1.0	83.0 \pm 1.0	Sandy loam
0-2 year old spoil	0-10	6.5 \pm 2.0	4.5 \pm 0.5	89 \pm 0.0	Sandy
	10-20	1 \pm 0.0	2 \pm 0.0	97 \pm 0.0	Sandy

Table 4.2. Bulk density, porosity and cation exchange capacity in the mine spoils and the control site. (\pm S.E.M.)

Site	Depth (cm)	Bulk density (g/cm ³)	Porosity (%)	Cation exchange capacity (ml 100g ⁻¹)
Control	0-10	1.42 \pm 0.003	46.42	11.48 \pm 0.08
	10-20	1.25 \pm 0.003	52.83	8.51 \pm 0.15
12-14 year old spoil	0-10	1.21 \pm 0.003	54.34	2.18 \pm 0.19
	10-20	1.17 \pm 0.003	55.85	2.10 \pm 0.04
6-8 year old spoil	0-10	1.09 \pm 0.003	58.86	1.59 \pm 0.11
	10-20	1.02 \pm 0.003	61.51	1.24 \pm 0.08
0-2 year old spoil	0-10	1.00 \pm 0.003	62.26	0.29 \pm 0.05
	10-20	0.96 \pm 0.003	63.77	1.22 \pm 0.01

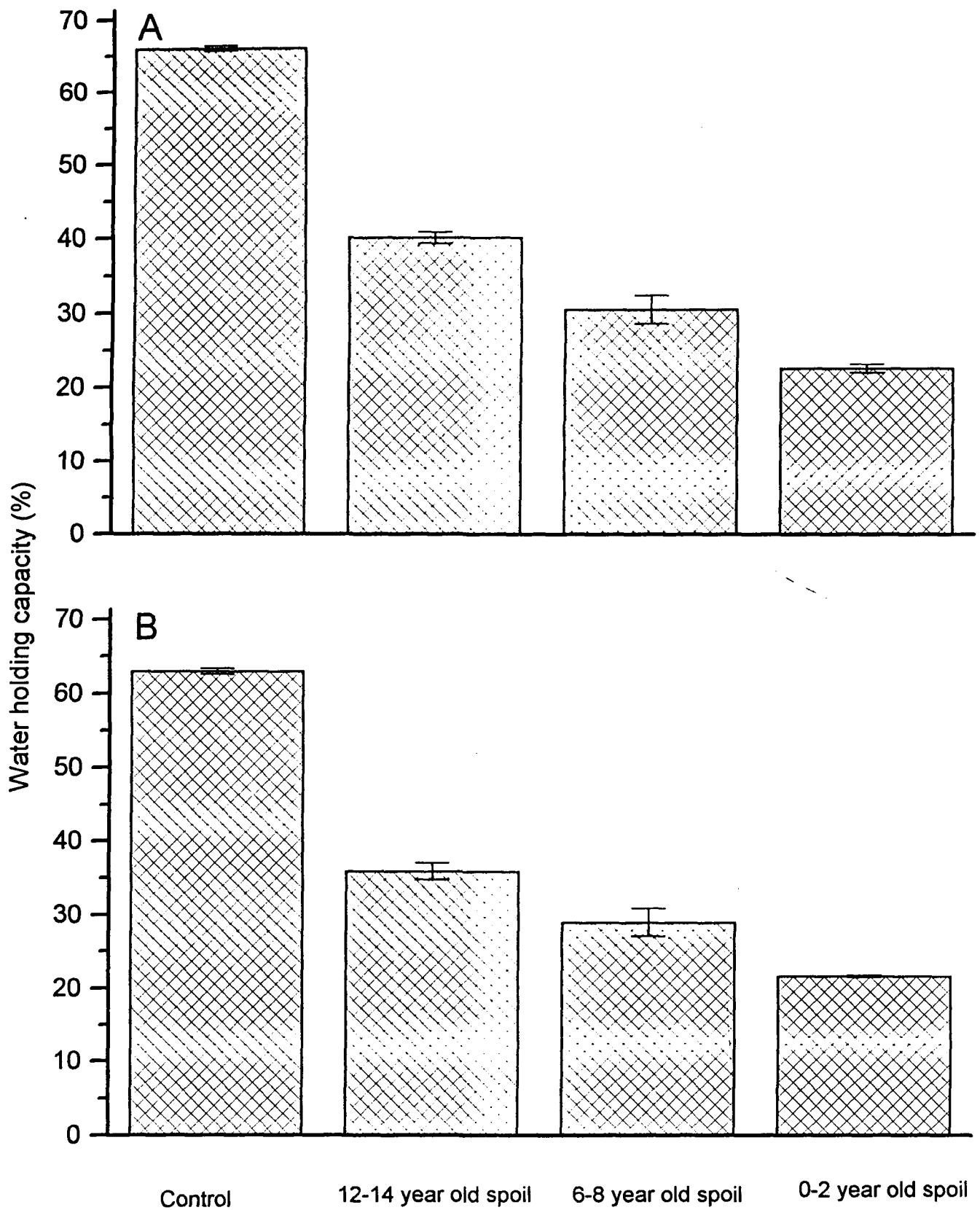


Fig.4.2. Water holding capacity of mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

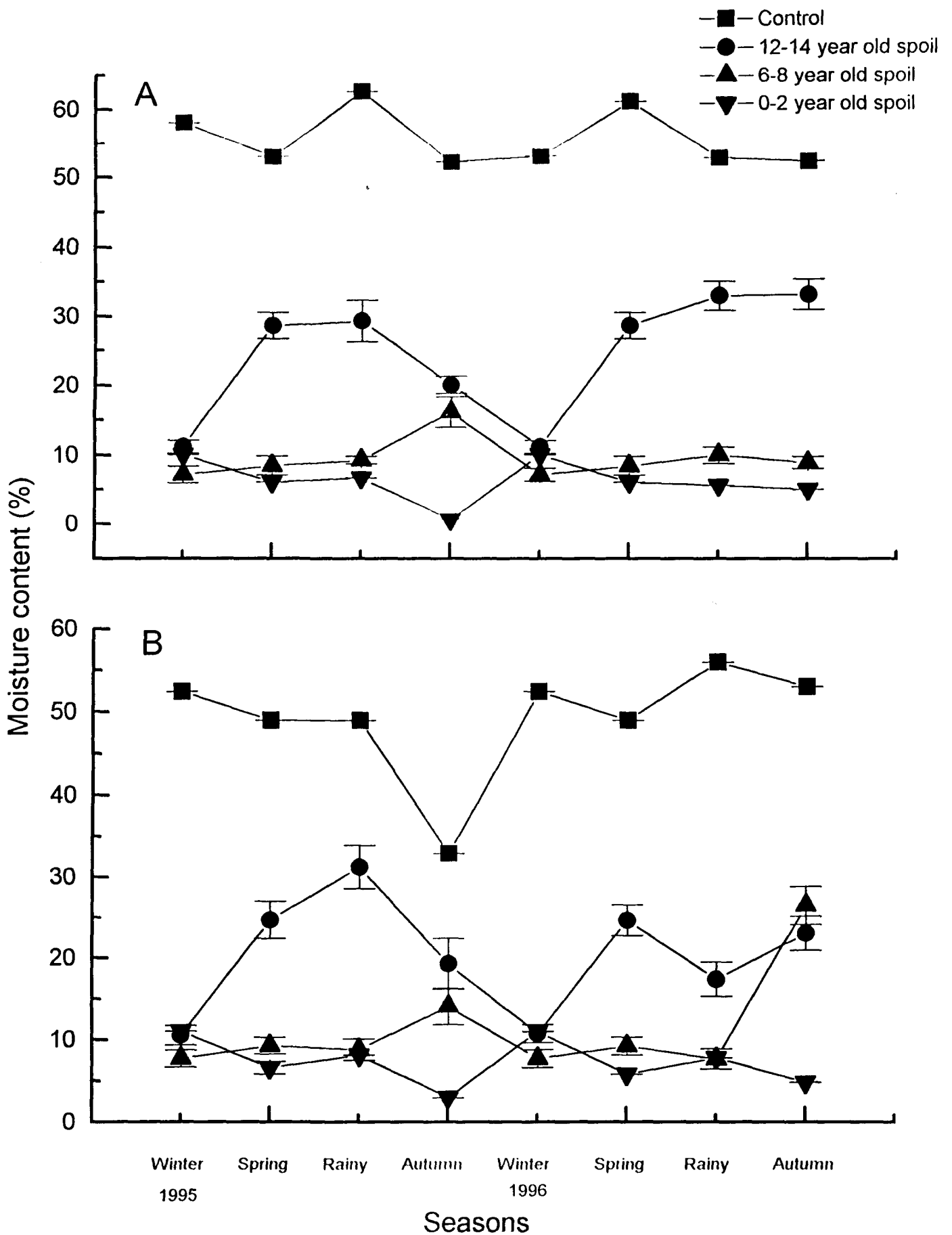


Fig. 4.3. Seasonal variation in moisture content of mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

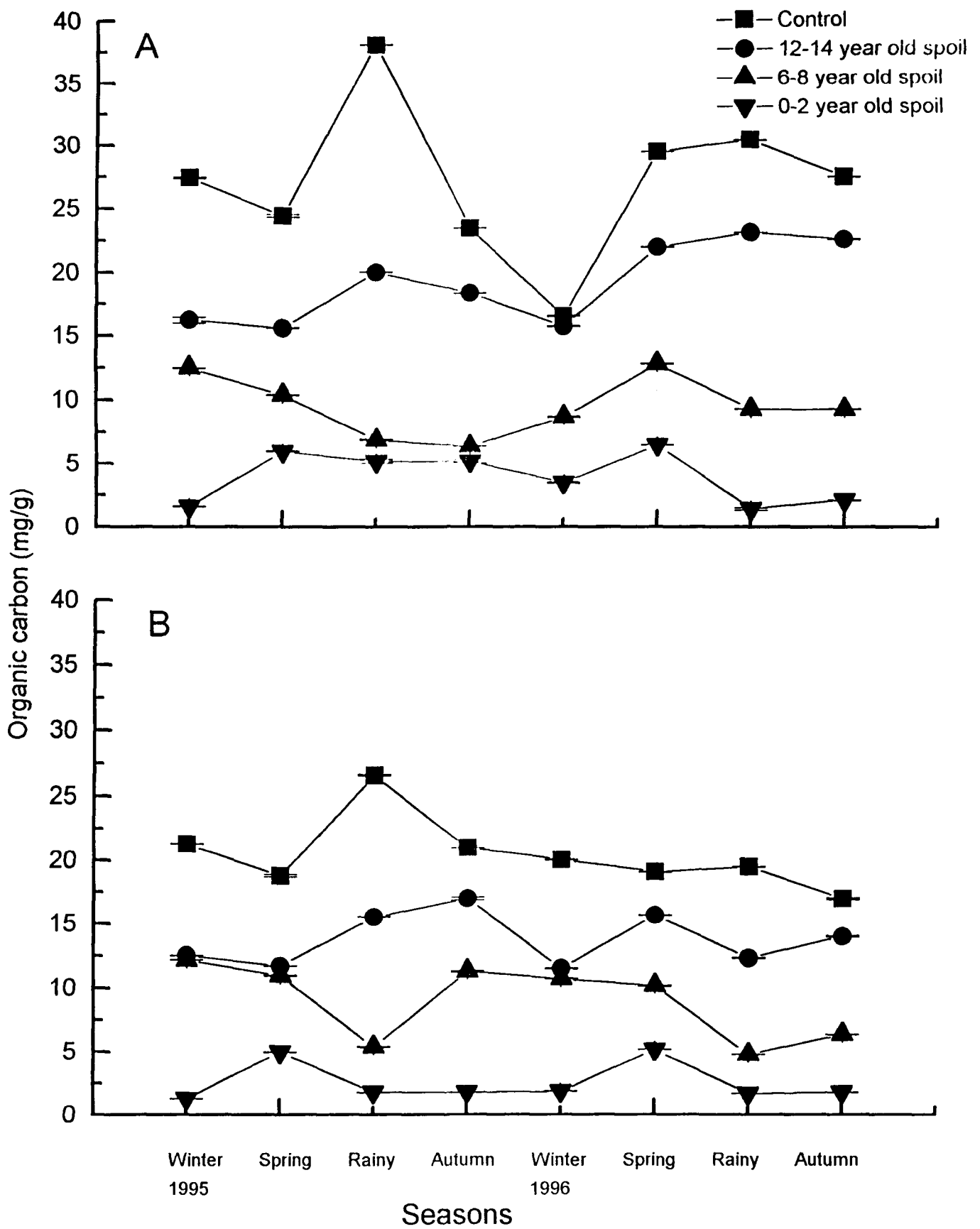


Fig. 4.4. Seasonal variation in organic carbon concentration in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

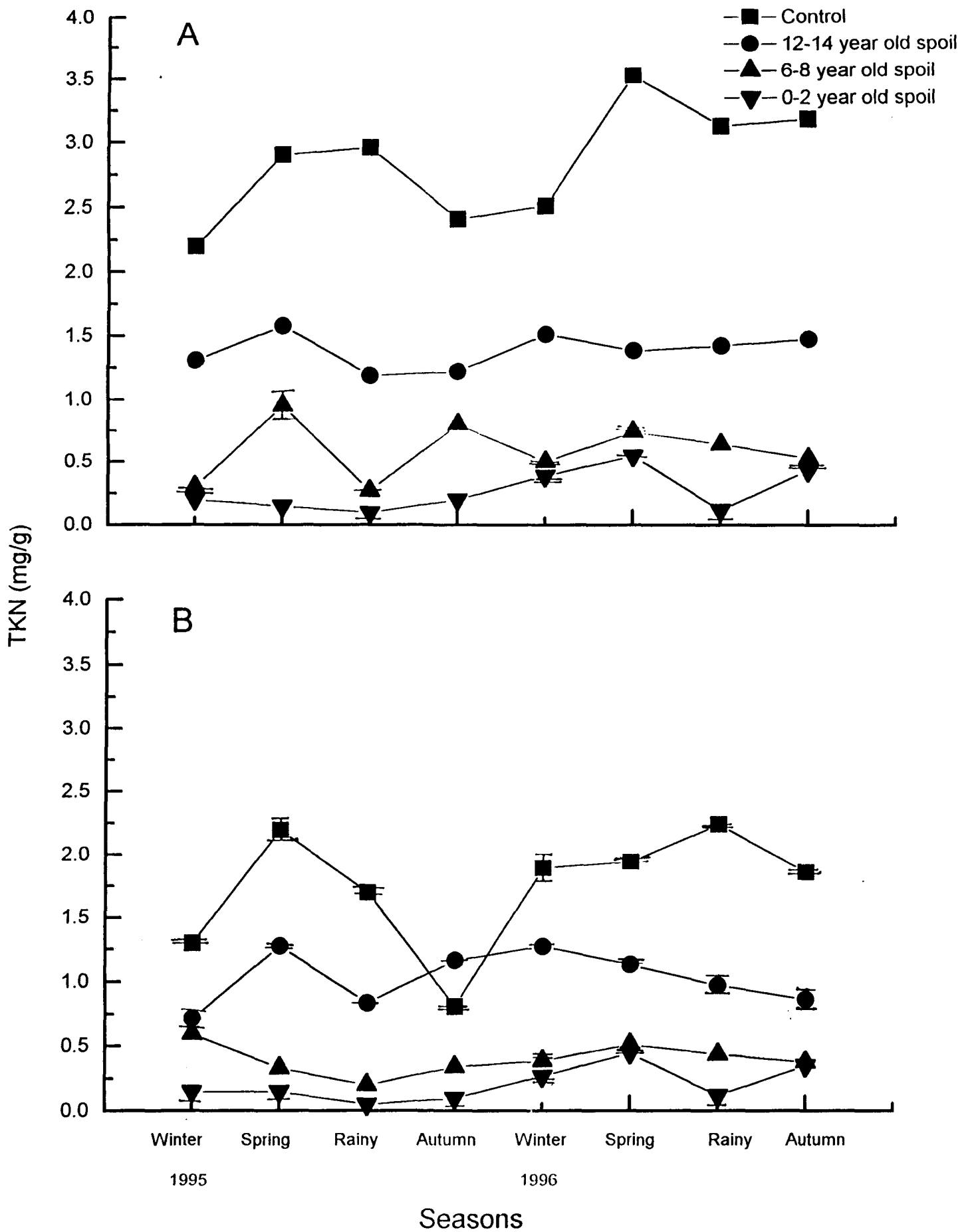


Fig.4.5. Seasonal variation in TKN concentration in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

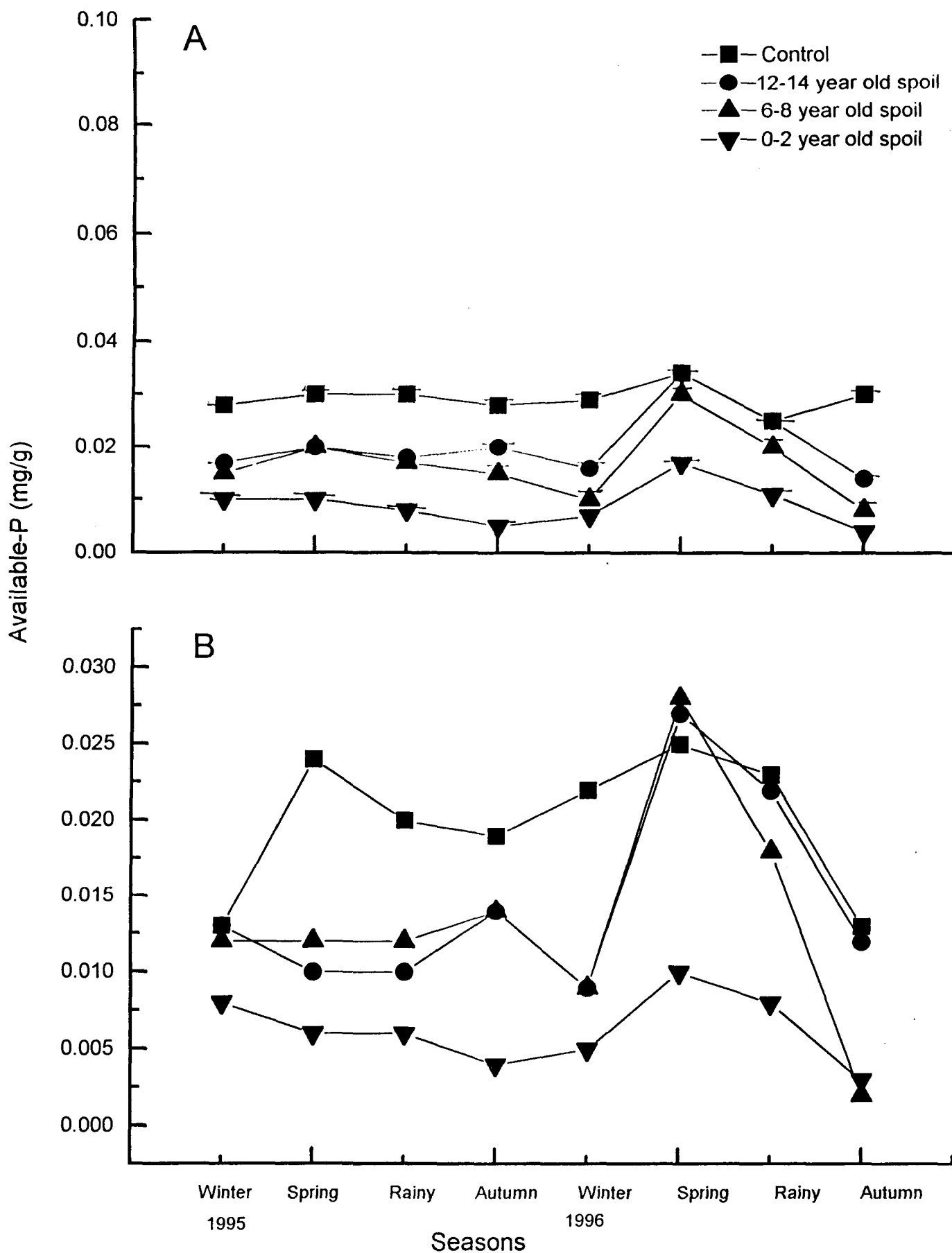


Fig.4.6. Seasonal variation in available - P concentration in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

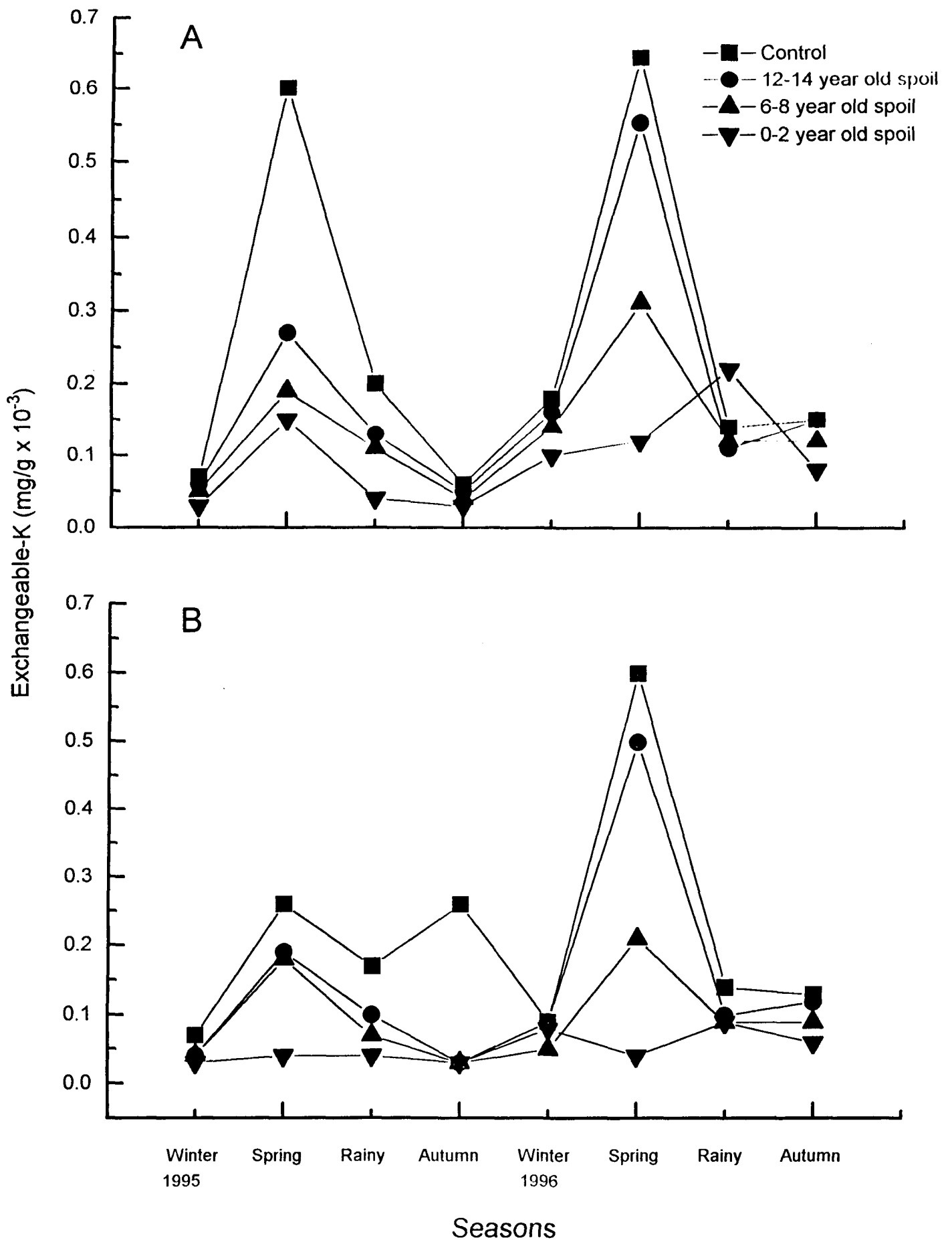


Fig. 4.7. Seasonal variation in exchangeable-K concentration of mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) depth (\pm standard error of mean).

CHAPTER V

VEGETATIONAL CHANGES ON COAL MINE SPOILS UNDERGOING NATURAL RECOVERY

Introduction

Surface mining of coal causes massive damage to landscape and biological communities (Down and Stocks 1977). Considerable restoration work needs to be undertaken to establish vegetation which is generally unrelated to the one originally present (Johnson and Bradshaw 1979). Factors controlling vegetation development on mine spoil are microclimate, spoil properties, surrounding flora, nutrient capacity and propagule dissemination (Russell and La Roi, 1986).

Plant communities which appear naturally on coal mine spoils are of enormous ecological interest. They reflect on the process of ecosystem reconstruction and natural ecosystem development (Bradshaw, 1983). Therefore, studies relating to floristic composition coupled with the physico-chemical properties of spoils have always evoked great interest among various workers in different parts of the globe (Cornwell 1971, Files *et al.* 1985, Game *et al.* 1982, Singh and Jha 1987 and Jha and Singh 1990).

Meghalaya, the tiny state of north-east India, is bestowed with rich natural vegetation and a large reserve of mineral resources. The depletion of natural vegetation and the transformation of forest land into grasslands have been brought

about by the age-old practice of slash and burn agriculture locally called "jhum" (Uma Shankar *et al.* 1991). During the last few decades, there have been phenomenal increase in mining of coal, limestone and sillimanite causing large scale destructions and deterioration of the natural vegetation of the state.

Excessive coal mining operation in the Jaintia Hills district of Meghalaya has been responsible for the conversion of original lush green landscape of the area into mine spoils. The primitive and unscientific "**rat hole**" method of mining adopted by private operators had caused ecosystem destruction on an alarming scale. There is a glaring dearth of information on the mode and degree of natural plant succession in Indian mine spoils. Prasad and Pandey (1985) have studied natural plant succession in the rehabilitated bauxite and coal mine overburden of Madhya Pradesh. Jha and Singh (1990) have analysed the vegetation developing naturally on sub-tropical mine spoils. Till today only a few studies (Lyngdoh *et al.* 1992, Lyngdoh 1995 and Pandey *et al.* 1993) have been carried out on the natural succession of plant communities on the mine spoils in Jaintia Hills district. This chapter presents a detailed analysis of the structure and dynamics of plant communities on abandoned coal mine spoils and an adjacent unmined site (control) with a view to understand the vegetation attributes of the coal mine spoils undergoing natural recovery.

Results

Floristic composition

The vegetation of the mine spoils showed significant variations with respect to the age of the spoil. The maximum number (39) of plant species were recorded at the unmined control site. The species number decreased with the decreasing age of the spoil. There were 28, 13 and 2 plant species in the 12-14 year, 6-8 year and 0-2 year old spoils, respectively (Table 5.1). A list of species recorded in the coal mine spoil of different ages and the control site is given in Table 5.2a. *Osbeckia stellata*, *Cyanotis vaga*, *Arundinella khasiana*, *Hypochaeris radicata*, *Axonopus compressus*, *Imperata cylindrica* and *Paederia foetida* occurred on both mine spoils and the control site, while the plant species such as *Gnaphelium leuto-album*, *Oxalis corniculata*, *Polygonum capitatum*, *Pteris* sp. and some mosses were present only on the mine spoils and absent from the control site. The fern species viz. *Dicranopteris linearis* was found to occur not only on the control, 12-14 year and 6-8 year old spoils, but was also seen to initiate the process of colonisation on the bare spoil (0-2 year) along with the mosses. The youngest spoil (0-2 year) was devoid of any vegetation except *D. linearis* and mosses. Maximum number of species at all sites was recorded during September which represented the peak vegetative period.

Besides the scattered distribution of Pine (*Pinus kesiya*), the control site had

9 shrub species in addition to several herbs of which 10 were annuals and 20 perennial (Table 5.1). Out of 39 species, 7 species belonged to Asteraceae thereby making it the largest family in the undisturbed site. Poaceae was represented by 6 species followed by Rubiaceae with 4 species, Commelinaceae with 3 species and Apiaceae and Scrophulariaceae with 2 species each. The remaining 13 species belonged to other families which were represented by one species each (Table 5.3). As regards the oldest spoil, it showed the presence of 10 annual and 14 perennial herbs, while the shrubs were 4 in number. In this spoil, Poaceae dominated with 5 species closely followed by Asteraceae with 4 species. Rubiaceae and Commelinaceae were represented by 3 species. While Melastomaceae contributed 2 species, the remaining 11 species were only solitary representatives from the rest of the families. Notwithstanding the reduction in species number with decrease in the age of the spoils, the family Poaceae had the maximum species (3) in comparison to all other families. Again it was Asteraceae which ranked second with 2 species in the older spoils, while other families were represented by single species. The site recorded the presence of 11 herbs (8 perennials, 3 annuals) and 2 shrubs. Unlike the older mine spoils and the control site, the youngest spoil (0-2 year) did not have any vegetation worth its name other than a few individuals of *D. linearis* (a fern) and mosses. Like species number, there was also a reduction in the number of families with decreasing age of the spoil, being 20 in the unmined

site, and 16, 10 and 2 in the 12-14, 6-8 and 0-2 year old spoils, respectively (Table 5.1). The proportion of annuals, perennials and shrubs decreased with decrease in mine spoil age. Dicotyledonous families were dominant in all the study sites.

Density and Importance value index (IVI)

There was significant decrease in plant density with decreasing age of the spoil. Maximum density (plants m⁻²) of colonising species was recorded in the control site followed by the 12-14 and 6-8 year old spoil. In the control site *Axonopus compressus* showed predominance over other species because of its very high density (229.67) it decreased to 92.56 in the 6-8 year old spoil. *Pratia begonifolia* had the highest density (170.33) among the dicots in the unmined site. It was found to be 27.11 in the 12-14 year old spoil. There was a similar reduction in plant density in the case of *Paederia foetida* from 103.67 in the control site to 98.67 and 66.67 in the 12-14 year and 6-8 year old spoils respectively. *Paspalum orbiculare* also exhibited reduction in the density from 88.89 in the unmined to 74.00 in the oldest (12-14 year) spoil. All the species showed maximum density in the control site (Table 5.5).

Axonopus compressus had the maximum IVI value (38.54) in the unmined control site. In the 6-8 year old spoil too, it showed maximum IVI (79.59). *Paederia foetida* registered the maximum value (50.27) in the 6-8 year old spoil,

which decreased to 41.96 in the 12-14 year old spoil, and to 20.87 in control site.

Dicranopteris linearis showed far greater IVI value (44.34) in the 6-8 year old spoil compared to the control site (21.74). This fern was not recorded on the 12-14 year old spoil during the rainy season.

In the control site, *Crossocephalum crepidiodes* had the lowest IVI (4.31), while in the 12-14 year old spoil, *Phyllanthus urinaria* recorded the lowest IVI (3.21). *Lycopodium clavatum*, a pteridophyte recorded the least IVI value (17.60) along with *Hypochoeris radicata* in the 6-8 year old spoil (Table 5.4).

Cover value

D. Linearis, *E. adenophorum*, *L. camara* and *Melastoma* sp. had the maximum canopy cover in the control site, whereas *A. khasiana*, *A. compressus*, *Crotolaria* sp. *C. crepidiodes*, *H. javanica*, *P. orbiculare* and *P. urinaria* occupied the next place in the scale (3). *H. cordata*, *I.khasiana* and *P. foetida* were placed in the next category (2). *C. asiatica*, *C. bengalensis* and *P. begonifolia* had the least cover.

The cover value in the oldest spoil (12-14 year) showed maximum coverage for *A. compressus*, *A. khasiana*, *E. adenophorum*, *G. luteo-album*, *H. macrophylla*, *H. cordata*, *H. radicata* and *L. clavatum* and *P. capitatum*. The canopy cover decreased further in *C. bengalensis*, *C. crepidiodes*, *D. linearis*, *P. foetida*, *P. begnofolia*, *P. urinaria*, *O. stellata*. *P. orbicularie* and *D. cordata* had the least

cover.

About 50% of the plant species growing on the 6-8 year old spoil had 6-25% cover, being placed at 4 in the scale. But, in contrast to other spoils and the unmined site, *D. linearis* registered the highest cover value (5) among all the species on the 6-8 year old spoil and on the other sites, *P. foetida* and *O. stellata* were placed at 3 in the cover scale on the basis of their cover values (Table 5.5).

Sociability

The sociability of plant species as depicted (Table 5.5) through 1-5 scale revealed the highest value of 4 for *A. compressus* among all sites and species *A. compressus* was the only species forming large patches while growing on the control site. *A. khasiana* and *H. cordata* forming small patches, where assigned class 3 in the Braun-Blanquet cover scale. Rest of the species were either growing singly or forming small clumps.

On the 12-14 year old spoil there were only two species, viz. *I. cylindrica* and *P. orbiculare* which forming small patches (class 3 in the scale). *A. khasiana*, *B. hispida*, *C. bengalensis*, *D. linearis* and *P. striatus* formed only small clumps (Class 2). The remaining species were found to grow singly on the spoil.

There was a very poor vegetative growth on the 6-8 year old spoil. here *A. compressus* and *P. foetida* formed small groups, while the other species occurred singly.

Persistence

The persistence reflected the capacity of the plant species to survive in extremely adverse situation. The persistence of the plant species was studied in relation to moisture stress and nutrient deficiency. It revealed that *A. compressus* and *P. begonifolia* were the only species which showed the maximum persistence value (1%) in the undisturbed site. *A. khasiana*, *C. bengalensis*, *D. linearis*, *E. adenophorum*, *H. javanica*, *Melastoma* sp. and *P. foetida* registered 0.66% persistence. All other species had 0.33% persistence in the control site.

In the oldest spoil (12-14 year old) *Pratia begonifolia* showed greater persistence value (0.77%) as compared to the other species though its value here was lesser than the control site (1.00%). *P. foetida* maintained its persistence (0.66%) at the same level as that recorded in control site. *O. corniculata* had also the same percentage persistence (0.66%). It declined to 0.55% in case of *C. bengalensis* and *P. orbiculare*. in comparison to the control site, *C. bengalensis* had a marginal reduction from 0.66 to 0.55% in the 12-14 year old spoil. The persistence value ranged from 0.11- 0.33% in case of other species.

The persistence value of *Axonopus compressus*, which was as high as 1% on the control site declined to 0.83% in the 6-8 year old spoil. The oldest (12-14 year) spoil did not record the presence of this species during the rainy season.

The maximum persistence value for *D. linearis* was found in the control site

(0.66%) which decreased to 0.22% in the 12-14 year old spoil, but it increased to 0.50% in the younger spoil. In the 6-8 year old spoil *P. foetida* and *O. stellata* (0.55%) showed a pattern similar to that of *D. linearis*. Other species showed low persistence ranging from 0.17-0.33% (Table 5.5).

Seed production and vegetative propagation

These ecological attributes were measured in terms of poor, fair, good and excellent seed production and vegetative propagation. The mine spoil substrate presented a very dismal nature of vegetative propagation coupled with meagre seed production (Table 5.5).

Seed production was appreciably good in the case of *Dicranopteris linearis*, *Lantana camara* and *Melastoma* sp. These three shrubs had the same ranking (i.e. 3). The vegetative propagation and seed production was fair in *C. bengalensis*, *E. adenophorum*, *I. khasiana*, *P. foetida* in the control site. Other species growing on the control site exhibited a poor seed production and vegetative propagation. *Drymeria cordata*, had better seed production and vegetative propagation (3 = good) than the dicotyledonous species like *B. hispida*, *G. luteo-album*, *H. radicata*, *P. capitatum*, *O. stellata* and *D. linearis* (a fern) in the oldest spoil site. The remaining species on this site were characterised by poor seed production and vegetative propagation.

The seed production in the species was adversely affected with decrease in

the age of the spoil. The extent of seed production and vegetative multiplication in *D. linearis* was appreciably higher on the control site compared to the mine spoils. *A. khasiana* showed uniformly poor vegetative propagation on all the study sites. *G. luteo-album*, *H. radicata* and *O. stellata* also showed a poor seed production vegetative propagation.

Relative Performance Index (RPI)

Computation of relative performance index (Table 5.5) used in assessing species adaptability to various spoil substrate indicated that three shrubs namely *D. linearis*, *E. adenophorum* and *Melastoma* sp. showed better performance in relation to other species in the control site. *Lantana camara*, a spiny bushy shrub, had 7.29% RPI. The RPI for rest of the species ranged from 0.57-2.25% in the control site.

The oldest spoil (12-14 year old) also offered a similar picture with *A. khasiana*, *I. cylindrica*, *G. luteo-album* registering a high RPI value of 7.92% closely followed by *P. capitatum* with 7.86% and *E. adenophorum*, *H. macrophylla*, *H. radicata*, *H. cordata*, *L. clavatum* with 7.81%. The remaining species had a comparatively low RPI varying from 0.10-2.14%.

Life form spectrum

Table 5.6 shows the percentage of various life forms on the coal mine spoils of different ages and the unmined control site.

On the control site, the percentage of chamaephytes was maximum (34.38%) followed by hemicryptophytes (21.88%). Both the therophytes and geophytes had 15.63% representation while the phanerophytes had only 12.5% representation. On the 12-14 year old spoil, chamaephytes were predominant with 38.46% followed by the hemicryptophytes (34.62%). The percentage of geophytes (15.39%) was greater than that of therophytes (7.70%) and phanerophytes (3.84%).

The trend as noticed in the control and 12-14 year old spoil was reversed in the case of 6-8 year old spoil, where hemicryptophytes with 42.86% had a preponderance over the chamaephytes and geophytes. The spoil sites did not contain any phanerophytes and therophytes.

The youngest spoil was conspicuous by the sole presence of hemicryptophytes (100%) and no other life forms were encountered on the spoil site.

The percentage of therophytes on the control site was more or less same as that of the Raunkiaer's normal biological spectrum (Raunkiaer's 1934), but much lesser than the values suggested by Hall's (1957) and Down's (1973) when it came to the mine spoils (Table 5.7). The percentage of therophytes for both control and the mine spoils was much lesser as compared to the values reported by Lyngdoh *et al.* (1992) from the coal mine areas of Jaintia Hills district. The percentage of hemicryptophytes approached the level as reported by Lyngdoh *et al.* (1992) but fell much below the values obtained by Raunkiaer (1934) and Hall (1957) and

Down (1973).

However, the percentage contribution of chamaephytes in the unmined and the mine spoil area was much higher than the values reported by these workers. The percentage of chamaephytes on the present study was almost double the value reported by Lyngdoh *et al.* (1992).

Index of floristic similarity (IFS)

The similarity between stands in terms of floristic composition increased with the increase in mine spoil age. The calculation based on the number of species common to the control and the oldest spoil site revealed 56.41% similarity between the control and 12-14 year old spoil which declined to 37.04% between the control and 6-8 year old site and finally to 20% between the 12-14 and 6-8 year old spoils. There was a perceptible decline in species similarity between the control and mine spoils of younger ages (Table 5.8).

Discussion

The result revealed that the development of vegetation on the mine spoils was very much related to their age. The vegetational attributes viz. species density, basal cover, persistence and sociability were significantly influenced by the age of the mine spoil. This is in agreement with the findings of Baig (1992). Jha and Singh (1990a) reported increased species diversity on the older spoils than the younger ones. Increase in species diversity with age has also been reported by

Sindelar (1979) in seeded coal mine spoils at Colstrip, Montana. Mishra *et al.* (1979) observed increased recruitment with increasing age of fly ash dykes in Madhya Pradesh. Cornwell (1971) has shown that the species richness on coal waste areas was related to spoil acidity and age. Iverson and Wali (1982) observed an increase in species richness with age in reclaimed coal mine spoils in North-Western Dakota. Bradshaw and Chadwick (1980) however, reported that there was no relationship between the species number and the age of the colliery spoil, species number is rather influenced by pH. Soni *et al.* (1980) reported that soil pH and the growth of vegetation in terms of density are directly related while studying the revegetation pattern of a rock-phosphate mine spoil at Dehra Dun. This conforms with the findings of the present study where the spoils with acidic pH were bereft of plant growth. Russell and La Roi (1986) reported higher species richness on fine textured spoil than on coarse textured coal mine spoils in Alberta, Canada. The relationship between species richness and spoil age is also probably related to spoil moisture stress and nutrients. Down (1973) reported that the colonization by plant species on the coal mine spoils did not take place before 10 years of spoil age. Kimmerer (1984) working on lead mine wastes observed that lack of initial colonization on any mine waste may be attributed to the lack of propagules capable of growing in such a harsh environment. Similarly, Leisman (1957) and Gibson *et al.* (1985) stressed the importance of surrounding vegetation and the dissemination

efficiency of propagules in spoil seed banks.

In the present investigation, colonization by plant species was observed at the fag end of the study on the youngest spoil when ferns and mosses were seen to invade the spoil substrate slowly but gradually. This could be due to the availability of propagules as a result of transportation of the same from the adjacent vegetation as well as patchy nature of the mine spoils. In most of the sites, individuals were found as clusters, which in turn, were separated by large bare areas. Initial colonization occurred in certain more favourable microsites where moisture was apparently available to the plants to get established during spring and early rainy season. This conforms with the reports of Barnes and Standbury (1951), Brierley (1956), Game *et al.* (1982) and Baig (1992).

Total density per stand increased with age of the spoil due to the increase in species richness, and ability of the colonising species to multiply. Lyngdoh's work (1995) lends support to the present findings. The unmined site had greater plant density compared to the mine spoils mainly because of acidic pH, moisture stress and nutrient poverty of the latter.

The oldest mine spoil and the control site had a predominance of perennials over annuals and shrubby species. These traits permit occupation of the degraded sites for a longer time period as seed production, germination and seedling establishment are opportunistic and limited to favourable years on the disturbed

sites (Brown *et al.* 1978). This draws support from the findings of Baig (1992). There was overall dominance of chamaephytes and therophytes unlike the findings of Lyngdoh *et al.* (1992) and Down (1974). With the exception of few shrubs and grass species, there was hardly any appreciable cover and sociability, seed production, vegetative propagation of the species were also low. This is in accordance with the findings of Baig (1992) that low growth form and ability to tolerate low nutrient levels and low moisture conditions are probably the adaptations to the harsh physical nature of the substrate. Low nutrient habitats are usually colonised by species with low relative growth rates. These adaptations enable colonising species to maximise the nutrient uptake and ensure high nutrient use efficiency in low nutrient environments (Baig 1992).

The gradual sign of vegetation recovery with increase in spoil age was evident from the data obtained from the floristic similarity index (IFS) which was maximum in the unmined control site and minimum in the 6-8 year old spoil. The relatively higher percentage of similarity between the oldest mine spoil and the control site showed a sign of recovery.

The IVI of *A. khasiana*, *A. compressus*, *P. foetida* and *G. luteo-album* were greater in the younger spoils. *A. compressus* registered the highest IVI (79.59%) not only in the younger spoils but also among all the species thereby suggesting its ability to multiply rapidly in disturbed environments. This perennial

grass by virtue of its stolon and rooting at each node can bind the soil particles, making the soil more stable. Similarly, *P. foetida* also had a high IVI value (50.27) in the younger spoil. This is in agreement with the findings the Ries and De Puit (1984) who observed that perennial grasses are well suited to grow in the spoils. In the present study legumes were not recorded on the mine spoils. This could be due to the fact that legumes were very rare on the adjacent unmined land. In addition to determining the IVI of different species, relative performance index (RPI) was also calculated to assess species suitability in revegetation measures involving mine spoils. The data revealed an overall dominance of *D. linearis* with the highest RPI (19.3) on all the sites. It also recorded high IVI value (44.34) in the 6-8 year old spoil. This makes the fern species a very important coloniser of stressed environments. This is well supported by the findings of Baig (1992) who reported 50% RPI for a particular type of forb and 50.1% for some shrub, graminoids and forbs growing on coal mine spoils in Alberta, Canada.

A. compressus, *A. khasiana*, *E. adenophorum*, *L. camara* and *P. foetida* also exhibited high RPI value. IVI which is a summation of relative frequency, relative density and relative dominance gives the total picture of sociological structure of the species, but it does not furnish any information about species biomass or vegetal cover which are of greater ecological significance in plant distribution than density (Forsbery 1961, Rice 1967, Daubenmire 1968). Above all, the use of relative rather

than actual parameters is of limited information value. In contrast, relative performance index (RPI) assesses the species suitability for revegetation by taking into account percent cover, sociability values and persistence in order to identify the most important pioneering species. It would certainly be more profitable to use such species for revegetation purposes, if they are also indigenous.

The maximum percentage of therophytes observed to be present on the unmined site was in line with the Raunkiaer's, Hall's and Down's life form spectra. The mine spoils had a very low therophytes presence. The values obtained in the present study for the therophytes were much lesser compared to the values reported by Lyngdoh *et al.* (1992). The percentage of hemicryptophytes recorded in the present study agrees with the findings of Lyngdoh *et al.* (1992), and Raunkiaer (1937), but fell much below the values reported by Down (1973) and Hall (1957). The present study emphatically demonstrated the dominance of chamaephytes in all spoils and on the control site. The younger mine spoil was colonised only by hemicryptophytic species.

The floristic composition of mine spoils besides density, basal cover, persistence and relative performance index of the species growing on them clearly brought forth the point that species composition and phytosociological parameters of the species were directly related to the mine spoil age. There was a gradual but significant increase in plant population and in the ability of certain plant species to

colonise these stressed habitats and proliferate there. Such plant species hold a great promise in the revegetation of mine spoils of Jaintia Hills district..

Table 5.1. Number of plant species in coal mine spoils of different ages and the control site.

Species groups	Control	12-14 year old spoil	6-8 year old spoil	0-2 year old spoil
Herbs				
Annuals	10	10	3	-
Perennials	20	14	8	2
Shrubs	9	4	2	-
Total	39	28	13	2

Table 5.2. Floristic composition and life form of species in the mine spoils of different ages and the control site.

Family	Species	Control	12-14 year old spoil	6-8 year old spoil	0-2 year old spoil	Habit	Life form
Apiaceae	<i>Centella asiatica</i> (L) Urb.	+	-	+	-	Perennial herb	Hemicryptophyte
	<i>Hydrocotyl javanica</i> Thumb.	+	-	-	-	Perennial herb	Hemicryptophyte
Araceae	<i>Arisaema tortuosum</i> Wall.	+	-	-	-	Perennial fleshy herb	Geophyte
Asteraceae	<i>Ageratum conyzoides</i> Linn.	+	-	-	-	Annual hairy herb	Therophyte
	<i>Anaphalis linearis</i> Hk.f.	+	-	-	-	Perennial herb	Therophyte
	<i>Ainsliaea latifolia</i> (D.Don) Sch.	+	-	-	-	Perennial herb	Chamaephyte
	<i>Crossocephalum crepidiodes</i> Benth.	+	+	-	-	Perennial herb	Phanerophyte
	<i>Eupatorium adenophorum</i> DC.	+	+	-	-	Undershrub	Chamaephyte
	<i>Gnaphelium luteo-album</i> Linn	-	+	+	-	Annual wooly herb	Therophyte

	<i>Hypochoeris radicata</i> Linn.	+	+	+	-	Annual herb	Geophyte
	<i>Senecio densiflorus</i> Wall	+	-	-	-	Perennial undershrub	Phanerophyte
Balsaminaceae	<i>Impatiens khasiana</i> Hk.f.	+	-	-	-	Perennial herb	Therophyte
Caryophyllaceae	<i>Drymeria cordata</i> Willd	+	+	--	-	Annual herb	Hemicryptophyte
Commelinaceae	<i>Commelina bengalensis</i> Linn.	+	+	-	-	Annual creeping herb	Chamaephyte
	<i>Commelina sp.</i>	+	+	-	-	Annual herb	Chamaephyte
	<i>Cyanotis vaga</i> (Lour)	+	+	+	-	Annual herb	Geophyte
Euphorbiaceae	<i>Phyllanthus urinaria</i> Hb. Russ	+	+	-	-	Annual procumbent herb	Therophyte
Fabaceae	<i>Crotolaria sp.</i>	+	-	-	-	Perennial undershrub	Chamaephyte
Lamiaceae	<i>Plectranthus striatus</i> Benth.	+	+	-	-	Perennial herb	Hemicryptophyte
Lycopodiaceae	<i>Lycopodium clavatum</i> Linn.	+	+	+	-	Perennial	Hemicryptophyte
Malvaceae	<i>Sida acuta</i> Burm. f.	+	-	-	-	Perennial undershrub	Chamaephyte
Melastomaceae	<i>Melastoma sp.</i>	+	+	-	-	Perennial undershrub	Chamaephyte
	<i>Osbeckia stellata</i> DC.	+	+	+	-	Perennial shrub	Chamaephyte
Oxalidaceae	<i>Oxalis corniculata</i> Linn.	-	+	-	-	Perennial pubescent herb	Hemicryptophyte
Poaceae	<i>Arundinella khasiana</i> Nees.	+	+	+	-	Perennial herb	Chamaephyte
	<i>Axonopus compressus</i> (SW) Beauv.	+	+	+	-	Perennial herb	Hemicryptophyte

	<i>Eleusine nigra</i> Linn.	+	+	-	-	Annual herb	Chamaephyte
	Grasses	+	-	-	-	Perennial	Therophyte
	<i>Imperata cylindrica</i> Beauv.	+	+	+	-	Perennial herb	Chamaephyte
	<i>Paspalum orbiculare</i> Forst.	+	+	-	-	Perennial herb	Hemicryptophyte
Plantaginaceae	<i>Plantago major</i> Linn.	+	-	+	-	Perennial herb	Geophyte
Polygonaceae	<i>Polygonum capitatum</i> Hum.	-	+	-	-	Perennial creeping herb	Geophyte
Pteridaceae	<i>Pteris</i> sp.	-	+	-	-	Perennial creeper	Geophyte
Rosaceae	<i>Rubus alceifolius</i> Linn.	+	-	-	-	Perennial sub-scandent shrub	Phanerophyte
Rubiaceae	<i>Anotis wightenia</i> Hk.f.	+	-	-	-	Perennial herb	Geophyte
	<i>Borreria hispida</i> Linn.	+	+	-	-	Perennial herb	Chamaephyte
	<i>Hedyotis macrophylla</i> Wall.	+	+	-	-	Annual herb	Hemicryptophyte
	<i>Paederia foetida</i> Linn.	+	+	+	-	Perennial twiner shrub	Chamaephyte
Saururaceae	<i>Houttuynia cordata</i> Thumb.	+	+	-	-	Perennial herb	Hemicryptophyte
Scrophulariaceae	<i>Lindernia</i> sp.	+	-	-	-	Annual herb	Therophyte
	<i>Pratia begonifolia</i> (Wall) Lindl.	+	+	-	-	Annual herb	Chamaephyte
Thelypteridaceae	<i>Dicranopteris linearis</i> Ching.Holt.	+	+	+	+	Perennial herb	Hemicryptophyte
Verbenaceae	<i>Lantana camara</i> Linn.	+	-	-	-	Perennial spiny bushy shrub	Phanerophyte
	Mosses	+	+	+	+	Perennial herb	Hemicryptophyte

Table 5.3. Family- wise distribution of species in the coal mine spoils of different ages and the control site

Family	Control	12-14 year old spoil	6-8 year old spoil	0-2 year old spoil
Apiaceae	2	-	1	-
Araceae	1	-	-	-
Asteraceae	7	4	2	-
Balsaminaceae	1	-	-	-
Caryophyllaceae	1	1	-	-
Commelinaceae	3	3	1	-
Euphorbiaceae	1	1	-	-
Fabaceae	1	-	-	-
Lamiaceae	1	1	-	-
Lycopodiaceae	1	1	1	-
Malvaceae	1	-	-	-
Melastomaceae	2	2	1	-
Oxalidaceae	-	1	-	-
Poaceae	6	5	3	-
Plantaginaceae	1	-	1	-
Polygonaceae	-	1	-	-
Pteridaceae	-	1	-	-
Rosaceae	1	-	-	-
Rubiaceae	4	3	1	-
Saururaceae	1	1	-	-
Scrophulariaceae	2	1	-	-
Thelypteridaceae	1	1	1	1
Verbenaceae	1	-	-	-
Mosses	1	1	1	1
Total	21	16	10	2

"-" indicates absence

Table 5.4a. Vegetation analysis of plant species growing on unmined control site

Name of the Species	Relative Frequency	Relative Density	Relative Dominance	IVI	IVI Ranking
1. <i>Arundinella khasiana</i> Nees	3.70	6.31	2.98	12.99	9
2. <i>Axonopus compressus</i> (Sw) Beauv	7.41	27.94	3.19	38.54	1
3. <i>Centella asiatica</i> L (Urb)	3.70	0.45	0.22	4.37	17
4. <i>Commelina bengalensis</i> Linn.	7.41	4.95	0.24	12.60	11
5. <i>Crossocephalum crepidiodes</i> Benth.	3.70	0.45	0.16	4.31	18
6. <i>Crotolaria sp.</i>	3.70	0.45	3.12	7.27	14
7. <i>Dicranopteris linearis</i> Ching Holt	7.41	0.89	13.44	21.74	7
8. <i>Eupatorium adenophorum</i> DC	7.41	3.61	23.83	34.85	2
9. <i>Houttuynia cordata</i> Thumb.	3.70	1.35	0.98	6.03	15
10. <i>Hydrocotyl javanica</i> Thumb.	7.41	2.70	2.50	12.61	10
11. <i>Impatiens khasiana</i> Hk. f.	3.70	0.45	1.15	5.30	16
12. <i>Lantana camara</i> Linn.	3.70	0.91	20.66	25.27	5
13. <i>Melastoma sp.</i>	7.41	3.61	14.87	25.89	4
14. <i>Paederia foetida</i> Linn.	7.41	12.61	0.85	20.87	6
15. <i>Paspalum orbiculare</i> Forst.	3.70	10.81	3.08	17.59	8
16. <i>Phyllanthus urinaria</i> Hb. Russ.	3.70	1.35	3.24	8.29	12
17. <i>Plectranthus striatus</i> Benth.	3.70	0.45	4.09	8.24	13
18. <i>Pratia hegouifolia</i> (Wall.) Lindl.	11.11	20.72	0.002	31.83	3
	99.98	100.01	98.60	298.59	

Table 5.4b. Vegetation analysis of plant species growing on the 12-14 year old coal mine spoil

Name of the Species	Relative Frequency	Relative Density	Relative Dominance	IVI	IVI Ranking
1. <i>Arundinella khasiana</i> Nees	5.26	4.84	6.05	16.15	9
2. <i>Imperata cylindrica</i> Hk.f	5.26	9.36	6.19	20.81	4
3. <i>Borreria hispida</i> Linn.	1.75	0.34	1.12	3.21	19
4. <i>Commelina bengalensis</i> Linn.	8.77	6.59	3.64	19.0	6
5. <i>Crossocephalum crepidiodes</i> Benth.	3.51	1.37	4.06	8.94	13
6. <i>Dicranopteris linearis</i> Ching Holt	3.51	1.37	3.16	8.04	15
7. <i>Eupatorium adenophorum</i> DC	1.75	1.72	13.39	16.86	8
8. <i>Gnaphelium luteo-album</i> Linn.	5.26	4.15	10.74	20.15	5
9. <i>Hedyotis macrophylla</i> Wall.	1.75	0.34	6.19	8.28	14
10. <i>Houttuynia cordata</i> Thumb.	1.75	0.34	15.59	17.68	7
11. <i>Hypochaeris radicata</i> Linn.	1.75	0.34	5.89	7.98	16
12. <i>Lycopodium clavatum</i> Linn.	1.75	0.34	6.19	8.28	17
13. <i>Oxalis corniculata</i> Linn.	10.53	3.46	1.04	15.03	10
14. <i>Paederia foetida</i> Linn.	10.53	27.72	3.71	41.96	1
15. <i>Paspalum orbiculare</i> Forst.	8.77	20.79	0.52	30.08	2
16. <i>Plectranthus striatus</i> Benth.	1.75	1.03	1.04	3.82	18
17. <i>Polygonum capitatum</i> Ham.	3.51	1.03	6.19	10.73	10
18. <i>Pratia begouifolia</i> (Wall.) Lindl.	12.28	7.62	1.12	21.02	3
19. <i>Phyllanthus urinaria</i> Hb. Russ.	1.75	0.34	1.12	3.21	20
20. <i>Osbeckia stellata</i> DC.	5.26	1.37	2.59	9.22	22
21. <i>Drymeria cordata</i> Willd.	3.51	5.52	0.46	9.49	11
	99.96	99.98	100.00	299.94	

Table 5.4c. Vegetation analysis of plant species growing on the 6-8 year old coal mine spoil

Name of the Species		Relative Frequency	Relative Density	Relative Dominance	IVI	IVI Ranking
1. <i>Axonopus compressus</i> (Sw) Beauv		23.81	43.16	12.62	79.59	1
2. <i>Arundinella khasiana</i> Nees		4.76	7.77	12.62	25.15	4
3. <i>Centella asiatica</i> L (Urb)		9.52	3.42	7.39	20.33	6
4. <i>Dicranopteris linearis</i> Ching Holt		14.29	3.42	26.63	44.33	3
5. <i>Gnaphelium luteo-album</i> Linn.		9.52	6.89	8.28	24.69	5
6. <i>Hypochaeris radicata</i> Linn.		4.76	0.83	12.01	17.60	8
7. <i>Lycopodium clavatum</i> Linn.		4.76	0.83	12.01	17.60	8
8. <i>Paederia foetida</i> Linn.		14.29	31.09	4.89	50.27	2
9. <i>Osbeckia stellata</i> DC.		14.29	2.59	3.22	20.10	7
		100.00	100.00	99.67	299.67	

Table: 5.5a. Vegetation analysis of plant species growing on the unmined control site

Name of the Species	Density (Plants/m ²)	Cover Value	Sociability	Persistence (%)	Seed Production & Veg. propagation	Relative Performance Index (RPI)	RPI Ranking
1. <i>Arundinella khasiana</i> Nees	51.88	3	3	0.66	1	2.08	4
2. <i>Axonopus compressus</i> (Sw) Beauv	229.67	3	4	1.0	2	2.25	3
3. <i>Centella asiatica</i> L (Urb)	3.67	1	1	0.33	1	1.42	8
4. <i>Commelina bengalensis</i> Linn.	40.67	1	2	0.66	2	1.58	7
5. <i>Crossocephalum crepidioides</i> Benth.	3.67	3	1	0.33	1	1.92	5
6. <i>Crotolaria</i> sp.	3.67	3	1	0.3	1	1.92	5
7. <i>Dicranopteris linearis</i> Ching Holt	7.33	4	2	0.66	3	8.08	1
8. <i>Eupatorium adenophorum</i> DC	29.67	4	1	0.66	2	8.08	1
9. <i>Houttuynia cordata</i> Thumb.	11.11	2	3	0.33	1	0.57	10
10. <i>Hydrocotyl javanica</i> Thumb.	22.22	3	2	0.66	1	2.08	4
11. <i>Impatiens khasiana</i> Hk. f.	3.67	2	1	0.33	2	0.57	10
12. <i>Lantana camara</i> Linn.	7.44	4	2	0.33	3	7.92	2
13. <i>Melastoma</i> sp.	29.67	4	1	0.66	3	8.08	1
14. <i>Paederia foetida</i> Linn.	103.67	2	1	0.66	2	0.73	9
15. <i>Paspalum orbiculare</i> Forst.	88.89	3	2	0.33	1	1.92	5
16. <i>Phyllanthus urinaria</i> Hb. Russ.	11.11	3	1	0.33	1	1.92	5
17. <i>Plectranthus striatus</i> Benth.	3.671	3	2	0.33	1	1.92	5
18. <i>Pratia begonifolia</i> (Wall.)Lindl.	170.33	1	1	1.00	1	1.75	6

Table 5.5b. Vegetation analysis of plant species growing on the 12-14 year old coal mine spoil

Name of the Species	Density (Plants/m ²)	Cover Value	Sociability	Persistence (%)	Seed Production & Veg. propagation	Relative Perform- ance Index (RPI)	RPI Ranking
1. <i>Arundinella khasiana</i> Nees	17.22	4	2	0.33	1	7.92	1
2. <i>Imperata cylindrica</i> Hk.f	33.33	4	3	0.33	1	7.92	1
3. <i>Borreria hispida</i> Linn.	1.22	2	2	0.11	2	0.10	13
4. <i>Commelina bengalensis</i> Linn.	23.44	3	2	0.55	1	2.03	6
5. <i>Crossocephalum crepidiodes</i> Benth.	4.89	3	1	0.22	1	1.86	8
6. <i>Dicranopteris linearis</i> Ching Holt	4.89	3	2	0.22	2	1.86	8
7. <i>Eupatorium adenophorum</i> DC	6.11	4	1	0.11	1	7.81	3
8. <i>Gnaphelium luteo-album</i> Linn.	14.77	4	1	0.33	2	7.92	1
9. <i>Hedyotis macrophylla</i> Wall.	1.22	4	1	0.11	1	7.81	3
10. <i>Houttuynia cordata</i> Thumb.	1.22	4	1	0.11	1	7.81	3
11. <i>Hypochaeris radicata</i> Linn.	1.22	4	1	0.11	2	7.81	3
12. <i>Lycopodium clavatum</i> Linn.	1.22	4	1	0.11	-	7.81	3
13. <i>Oxalis corniculata</i> Linn.	12.33	2	1	0.66	1	0.37	11
14. <i>Paederia foetida</i> Linn.	98.67	3	1	0.66	1	2.08	5
15. <i>Paspalum orbiculare</i> Forst.	74.00	1	3	0.55	1	0.40	10
16. <i>Plectranthus striatus</i> Benth.	3.67	2	2	0.11	-	0.10	13
17. <i>Polygonum capitatum</i> Ham.	3.67	4	1	0.22	2	7.86	2
18. <i>Pratia begonifolia</i> (Wall.) Lindl.	27.11	3	1	0.77	1	2.14	4
19. <i>Phyllanthus urinaria</i> Hb. Russ.	1.22	3	1	0.11	-	1.81	4
20. <i>Osbeckia stellata</i> DC.	4.88	3	1	0.33	2	1.92	7
21. <i>Drymeria cordata</i> Willd.	19.67	1	2	0.22	3	0.24	12

Table: 5.5c. Vegetation analysis of plant species growing on the 6-8 year old coal mine spoil

Name of the Species	Density (Plants/m ²)	Cover Value	Sociability	Persistence (%)	Seed Production & Veg. propagation	Relative Performance Index (RPI)	RPI Ranking
1. <i>Axonopus compressus</i> (Sw) Beauv	92.56	4	2	0.83	2	8.17	2
2. <i>Arundinella khasiana</i> Nees	16.67	4	1	0.17	1	7.84	4
3. <i>Centella asiatica</i> L (Urb)	7.33	4	1	0.33	-	7.92	3
4. <i>Dicranopteris linearis</i> Ching Holt	7.33	5	1	0.50	2	19.3	1
5. <i>Gnaphelium luteo-album</i> Linn.	14.78	4	1	0.33	1	7.92	3
6. <i>Hypochaeris radicata</i> Linn.	1.78	4	1	0.17	1	7.84	4
7. <i>Lycopodium clavatum</i> Linn.	1.789	4	1	0.17	-	7.84	4
8. <i>Paederia foetida</i> Linn.	66.67	3	2	0.50	2	2.00	5
9. <i>Osbeckia stellata</i> DC.	5.56	3	1	0.50	1	2.00	5

Table 5.6. Percentage contribution of different life form spectrum in the coal mine spoils and the control site.

Site	Chamaephytes	Hemicryptophyte	Phanerophytes	Therophytes	Geophytes
Control	35.89 (14)	25.64 (10)	10.26 (4)	15.39 (6)	12.82 (5)
12-14 year old spoil	39.29 (11)	35.71 (10)	3.57 (1)	7.14 (2)	14.29 (4)
6-8 year old spoil	30.77 (4)	38.46 (5)	-	7.69(1)	23.08 (3)
0-2 year old spoil	-	100 (2)	-	-	-

Table 5.7. Comparison of Life Form Spectra 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.

	Phanerophyte	Chamaephyte	Hemicryptophyte	Geophyte	Therophyte
Raunkiaer (1937)	46.00	9.00	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
<u>T. Lyndoh (1995)</u>					
Control site	11.4	15.9	20.5	11.4	45.4
10-year old spoil	0.0	19.0	33.4	23.8	23.8
5-year old spoil	0.0	44.4	56.6	0.0	0.0
2-year old spoil	0.0	14.3	57.1	0.0	28.6
<u>Present study (1999)</u>					
Control site	10.26	35.89	25.64	12.82	15.39
12-14 year old spoil	3.57	39.29	35.71	14.29	7.14
6-8 year old spoil	-	30.77	38.46	23.08	7.69
0-2 year old spoil	-	-	100	-	-

Table 5.8. Similarity index (%) of plant species in the control site and the coal mine spoils of different ages.

Control Vs 12 -14 year old spoil	: 56.41
Control Vs 6-8 year old spoil	: 37.04
12-14 year old Vs 6-8 year old spoil	: 20.00

Table :5.9. Comparison between IVI and RPI of some important species growing on the mine spoils and the control site during the peak vegetative growth. Only those species with IVI above 11 and RPI above 2 have been listed individually. "-" indicates absence.

Name of the specie	Control		12-14 year old spoil		6-8 year old spoil	
	IVI	RPI	IVI	RPI	IVI	RPI
1. <i>Arundinella khasiana</i> Nees	12.99	2.08	16.15	7.92	25.15	7.84
2. <i>Axonopus compressus</i> (Sw) Beauv.	38.54	2.25	-	-	79.59	8.17
3. <i>Commelina bengalensis</i> Linn.	-	-	19.0	2.03	-	-
4. <i>Centella asiatica</i> L. (Urb)	-	-	-	-	20.33	7.92
5. <i>Dicranopteris linearis</i> Ching Holt	21.74	8.08	-	-	44.34	19.3
6. <i>Eupatorium adenophorum</i> DC	34.85	8.08	16.86	7.81	-	-
7. <i>Gnaphelium luteo-album</i> Linn.	-	-	20.15	7.92	24.69	7.92
8. <i>Houttuynia cordata</i> Thumb.	-	-	17.68	7.81	-	-
9. <i>Hypochoeris radicata</i> Linn.	-	-	-	-	17.60	7.84
10. <i>Lantana camara</i> Linn.	25.27	7.92	-	-	-	-
11. <i>Lycopodium clavatum</i> Linn.	-	-	-	-	17.60	7.84
12. <i>Melastoma</i> sp.	25.89	8.08	-	-	-	-
13. <i>Paederia foetida</i> Linn.	-	-	41.96	2.08	50.27	2.00
14. <i>Polygonum capitatum</i> Ham.	-	-	10.73	7.86	-	-
15. <i>Pratia begonifolia</i> (Wall.) Lindl.	-	-	21.02	2.14	-	-
16. <i>Osbeckia stellata</i> DC.	-	-	-	-	20.10	2.0

CHAPTER VI

COMMUNITY STRUCTURE AND ACTIVITY OF SOIL MICRO-ORGANISMS ON COAL MINE SPOILS OF DIFFERENT AGES

Introduction

Land degradation as a result of protracted and indiscriminate mining brings about significant changes in the soil environment which in turn alters microbial community structure, their activities and associated processes of decomposition and nutrient cycling. Relatively little work has been done on the microbiology of reclaimed mine spoils or on mine spoils undergoing natural recovery. Recently, the deleterious effects of major disturbances such as opencast coal mining on the soil microbial communities have been documented (Stroo and Jencks 1982, Insam and Domsch 1988, Harris and Birch 1989). Restoration of a stable and productive soil following such disturbances, requires that a self-sustaining soil-plant-microbe system is established in which nutrient release rates are adequate for plant growth (Bradshaw *et al.* 1986). Zak *et al.* (1990) studied the importance of microbial community in managing the reclamation of mine spoils. Soil organic matter, moisture contents and microbial populations increase with the increase in age of the mine spoils. Microorganisms especially fungi are involved in water and nutrient uptake by woody plants on surface mined lands. Lawrey (1977 a, b) isolated fungi from stripmine habitats and undisturbed sites and found lowest number of fungal

genera in the unvegetated habitat and this was attributed to the absence of litter. Fresquez and Lindemann (1982) opined that the available carbon source is a critical factor to stimulate spoil microflora in mine spoils. Barth (1986) found the lowest activity of microbial community in mine spoils. However, when the spoil was covered with topsoil, the microbial activity increased appreciably.

Hendrick and Wilson (1956) found that in mine spoils, CO₂ evolution was 14% lower than that of the unmined soil. Fyles (1985) reported that CO₂ evolution increased with increasing age of mine spoils in Southern British Columbia. Stroo and Jencks (1982) found lower microbial respiratory and enzymatic activity in barren mine spoils than the native soils. They emphasized the importance of the link between vegetation and the development of microbial activity in mine spoils. Hershman and Temple (1968) used ATP content as a parameter for characterising the microbial status of coal mine spoils in Montana and observed that the native range soils contained higher levels of ATP than the spoils.

Microorganisms are an important source of soil enzymes like dehydrogenase. Measurement of dehydrogenase activity (DHA) has often been used as an index of microbial activity. However, there are a very few studies on enzyme activity in coal mine spoils. The work of Stroo and Jencks (1982) merits a mention. They found lower rate of enzymatic activity in mine spoils in comparison to the native soils. In India, there is a dearth of studies relating to the soil enzymatic activities in mine

spoils. Tiwari and Das Gupta (1993) reported reduced rate of dehydrogenase, phosphatase and esterase activities in agricultural soils affected by coal mining.

The microbial biomass and the ratio of microbial biomass-C to total organic-C in particular have been suggested as indicators of the state and modification of SOM. The quantity and composition of microbial biomass are sensitive to changes in the soil chemical and physical environment (Wolters and Joergensen 1991, Bauhus and Khanna 1994, Beck *et al.* 1995). Srivastava *et al.* (1989) have hypothesized that SMB is a critical factor in recovery of mine spoils as it aids in the reestablishment of nutrient cycling. The level of biomass -C can be taken as a functional index of soil development as it is influenced by soil texture and soil organic matter quality (Wardle 1992, Ross and Tate 1993, Bosatta and Agren 1994, Hassink 1994).

There is a general dearth of information pertaining to the N-mineralization in coal mine spoils the world over. Cornwell and Stone (1968) found that acid pyrite black shale spoil from anthracite mining released plant-available ammonium nitrogen on weathering. Loss of $\text{NO}_3\text{-N}$ takes place from the surface to 30-cm deep layer of spoil. Nitrogen-mineralization and nitrification in mine spoils have been studied by Wilson (1965), Williams and Cooper (1976) and Fyles and McGill (1987). Lower rate of ammonification in both vegetated and non-vegetated mine spoils than in undisturbed habitats was reported by Wilson (1965).

Coal mine spoils are characterised by a very reduced level of microbial enzyme activity, respiration and mineralization rates. An attempt has been made to study the above attributes in addition to their population counts and microbial biomass-C accumulation in the mine spoils undergoing natural recovery.

Results

Bacterial population

Bacterial population in the mine spoils as well as soils of the control site varied significantly ($P < 0.01$) between the seasons and sites. During both years, of study, the highest population of bacteria was recorded during rainy season whereas, the lowest population was observed during the spring season. There was a marked reduction in bacterial population from the control site to the youngest spoil and it also decreased significantly ($P < 0.05$) from the surface to the sub-surface soil layer (Fig. 6.1).

Fungal population

The population of colony forming propagules of filamentous fungi showed a very wide range of seasonal, depth-wise and site-wise variations. The maximum count of fungi was recorded during spring in both the sampling years and the least number of fungal propagules were recorded during autumn. The unmined control site recorded the maximum and the bare spoil the minimum fungal population. There was a significant ($P < 0.05$) decline in the fungal population with increasing

depth and decreasing spoil age (Fig.6.2).

Yeast population

The yeast population also varied significantly ($P < 0.05$) between the seasons. It also declined significantly and steadily from the unmined control to the youngest spoil and from the surface to the sub-surface soil layer. It showed a highest value during autumn in all the sites (Fig. 6.3).

Composition of the fungal flora

The fungal species composition varied from site to site. The unmined site recorded the maximum number of species (18) followed by the oldest spoil with 16 species, partially colonised spoil with 12 species and the bare spoil with 5 species. Altogether 21 species were isolated and the species such as *Aspergillus niger*, *Mucor heimalis*, *Mucor plumbeus*, *Penicillium chrysogenum* and *Sporobolomyces* sp. (yeast) were common to all the sites.

Alternaria sp., *Aspergillus flavus*, *Aspergillus niger*, *Cladosporium* sp., *Mucor heimalis*, *Mucor plumbeus*, *Penicillium chrysogenum*, *Trichoderma viride* and *Sporobolomyces* sp. were found to occur in three sites viz., the unmined control site, 12-14 year old spoil and 6-8 year old spoil. *A. niger*, *M. heimalis*, *M. plumbeus*, *P. chrysogenum* and *Sporobolomyces* were common to the 6-8 and 0-2 year old spoils. *A. cylindrospora* and *Scopulariopsis* sp. were found only in the control site, whereas, *Helminthosporium* sp. was confined to the oldest spoil. *P.*

brevicompectum was reported only from the 6-8 year old spoil (Table 6.1).

The fungal species similarity index was found to be 82.35% between the unmined control site and the 12-14 year old spoil, 66.67% between the control site and 6-8 year old spoil , 43.48% between control and the 0-2 year old spoils , 35.71% between the 12-14 and 6-8 year old spoil, 47.62% between 12-14 and 0-2 year old spoils and 58.82% between 6-8 and 0-2 year old spoils. It was clear from the similarity index that the fungal community composition at the oldest site (12-14 year) was quite similar to the unmined site (Table 6.2).

Dehydrogenase activity (DHA)

The mine spoils as well as the soils of the unmined site had a very low rate of dehydrogenase activity. The rate of enzymatic activity was generally low, however, it was maximum during the spring season in the surface layer of the unmined site. The lowest level of dehydrogenase activity was in the sub-surface layer of the youngest spoil during the autumn season. The DHA declined with increasing depth and decrease in spoil age. Seasonal mean values also showed a decrease with increase in depth and decrease in the age of the spoils. There was a marginal increase in enzymatic activity during the second year (Fig. 6.4).

Microbial biomass-C

Microbial biomass-C showed a clear cut seasonal variation; the peak value was obtained during spring and the lowest value during rainy season. The

maximum value was recorded for the unmined site at both the soil depths, whereas the youngest spoil showed very low value. The values obtained by summing up all the seasonal values for the entire sampling period reflected a definite downward trend with increasing depth and decreasing spoil age. There was a noticeable increase in microbial biomass-C during the second year of study in almost all the sites and depths (Fig. 6.5).

The microbial biomass-C expressed as percent of soil organic carbon showed higher values during the spring season in all the sites and depths compared to the other seasons. The percentage of microbial biomass-C to organic-C in the unmined site was generally higher in the upper depth and it was least in the sub-surface layer of the youngest spoil. The percentage mean values showed an appreciable increase from the first to the second year. It ranged from 2.27% in the bare spoil to 5.85% in the unmined site (Table 6.3). The relative contribution of $\mu\text{g CO}_2$ to $\mu\text{g biomass-C}$ was found to be always high during the rainy season in all the sites and depths. The mine spoils and the unmined control site exhibited uniform pattern in this respect during both the sampling years (Fig. 6.6).

N-mineralization

Nitrogen mineralization exhibited a sharp seasonal variation with the autumn season registering the highest values of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ concentration in relation to other three seasons (Fig. 6.7 A & B) followed by spring and winter

seasons. Rainy season recorded the lowest rate of activity. This trend was discernible in the second year also. This distinctive pattern was observed for $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ in all the sites and seasons. The unmined site showed the maximum mineralization and the youngest spoil the minimum. The surface soil layer (0-10 cm) showed higher rate of N-mineralization than the lower depth (10-20 cm). The rate of N-mineralization increased with increase in age of mine spoil. There was a substantial increase in the mean seasonal rate of N-mineralization from the first to the second year. During the first year, 6.41 mg/g in the control site was the maximum and 0.39 mg/g in the bare spoil the minimum. During the second year also, the same trend was followed with a slight increase over the previous year.

The rate of net N-mineralization decreased with increasing depth and same was the case with ammonification and nitrification. The surface soil layer on the unmined site showed maximum rates of ammonification, nitrification and net N-mineralization. Lowest rate of mineralization was recorded in the sub-surface layer of the bare spoil (Fig. 6.7c).

Soil respiration

Soil respiration rate was high during spring and low during winter season. It decreased with increasing soil depth and decreasing spoil age. During the second year of study, the control site recorded the highest rate of respiration during spring season (12.77 mg CO_2 /kg/24 hrs) and lowest (6.84 CO_2 kg/24/hr) during the

winter season. The mean seasonal values declined gradually with decreasing age of the spoil from the unmined site (9.76 mg CO₂/kg/24 hrs) to the youngest spoil (0.85 mg CO₂/kg/24 hrs). The surface layer (0-10 cm) always had higher values than the lower depth (10-20 cm) (Fig. 6.8).

Discussion

Analysis of various microbiological attributes clearly revealed that the bacterial population was maximum in the soil of the unmined control site and mine spoils always had a lower population. The unmined site had consistently higher microbial population than the mine spoil, which is corroborated by the works of Martin and Focht (1975). The fungal population also showed a similar trend with the unmined site registering higher populations than the mine spoil sites. This could be attributed to the significant decrease in organic-C content of the spoil subsequent to mining which, however, builds up with increasing age of the spoil (Chapter IV). The organic-C was positively correlated with bacterial and fungal population (P<0.01) level. The reduction in bacterial and fungal population from the surface to the sub-surface soil layer was mainly due to the decline in nutrient level, aeration and root accumulation. The high microbial population during rainy season may be ascribed to the favourable moisture content and better availability of nutrients to the microbes. The youngest mine spoil harboured the lowest microbial population probably due to the harsh microenvironmental conditions like direct

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sunlight, low relative humidity, very low organic carbon content and water holding capacity prevailing there. Thompson et al.(1999), Voordouw et al.(1994) and Miller and Cameron (1976) also reported decreased microbial activity in disturbed ecosystems. The similarity index in terms of fungal species composition shows that the fungal community of the 12-14 years old spoil has become very much similar to that of the unmined site depicting that after natural recovery of 12-14 years, the fungal community could be restored to a great extent.

The rate of soil respiration showed positive correlation with MB-C and microbial populations at $P < 0.01$ and 0.05 levels. The reduction in soil respiration from the unmined control site to the youngest spoil with the reduction in bacterial and fungal population and also with The decline in the contents of soil organic matter, nutrients and vegetal cover. The decline in soil respiration from the surface to the sub-surface soil layer could also be attributed to the declining bacterial and fungal population also from the surface to the sub-surface soil layer. The reduction in soil respiration rate in the present study with increasing depth and decreasing mine spoil age has been corroborated by the studies of Stroo and Jencks (1982). The population and the activities of microorganisms in the coal mine spoils under study were not affected by any heavy metals as these metals were not found in toxic proportions. This is in contrast to the findings of Brookes and McGrath (1984) and Brookes et al. (1984) who reported unhindered microbial respiration at heavy metal

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concentration at around EU mandatory limits, but observed a decline in soil respiration at high metal concentration.

The trend of dehydrogenase activity in mine spoil bore similartiy with soil respiration, which is in agreement with the findings reported by Tiwari and DasGupta (1993) from the rice fields affected by coal mining in Meghalaya. DHA measurement showed that during most seasons DHA was not detectable, however, the spring measurements clearly depicted that the dehydrogenase activity was severely disrupted due to mining and it increased with the age of the spoil. The DHA was studied by Stroo and Jencks (1982) in mine spoils in the initial state of soil formation and on comparing it with native soils, they found reduced rates of DHA in the former. The present study agrees with the works of Schinner and Gurschler (1978) who reported higher rate of enzyme activity in surface soils compared to sub-surface ones.

The microbial biomass-C also showed the maximum concentration in the unmined control site and it declined with decreasing spoil age and depth. This finding is in conformity with the works of Srivastava et al. (1989) who observed a higher level of biomass C, N and P in native forest soils than in the 5-year old spoil in Jhingurda, India. Maithani *et al.* (1997) reported an enhanced level of microbial biomass C, N and P in the surface soil layer than the sub-surface layer in sub-tropical forest regrowths in Meghalaya, which agrees with the findings of

the present study. The study demonstrates that the microbial biomass carbon shows a wide range of seasonal variation. Generally, during spring a larger proportion of soil organic carbon was allocated to microbial biomass pool. With the conditions turning favourable for microbial growth there is a clear shift of carbon from SOC to MB-C. This finding leads to the stipulation that higher allocation of organic carbon to SMB is an indicator of soil ecosystem health as it is seen that in the unmined soils and in the spoils which have undergone recovery for longer duration there is significantly a higher allocation of organic carbon towards microbial biomass.

The pattern of N-mineralization as observed in this study also conformed to the trends manifested by respiration, dehydrogenase activity and microbial biomass-C. It decreased with increasing depth and declining spoil age. Abrupt drop in N-mineralization subsequent to mining and slow but very steady build up with the age of the spoils shows that N-mineralization can be a potential indicator of degree of restoration in coal mining affected soils. This is supported by the findings of Fyles and McGill (1987) and Wilson (1965) who observed lower rates of ammonification and nitrification in both vegetated and non-vegetated mine spoils than in undisturbed habitats. Incidentally, the N-mineralisation was positively ($P < 0.01$ and 0.05) correlated with soil physico-chemical and microbial parameters.

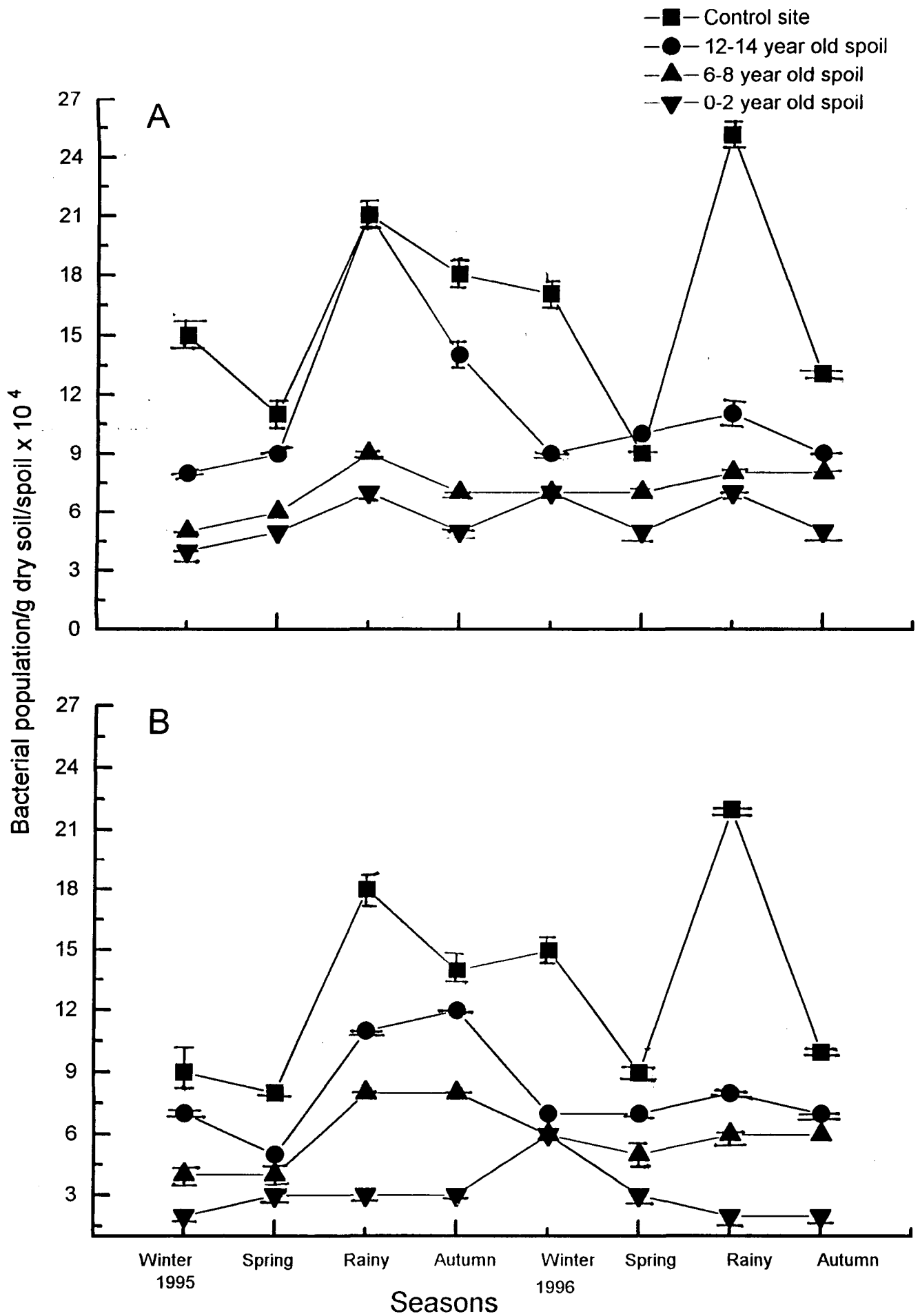


Fig. 6.1. Seasonal variation in bacterial population in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

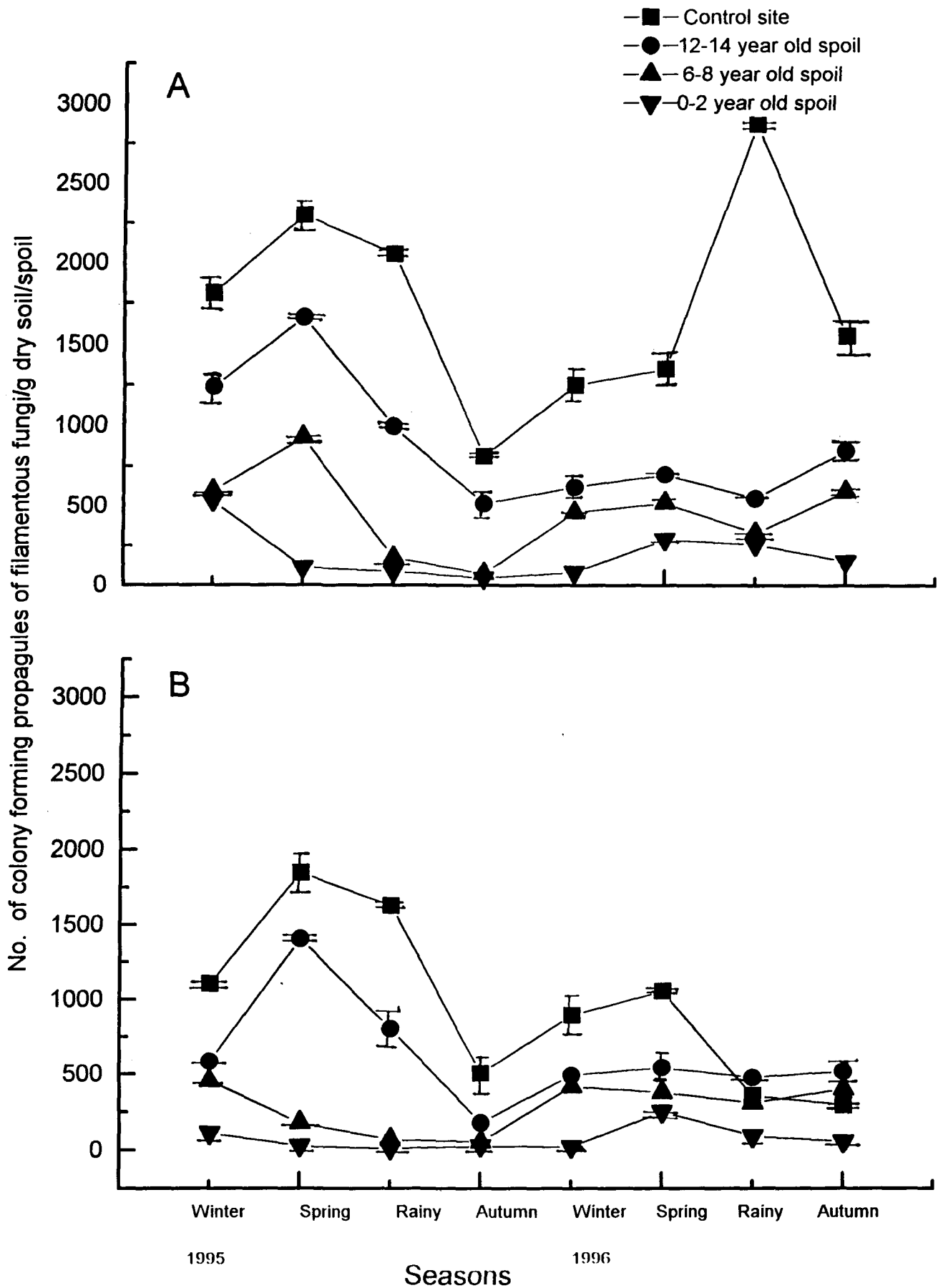


Fig. 6.2. Seasonal variation in filamentous fungal population in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

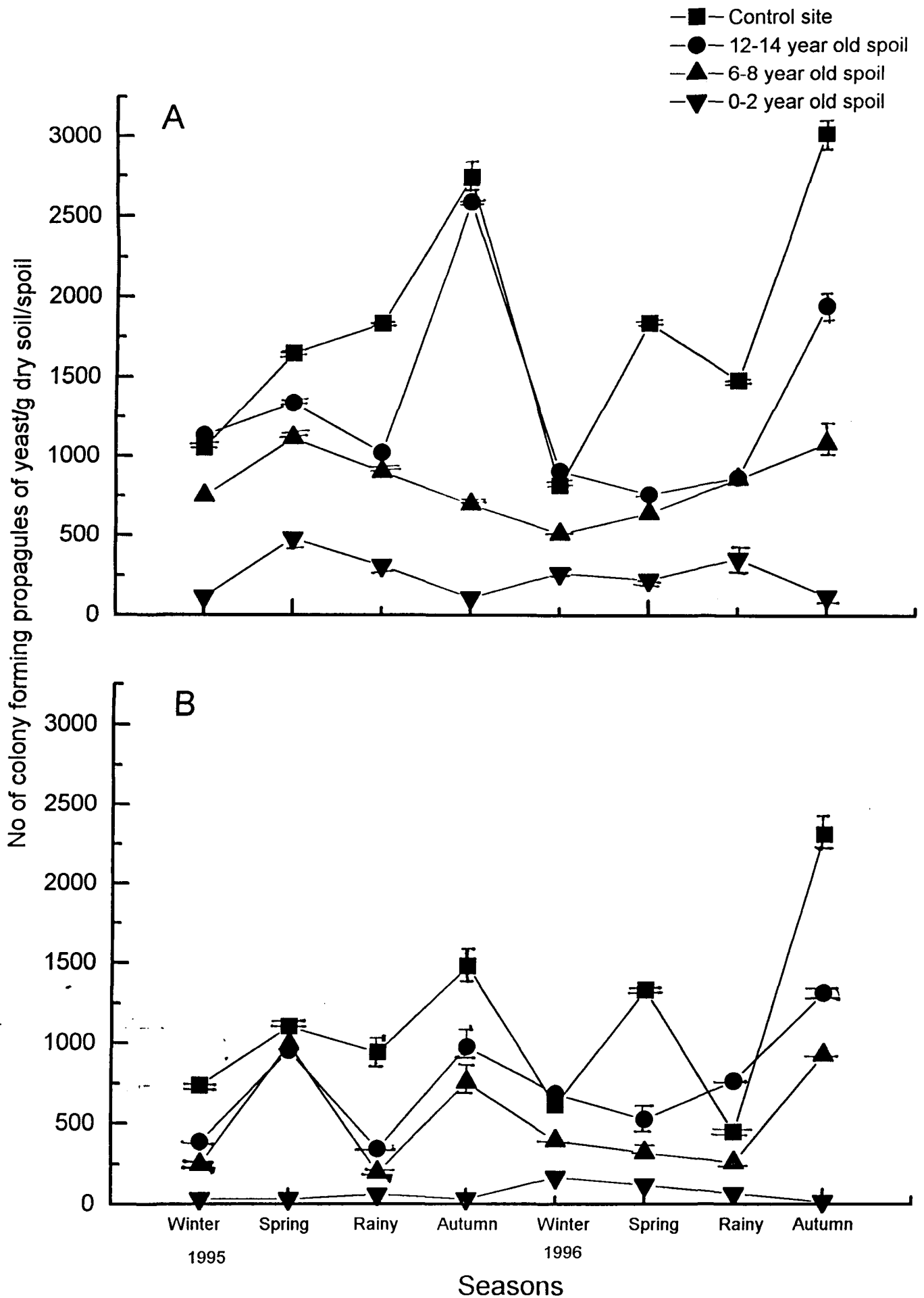


Fig. 6.3. Seasonal variation in yeast population in coal mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

Table 6.1. Composition of fungal flora in the coal mine spoils of different ages and in the soils of the control site.

Name of fungal species	Control	12-14 year old spoil	6-8 year old spoil	0-2 year old spoil
<i>Absidida cylindrospora</i>	+	-	-	-
<i>Absidia glauca</i>	+	+	-	-
<i>Alternaria sp.</i>	+	+	+	-
<i>Aspergillus flavus</i>	+	+	+	-
<i>Aspergillus niger</i>	+	+	+	+
<i>Aspergillus nidulans</i>	+	+	-	-
<i>Aspergillus sp.</i>	-	+	+	-
<i>Cladosporium sp.</i>	+	+	+	-
<i>Helminthosporium sp.</i>	-	+	-	-
<i>Mucor heimalis</i>	+	+	+	+
<i>Mucor plumbeus</i>	+	+	+	-
<i>Mucor racemosus</i>	+	+	-	-
<i>Monilia humicola</i>	+	+	-	-
<i>Penicillium chrysogenum</i>	+	+	+	+
<i>Penicillium brevicompactum</i>	-	-	+	-
<i>Pythium intermedium</i>	+	+	-	-
<i>Pythium irregulans</i>	+	-	+	-
<i>Sporobolomyces sp.</i>	†	†	†	†
<i>Scopulariopsis sp.</i>	+	-	-	-
<i>Trichosporium sp.</i>	+	-	-	-
<i>Trichoderma viride</i>	+	+	+	-

Table 6.2. Similarity index (%) based on the fungal species composition of the coal mine spoils of different ages and the soils of the control site.

Control Vs 12-14 year old spoil	: 82.35
Control Vs 6-8 year old spoil	: 66.67
Control Vs 0-2 year old spoil	: 43.48
12-14 year old spoil Vs 6-8 year old spoil	: 35.71
12-14 year old spoil Vs 0-2 year old spoil	: 47.62
6-8 year old spoil Vs 0-2 year old spoil	: 58.82

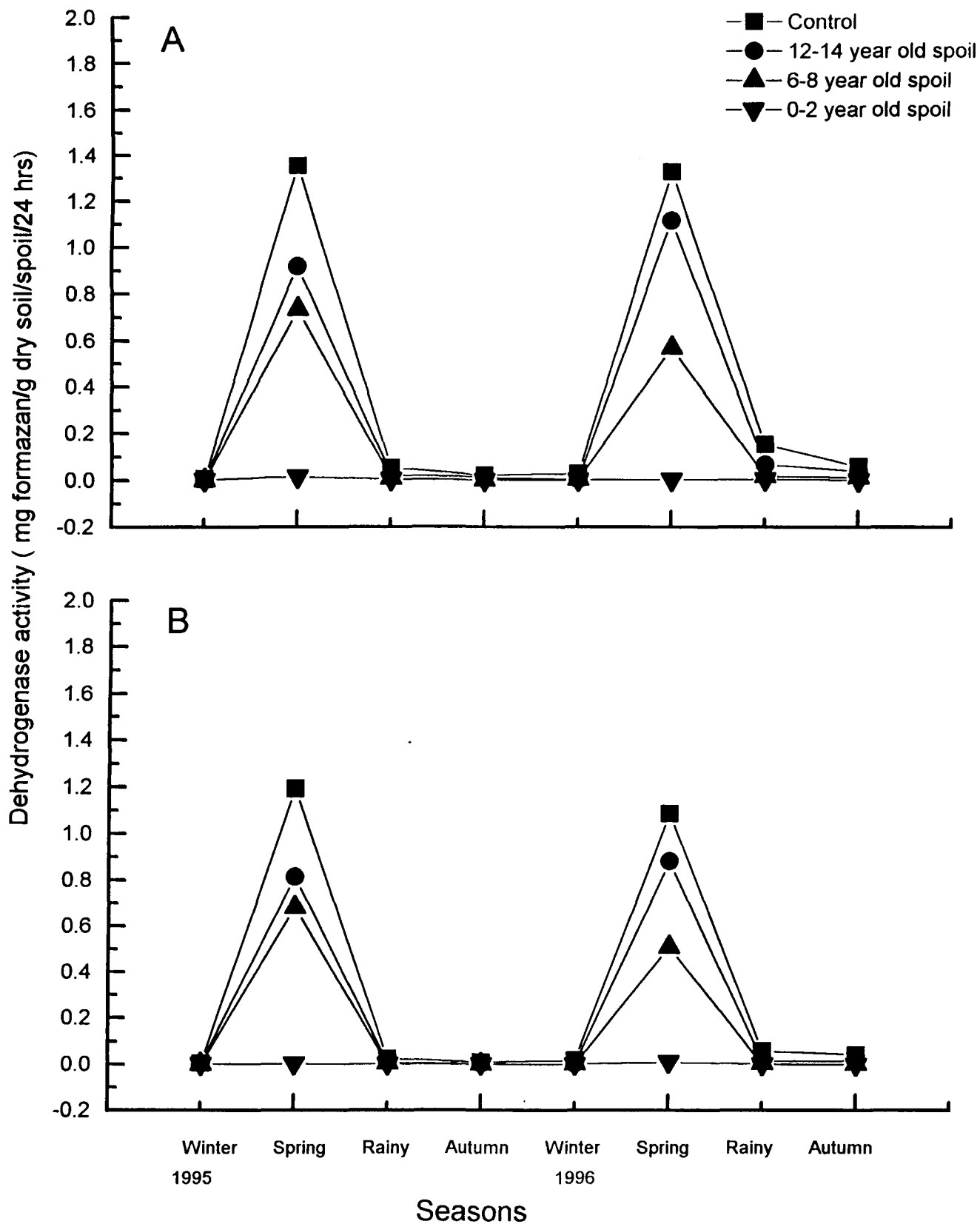


Fig.6.4. Seasonal variation in dehydrogenase activity in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean) .

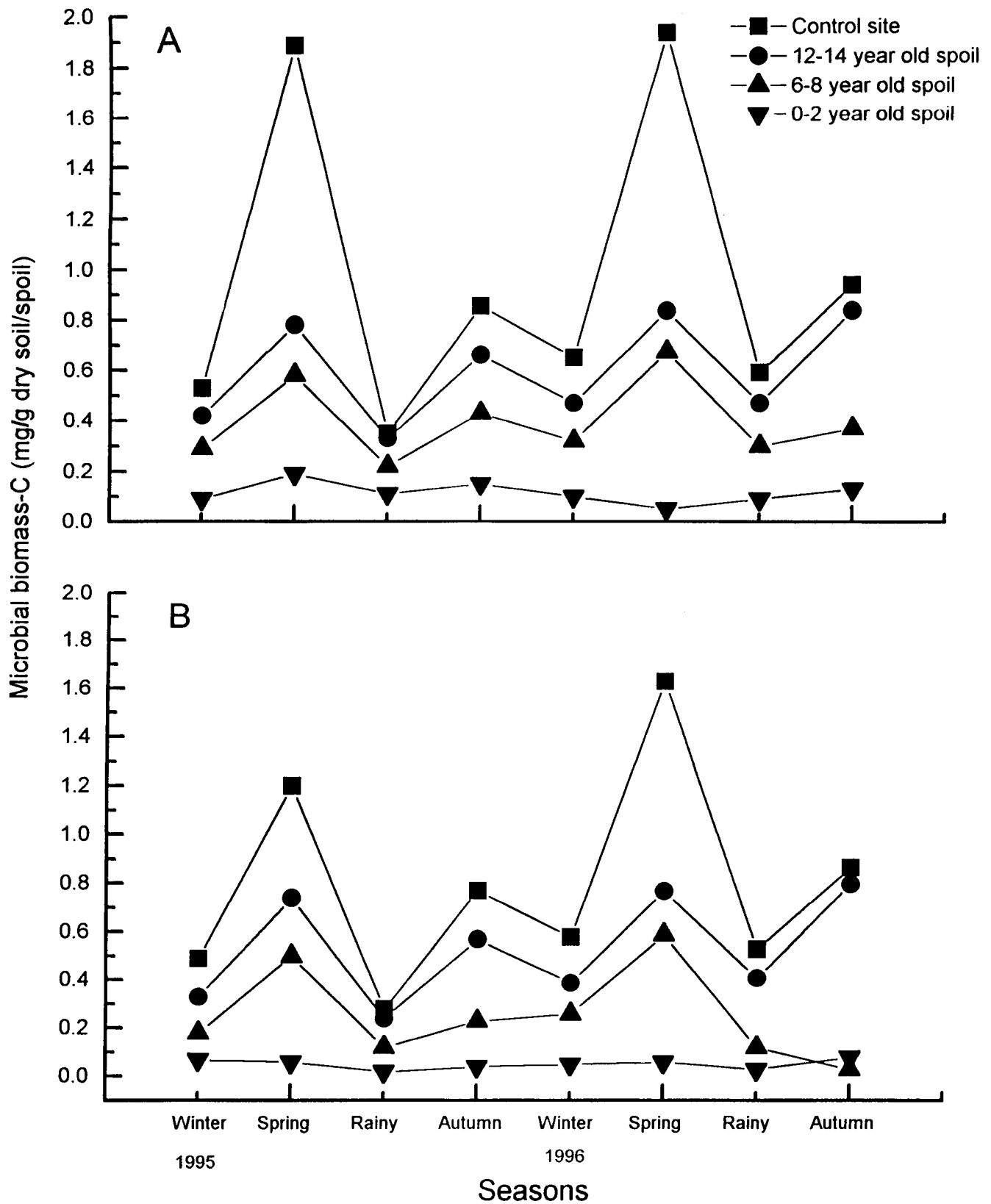


Fig.6.5. Seasonal variation in microbial biomass -C in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

Table 6.3. Biomass-C as percentage of organic-C in the mine spoils of different ages and the soils of the control site (\pm SEM).

Sites	Depth (cm)	Winter 1995	Spring	Rainy	Autumn	Winter 1996	Spring	Rainy	Autumn
Control	0-10	1.93 ± 0.32	7.71 ± 1.21	0.92 ± 0.05	3.63 ± 0.43	3.94 ± 1.10	6.55 ± 1.62	1.95 ± 0.07	3.41 ± 0.91
	10-20	2.30 ± 1.31	6.38 ± 1.01	1.05 ± 0.56	3.66 ± 1.16	17.06 ± 2.38	8.53 ± 1.76	2.72 ± 0.56	5.12 ± 0.28
12-14 year old spoil	0-10	2.58 ± 1.71	5.00 ± 0.76	1.63 ± 0.21	3.61 ± 1.78	2.99 ± 0.86	3.79 ± 1.09	2.04 ± 1.32	10.23 ± 1.87
	10-20	2.63 ± 0.26	6.31 ± 1.38	1.54 ± 0.06	3.35 ± 1.13	3.38 ± 0.71	4.90 ± 1.27	3.33 ± 1.03	10.96 ± 2.32
6-8 year old spoil	0-10	2.32 ± 0.27	5.58 ± 1.41	3.19 ± 1.01	6.72 ± 1.61	3.68 ± 0.93	5.23 ± 1.61	3.23 ± 1.43	3.98 ± 1.26
	10-20	1.48 ± 0.83	4.55 ± 1.08	2.22 ± 0.76	2.04 ± 0.71	5.53 ± 1.21	5.78 ± 1.43	2.50 ± 1.03	0.48 ± 0.05
0-2 year old spoil	0-10	5.63 ± 0.32	3.17 ± 0.81	2.12 ± 0.69	2.89 ± 1.05	2.86 ± 0.63	0.78 ± 0.43	6.43 ± 0.66	6.19 ± 1.39
	10-20	5.39 ± 0.92	1.20 ± 0.27	1.11 ± 0.39	2.22 ± 1.08	-	1.15 ± 0.09	1.76 ± 0.27	5.33 ± 1.53

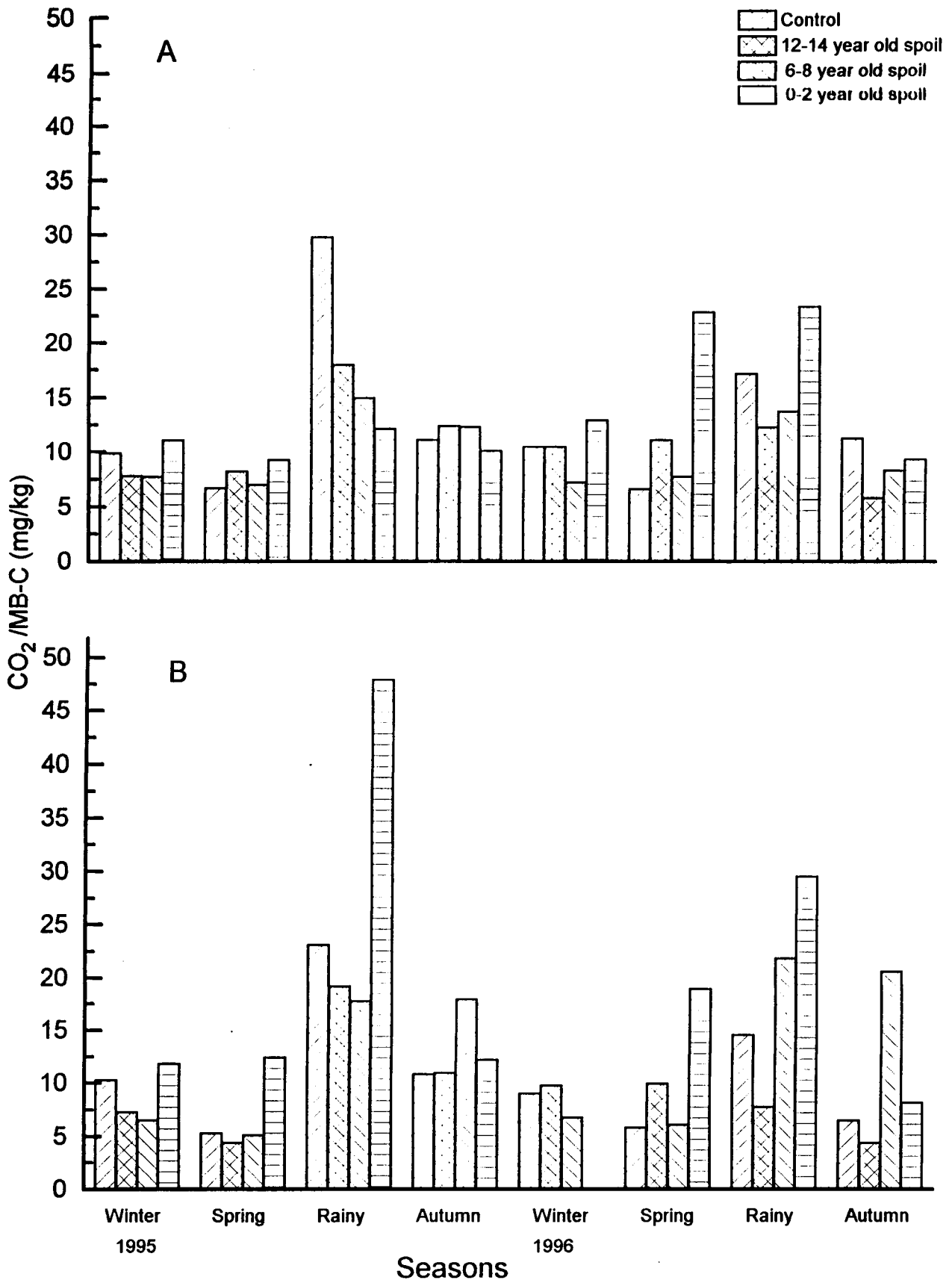


Fig.6.6. Biomass specific respiration in the coal mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

- Control site
- 12-14 year old spoil
- 6-8 year old spoil
- 0-2 year old spoil

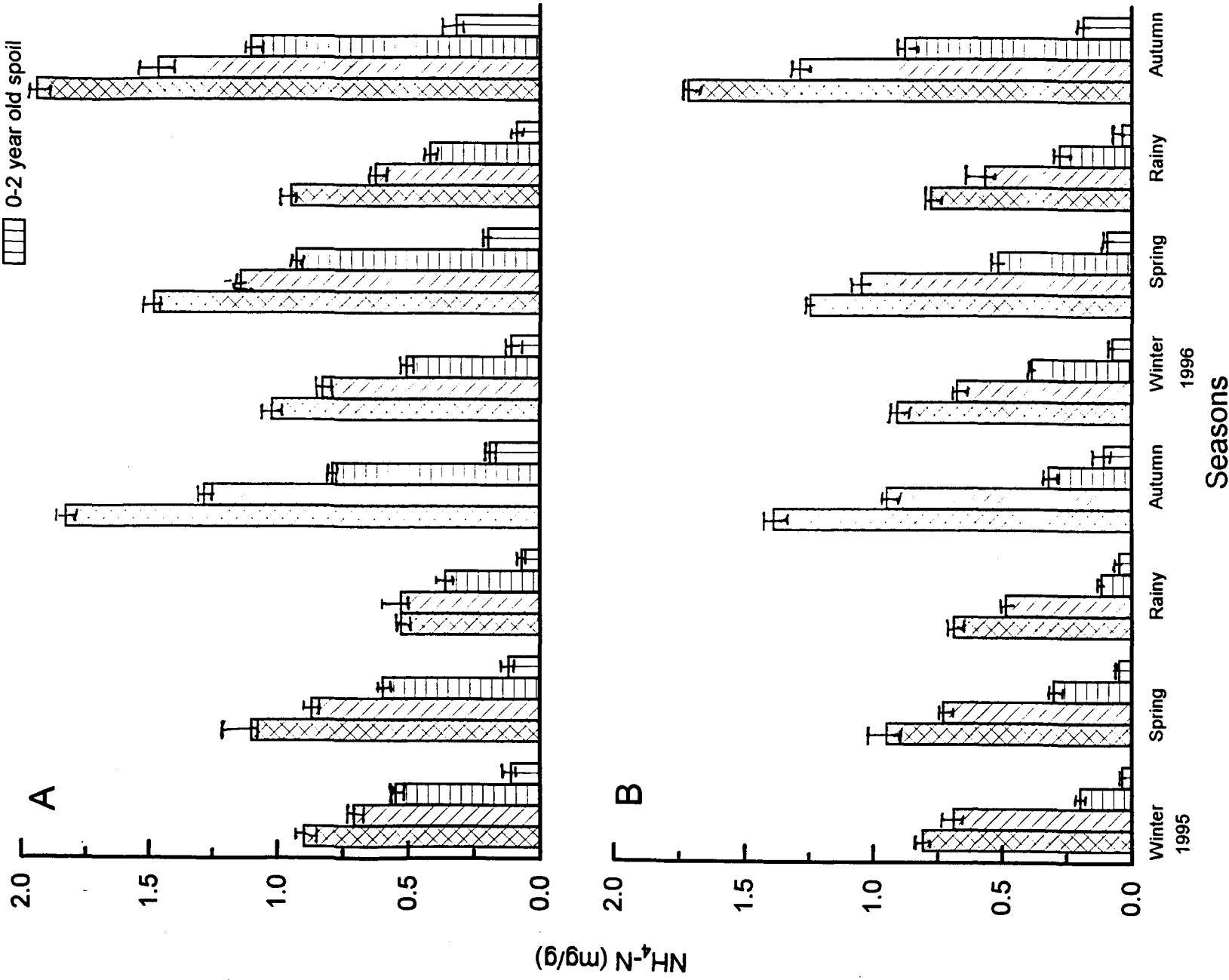


Fig.6.7a. Seasonal variation in NH_4-N in the coal mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

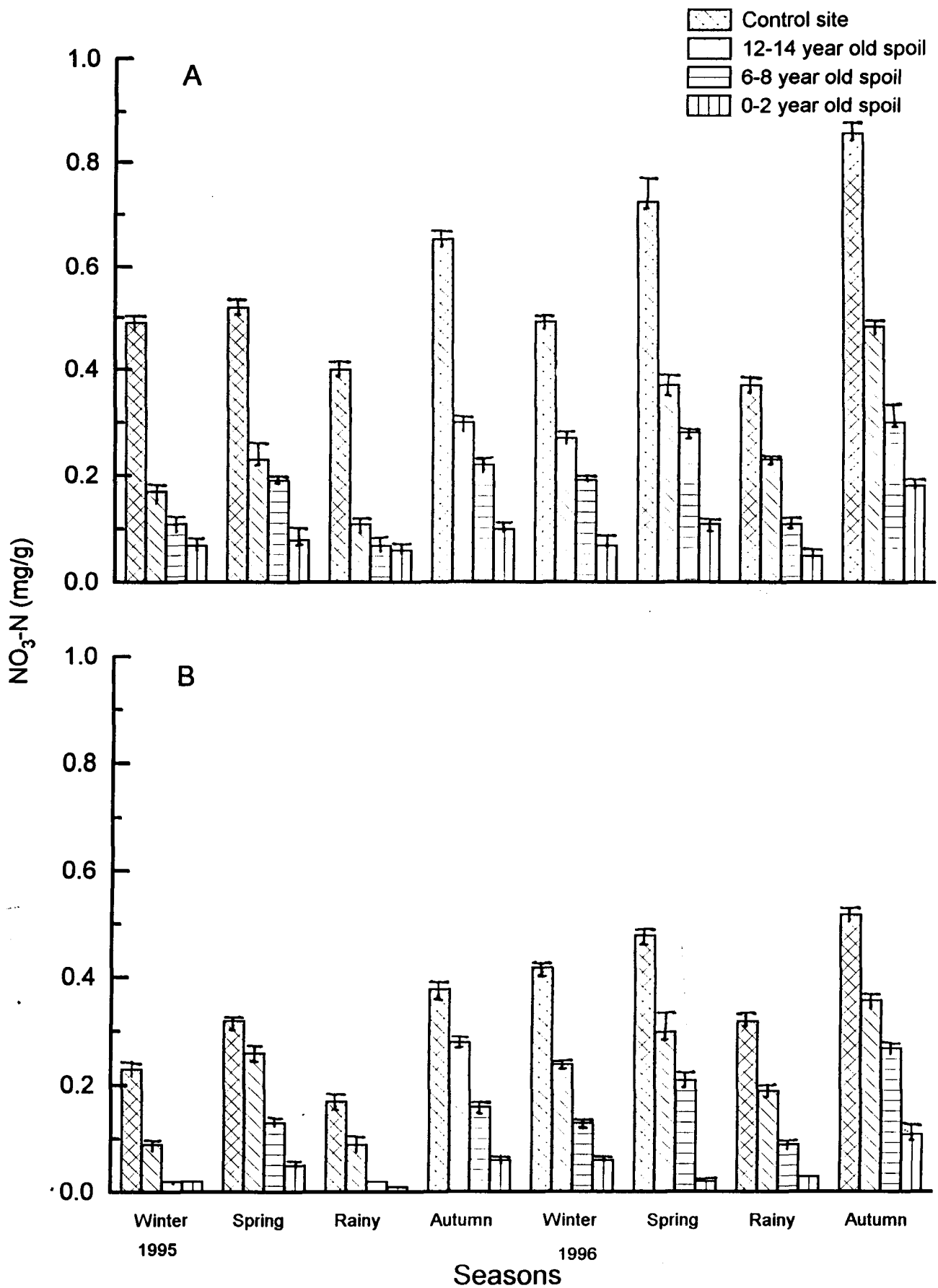


Fig.6.7b. Seasonal variation in NO₃-N in the coal mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (± standard error of mean).

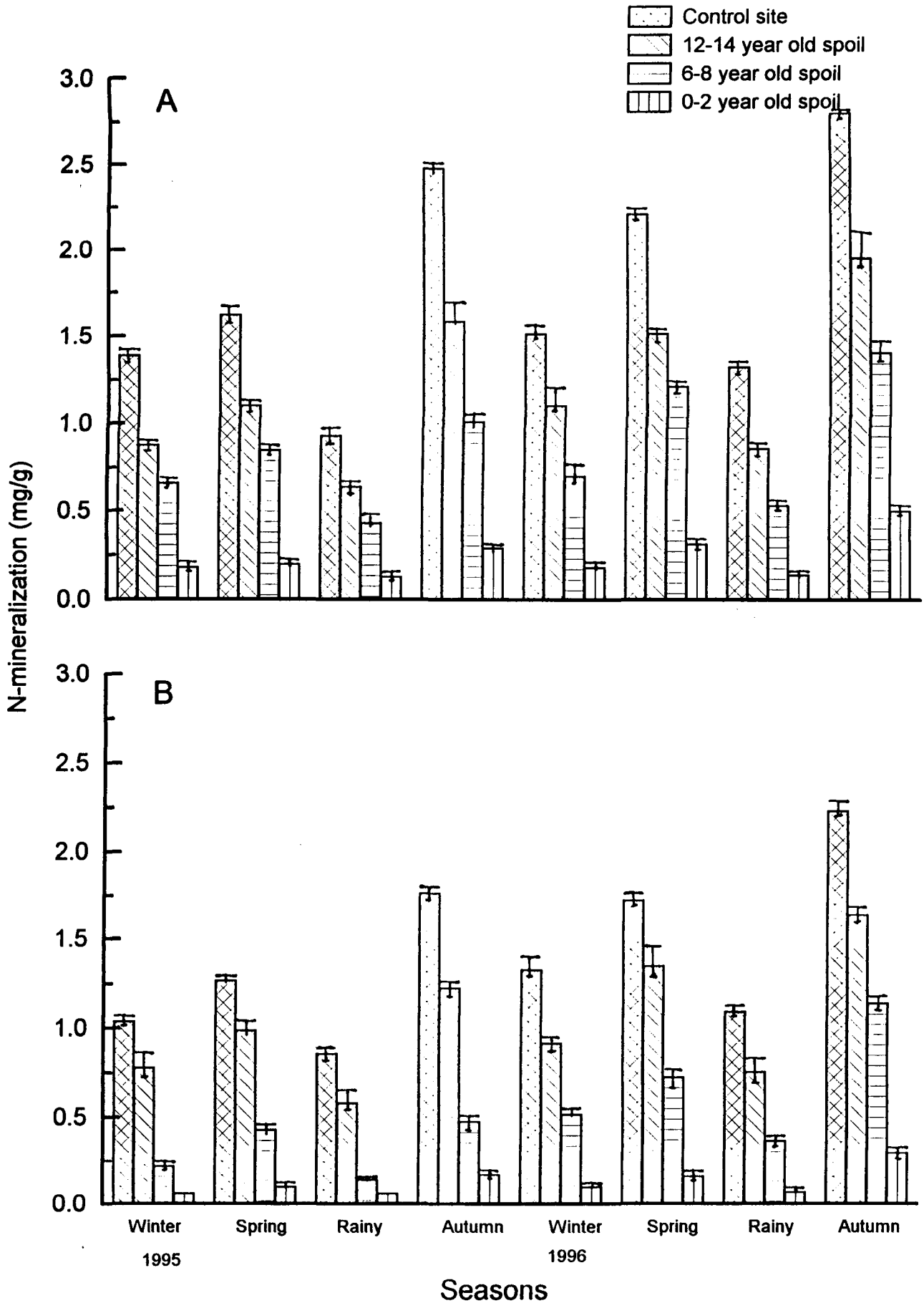


Fig. 6.7c. Seasonal variation in net N-mineralization in the coal mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

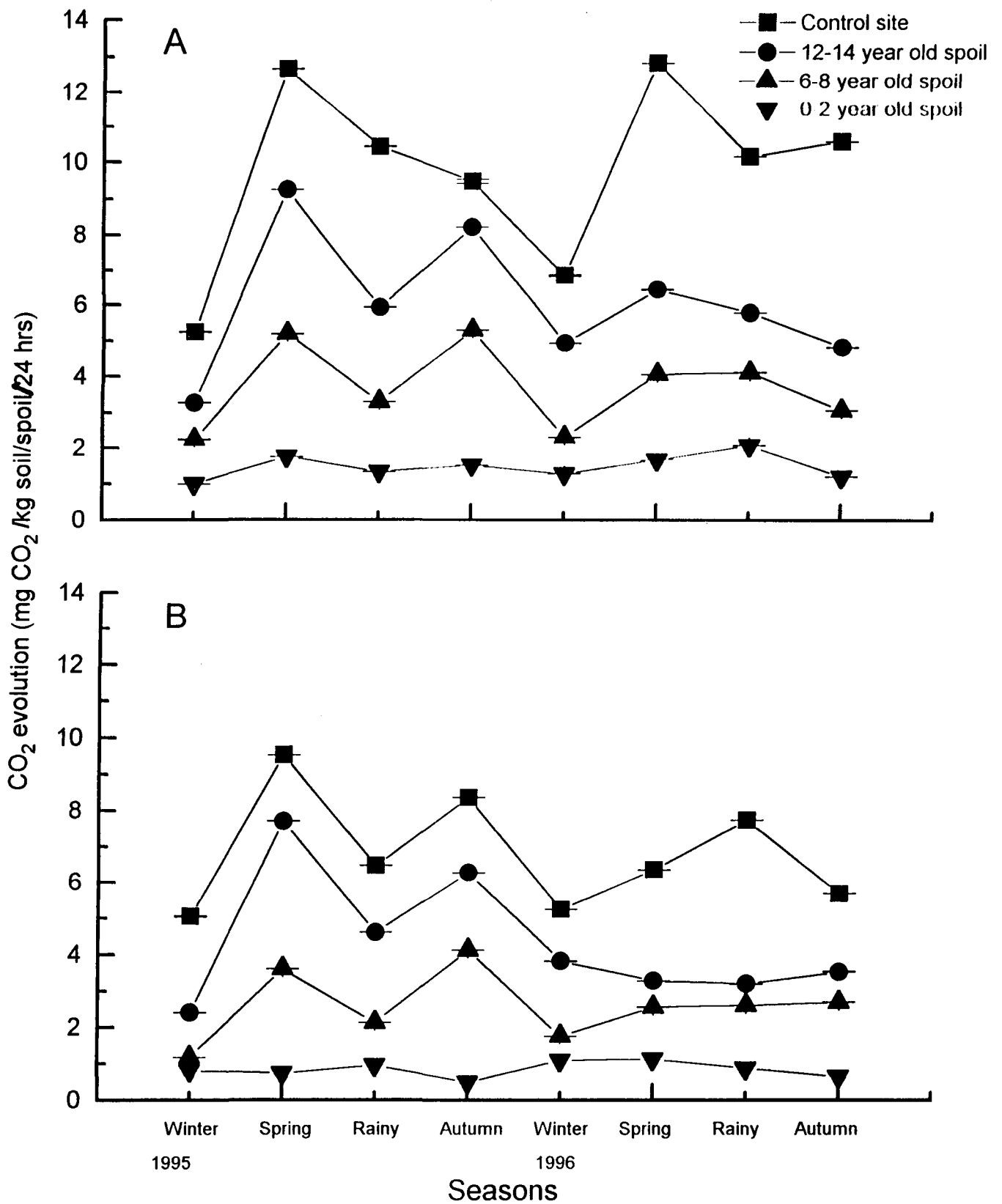


Fig.6.8. Seasonal variation in the rate of CO₂ evolution in the mine spoils of different ages and the soils of the control site at 0-10 cm (A) and 10-20 cm (B) soil depth (\pm standard error of mean).

CHAPTER VII

BIOMASS, PRIMARY PRODUCTIVITY AND NUTRIENT DYNAMICS IN COAL MINE SPOILS UNDERGOING NATURAL RECOVERY

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 the ecosystem. In the context of disturbed ecosystems, accumulation of biomass is very important and the success of reclamation of the disturbed ecosystems manifests itself in the site productivity (Hofmann *et al.* 1981) which has been aptly 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 workers (Johnson *et al.* 1982, Jha and Singh 1992). Direct relationship between the spoil age and productivity has also been reported by Schafer (1984) and Lyngdoh (1995).

Studies on biomass and productivity of coal mine spoil have been carried out by several workers (Carrel *et al.* 1979, Vail and Witter 1982, Johnson *et al.* 1982, Schafer 1984, Fyles *et al.* 1985, Sindelar 1979, Holecheck 1982, Fyles and McGill 1987). In India, such studies have been carried out by Jha (1989), Jha and Singh

(1990, 1992) in dry tropical condition and by Lyngdoh (1995), and Lyngdoh *et al.* (1992) on coal mine spoils in subtropical region.

A major problem for the establishment and maintenance of vegetation on mining wastes and derelict land soils is often a deficiency of nutrients in the parent material (Hutnik and Davis 1973, Goodman and Bray 1975, Bradshaw and Chadwick 1980). Of all the macro-nutrients, nitrogen, phosphorus and potassium are the most important ones as 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 also a vital 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 for photosynthesis and protein synthesis. It exists in soil solution equilibrium and as 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, soil moisture regime and on nutrient uptake capacity of the root system. They are partitioned into different compartments of vegetation. They are also retained in the dead organs of the plant and are finally returned to the soil as

litter and root detritus. Subsequent transformation leads to mineralization of the dead organic matter through which carbon is released to the atmosphere in the form of carbon dioxide and minerals are retained in the soil nutrient pool. Potassium is released primarily by physical weathering process called leaching i.e. removal from plants by the action of rain, dew, mist etc.

The accumulation of nutrients in different vegetation compartments and soil has been identified as an integral aspect of ecosystem development in both naturally colonised (Crocker and Major 1955, Dancer *et al.* 1977, Roberts *et al.* 1981, Marrs *et al.* 1981). and reclaimed environments (Bradshaw *et al.* 1975, Marrs and 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 and Chadwick 1980, Iverson and Wali 1992) and the development of ecosystems on these spoils is slowed down due to poor nutrient supply.

Cycling and compartmentation of nutrients have been studied in detail in long established stable ecosystems like forests (Vogt *et al.* 1986, Arunachalam 1996), heathlands (Gimingham 1972), grasslands (Bashbacher *et al.* 1988, Uma Shanker 1992) and secondary successional communities (Toky and Ramakrishnan 1983, Singh *et al.* 1992.).

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 developing ecosystems, 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 and hence, it deserves a systematic enquiry.

In this chapter, an attempt has been made to determine biomass, primary productivity, and nutrient (N, P & K) concentration as well as their accumulation in the coal mine spoils of varying ages and in the unmined control site. The changes in the compartmentation of these three essential nutrients in the vegetation of naturally recovering coal mine spoils during colonization and successional changes have also been assessed.

RESULTS

Aboveground biomass

The accumulation of biomass in the aboveground compartment (Table 7.1). It showed a wide seasonal variation on all the sites. The total biomass declined significantly ($P < 0.01$) with decrease in spoil age. *Arundinella khasiana* generally contributed maximum biomass in the control, 12-14 year as well as 6-8 year old spoils. The live green part contained greater amount of biomass compared to the standing dead in all the seasons. Maximum biomass was recorded during autumn in the unmined control, 12-14 year and 6-8 year old spoils. All the sites showed a

decrease in biomass from the first to the second year of the study. The total aboveground biomass increased from 11.71g/m² in the 6-8 year old spoil to 21.21g/m² in the unmined control site (Table 7.1).

Belowground biomass

Belowground biomass showed significant ($P < 0.05$) seasonal variation in all the cases. It showed a high value during autumn and a low value during either winter or spring irrespective of sites. The maximum accumulation of root mass (420.78 g/m²) was observed in the unmined control site during the autumn in the second year, whereas it was least (30.29 g m⁻²) in the 6-8 year old spoil during winter season of the first year of study. There was a significant ($P < 0.01$) and sharp drop in belowground biomass with decrease in spoil age (Table.7.2).

Litter

The accumulation of litter varied significantly between the seasons on all the sites (Table 7.3). Pine needle litter showed a much higher value in comparison to other fractions. The winter season favoured the accumulation of littermass in all the sites, whereas during autumn it was the least. Generally, the dicots had greater contribution towards accumulation of litter than the monocots in all the sites. There was an increase in litter accumulation from the first to the second sampling year. During most samplings, there was an increase in the miscellaneous litter fraction with the increase in the mine spoil age.

Primary Productivity

There was a significant ($P < 0.05$) variation in the aboveground production between the years. The live green contributed more than the dead fraction to the overall production (Table 7.4). There was an apparent decline in aboveground production from the first to the second year of study. The annual production showed a decreasing trend with decreasing spoil age.

The total belowground production showed significant ($P < 0.01$) annual and site-wise variation. This same trend was discernible in annual production notwithstanding the appreciable enhancement in root production from the first to the second year of study (Table 7.4).

The production of litter mass during the study period showed significant ($P < 0.05$) variation from site to site and year to year. The production of litter was maximum in the unmined control site whereas the minimum was recorded in the 6-8 year old spoil (Table 7.4). There was marked increase in litter production in all the sites from the first to the second year.

Nutrient Concentration

(A) Aboveground compartment

TKN

There was a significant ($P < 0.01$) seasonal variation in TKN concentration

between the sites with autumn recording the maximum in most categories of species and species groups analysed. In the live green biomass fraction, the monocots had the highest TKN concentration (25.9 mg/g) in the control site, while *A. compressus* recorded the lowest (0.20 mg/g) on the same site during winter in the second sampling year. As regards standing dead fraction, the monocots in the unmined control site had the maximum TKN (23.00 mg/g) during autumn and *A. khasiana* the minimum (0.75 mg/g) during the rainy season in the 12-14 year old spoil. There was a substantial increase in TKN concentration in both live as well as dead fractions from the first to the second sampling year (Table 7.6a).

Total- P concentration

The total-P concentration in the aboveground compartment of the vegetation also showed significant ($P < 0.01$) seasonal variation with autumn season registering higher values in comparison to other seasons on all the sites and for all the species. Monocots had the maximum concentration (4.09 mg/g) of total-P in the live biomass fraction on the unmined control site during autumn in the second year. The minimum P-concentration (0.02 mg/g) was also recorded in the live biomass of monocots during the first year of study (Table 7.6b). The dead fraction showed monocots as having the maximum (0.75 mg/g) concentration in the unmined control site and the minimum (0.01 mg/g) in the same site in case of ferns. Though minimal, the total -P concentration (both live green and standing dead) decreased with

decreasing spoil age irrespective of the seasons.

Exchangeable-K

The exchangeable-K concentration exhibited significant ($P < 0.05$) seasonal and site-wise variation. It was always higher in the live green fraction than in the dead fraction of the biomass. The concentration of exchangeable-K in different species and species groups exhibited minor variation (Table 7.6c). It showed an increase from the first to the second year of study.

Belowground compartment

TKN

A significant variation ($P < 0.05$) in the TKN concentration in the belowground compartment was observed between the seasons and sites. The highest TKN (22.8 mg/g) in root was recorded during the autumn season in the unmined control site and the lowest (10.4 mg/g) during winter in the 6-8 year old spoil (Table 7.5 A). There was a marginal drop in TKN level with decreasing age of the spoil. In the unmined control as well as the 6-8 year old spoil, there was an increase in nitrogen concentration from 1995 to 1996, whereas the 12-14 year old spoil did not show any such increase (Table 7.7 a).

Total-P

The concentration of total-P in roots showed a high of 0.17 mg/g in the unmined control site during the rainy season. As such the concentration of total-P

was very low in all the sites and seasons though there was a gradual reduction with decreasing spoil age (Table 7.7 b).

Exchangeable-K

Though the concentration of exchangeable-K was conspicuously low in all the sites and seasons, the maximum concentration was recorded in spring season (0.34 mg/g) in the unmined control site with rainy season recording the lowest (0.08 mg/g) in the 6-8 year old spoil. There was a perceptible enhancement in exchangeable- K concentration with increase in spoil age in the belowground segment of the vegetation. On the other hand, there was no increase in exchangeable-K from the first to the second year (Table 7.7c).

Litter

TKN

The highest concentration of TKN was found in the pine needles. It was followed by dicot, monocot and miscellaneous fractions in all the sites. The peak TKN concentration for all the litter fractions was achieved during autumn while the least concentration was recorded during spring in all the sites. The clear cut seasonal variation was marked by a distinct reduction in TKN concentration with decreasing spoil age (Table 7.8a).

Total-P

The highest value of total-P concentration in all types of litter was recorded

during autumn season. All the litter fractions viz., pine needles, dicot, monocot plants as well as the miscellaneous fractions showed a significant ($P < 0.01$) seasonal variation. The phosphorus concentration showed a marginal but a steady drop with decreasing spoil age (Table 7.8 b).

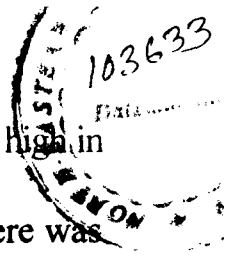
Exchangeable-K

The seasonal variation in the concentration of exchangeable-K showed a pattern similar to total-P in various litter fractions and was generally marked by a gradual increase from winter to autumn (Table 7.8c).

Nutrient Accumulation

The aboveground compartment showed significant ($P < 0.01$) site-wise variation in nutrient (N, P & K) input and accumulation (Table 7.5). The unmined control site had the highest input and accumulation of nutrients and the lowest in the 6-8 year old spoil. The livegreen fraction always recorded a higher value than the standing dead fraction in all the sites and seasons.

In the belowground compartment, the total N, P and K input was least in the 6-8 year old spoil, while highest values of nutrient input was recorded in the unmined control site. Accordingly, nutrient accumulation also declined from the control to the 6-8 year old spoil. Noticeably, there was a marked increase in N, P & K accumulation from 1995 to 1996 (Table 7.5).



The accumulation of nutrients in the litter segment showed a distinct high in the unmined control site with a reduction in the 12-14 year old spoil. There was significant increase in N,P & K accumulation of litter from 1995 to 1996. Among the nutrients, N had the maximum accumulation while K the minimum.

Discussion

The estimation of biomass is essential for determining the status and flux of biological materials in an ecosystem and for better understanding of the dynamics of ecosystem structure and function (Anderson,1977). There was significant seasonal variation in the accumulation of biomass in the aboveground compartment in all the sites and species with the unmined control site registering the maximum accumulation. There was a gradual but significant reduction in biomass accumulation with declining spoil age. This could be due to high plant density, species composition and growth behaviour of dominant species in the unmined control site. The increase in mean biomass accumulation in the aboveground part from 11.71g/m² in the 6-8 year old spoil to 21.21g/m² in the unmined site draws support from the findings of Pandey and Singh (1985) who also reported an increase in biomass over time. In the present study, however, the total biomass of even a 12-14 year old spoil was lower than that of the control site. Thus, it appears that it would take a longer time for these spoils to attain biomass comparable to the unmined control site. Incidentally, the coal mine spoils of more than 12-14 years age

were not available in the nearby areas and as such it was not possible to study the biomass of spoils older than 14 years.

The increase in biomass with spoil age has also been reported from other mine spoils like China-clay wastes (Marrs *et al.* 1980; and Roberts *et al.* 1981). Lyngdoh (1992) also reported similar results. Roberts *et al.* (1981) reported that even after seven years of abandonment, the biomass production on mine spoils was much lower than that on the unmined site. The peak biomass accumulation period was observed during autumn, whereas the winter recorded the least. Low aboveground biomass accumulation during winter on all sites can be ascribed to death and shattering of annual plants and tillers of perennial grasses following maturity. The maximum biomass accumulation during autumn could probably be due to the attainment of maturity by the plants and litter senescence. This is contrary to the findings of Lyngdoh (1995) who observed rainy and winter seasons with maximum and minimum biomass accumulation respectively. The conspicuous reduction in biomass accumulation from the first to the second sampling year was presumably due to grazing by animals and human disturbance in the study area. The monocots fraction recording a higher value than the dicots might be due to the nature of growth of the former who generally have prostrating stolon and a dense proliferation of fibrous roots. The total biomass values of aboveground vegetation growing on different ages of coal mine spoils were lower than the one reported by

Lyngdoh (1995) and Jha and Singh (1992). This could be due to variation in local edapho-climatic conditions of the study area of present study vis-a-vis that of other workers.

The accumulation of biomass in belowground compartment showed significant seasonal variation with autumn recording the highest biomass in the control site in both the sampling years. The seasonal biomass reached its peak (420.78 g/m²) in the unmined site during autumn in the second year i.e. 1996 and the least (30.29 g/m²) during winter in the 6-8 year old spoil in the first year i.e. 1995. There was a substantial increase in root biomass accumulation with increase in spoil age which conforms to the findings of Jha and Singh (1992) and Lyngdoh (1995). 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. Maximum biomass and nutrients in the underground parts could be a strategic way by which the community survives or lives on a harsh substrate. The overall annual increase in root production in all the sites might have been due to heavy rainfall and soil temperature in the study area. This agrees with the reports of Clark and Paul 1970; Reich *et al.* 1980; Andren and Paustian 1987. 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 than fertilized spoils (Holecheck 1982; Fyles *et al.*

1985; Fyles and McGill 1987). The higher belowground biomass in the 12-14 year old spoil observed in the present study indicated a stabilizing trend with increase in mine spoil age. Arunachalam (1995) also reported increased belowground biomass with age of a disturbed ecosystem.

The belowground to aboveground ratio (Bg/Ag) ranged from 3.21 in the 6-8 year old spoil to 9.59 in the in the unmined control site. High belowground to aboveground biomass ratio in nutrient poor habitats is a phenotypic response to reduced nutrient availability and increased root longevity as suggested by Chapin III (1980). Bernstein(1975) also believed it to be an adaptive strategy to increase the ratio of water absorbing to water transpiring organs.

There was a significant seasonal variation in the accumulation of litter. The litter fraction showed increased accumulation on an annual basis in all the sites from the first to the second year of study. The oldest mine spoil i.e. 12-14 year old spoil recorded a higher amount of litter biomass (53.31 g/m²) than the unmined site (18.01 g/m²). This probably points towards the level of site productivity with reference to herbaceous vegetation which was more in this site than the unmined site where due to greater canopy cover the same was much less (Joergensen *et al.* 1975).

Production in aboveground, belowground compartments and litter

The production of biomass in coal mine spoils is greatly determined by

factors like nutrient status, soil texture and water holding capacity of the spoils. Total primary productivity increased considerably with the age of the spoil. This is in agreement with Schafer (1984) who reported direct positive relationship between spoil age and productivity in Northern Great Plain. The aboveground primary productivity increased with increasing spoil age. This agrees with the findings of Lyngdoh (1995).

Belowground production increased with increasing age of the mine spoil. In the present study, the annual production in the belowground biomass was always higher than the aboveground compartment. This probably suggests that communities developing on mine spoils are allocating more resources to the belowground compartment. Higher rate of production in the unmined control site and 12-14 year old spoil can be attributed to greater density, better growth of the species growing on older site and more favourable physico-chemical and biological characteristics of soils of the sites (Chapter IV). This runs contrary to several reports where productivity has been reported to decrease as the community attains maturity (DePuit *et al.* 1978). This also indicates that the communities are still in seral stage and stability has not been achieved as yet. Increase in total biomass (aboveground and belowground) with spoil age, can also be due to increased water holding capacity and nutrient accumulation with the age of the spoils.

Similar to above and belowground productivity, litter production also showed

a marked increase with the increase in mine spoil age. This is contrary to the findings of Marrs *et al.* (1981) who reported a depletion of litter component with age in naturally colonised China-clay wastes. It appears that the disappearance of litter through decomposition and export is much slower here due to lower temperature condition and predominantly hilly topography of the study area. The values obtained in the present study for litter production are much lower than the ones reported by Arunachalam (1996) from disturbed forest regrowths of different ages.

Nutrient concentration

Nutrients are the most important plant resources that determine the structure of the plant communities and function of the ecosystems. Variations in nutrient concentrations between the different parts of the plant have been known for years (Chapin III, 1980), but few studies have examined these concentrations in ecological context. Nutrient concentration in different vegetation compartments is related to species composition of the community (Uma Shankar, 1991). There was significant seasonal impact on nitrogen concentration of the live biomass and necromass of the aboveground compartments. There was a steady increase in N-concentration from spring to autumn probably due to the initiation of increased metabolic activity of the plants during spring and growth of new shoots during this period.

Almost all the species fractions registered a high concentration of nitrogen in the live green fraction than the dead fraction in all the sites. The monocots always had higher concentration of nitrogen than other species and species groups especially the dicots.

The concentration of nitrogen in the dead fraction of the aboveground compartment was very low in both the unmined control site and the mine spoils. This indicates that there has been much withdrawal of nitrogen from the shoot following senescence (Morton, 1977; Uma Shankar, 1991; Boral, 1993). This also conforms with the findings of Woodmansee and Duncan (1980) in case of *Bromus mollis* and *Erodium* species. The findings of the present study also draws its support from Morton's (1977) observations who reported 75% withdrawal of nitrogen and phosphorus from the leaves of *Molinea caerulea*, a tussock forming grass before abscission.

The apparent reduction in nitrogen concentration during winter in the live biomass fraction could be related to low metabolic rate of the plants due to lowering of temperature (Fig.). Similar to nitrogen, the total-P concentration in the aboveground compartment though very low, showed marginal variation with monocot fraction registering a higher concentration of phosphorus in the live biomass segment over other species. The low concentration of phosphorus in the present study bears similarity with the reports of Iverson and Wali (1982a) who

observed P as limiting nutrient during the colonization and early succession processes for the surface-mined lands in North Dakota. Phosphorus was also found to be deficient in arid Western U.S. mine spoils (Bauer *et al.* 1977, Power *et al.* 1978a).

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 opening and closing of stomata. Hence its concentration is expected to be higher in the live shoot than in any other parts of the plants. The results also agrees with the findings of Uma Shankar (1991). The extremely low concentration of potassium in the dead fraction at all the sites could be attributed to withdrawal of potassium from the live shoots during senescence as well and leaching losses from the aerial parts of plant (Marton 1977, Uma Shankar 1991, Lyngdoh 1995). Potassium, being more mobile is readily leached from the leaves particularly those which are senescent or dead.

Similar to the concentration of N in the aboveground compartment, the belowground compartment also showed significant seasonal variation in N-concentration. Mining activity could have altered the flow of N-through a stable plant-microbial system (Reeder and Sabey 1987). Thus a greater seasonal variation

is expected in case of unstable ecosystems like coal mine spoils.

Very low concentration of phosphorus was noted in all the sites spread across the seasons in the belowground part of the vegetation. Wittwer *et al.* (1981) found N and P as limiting factors in the colonisation of south eastern Kentucky mine spoils. Low P- concentration probably contributed to the adverse plant growth in mine spoils as also suggested by Safaya and Wali (1979). Poor growth of plants and slow recovery of the mine spoils may be attributed to this cause.

In comparison to the P-concentration, K-concentration in belowground parts was extremely low as in the aboveground compartment as the area receives quite a high rainfall. The low level of K- in the root could be due to leaching taking place. The nitrogen concentration in litter increased with increased spoil age and it reached its peak in the unmined control site. This conforms to the N-concentration values from litter reported by Marrs *et al.* (1981) from naturally colonised China-clay wastes. The low concentration of nitrogen on the mine spoils as a whole could be the reason for low accumulation of biomass in the litter segment. It is possible that nitrogen is acting as a limiting factor in the vegetation establishment on the coal mine spoils.

The concentration of phosphorus was clearly at a very low level at all the sites irrespective of seasons. This was due to the chemical nature of the element and parent rock of the soil. Carlson *et al.* (1961) have suggested enhanced P-

concentration in several crops by returning topsoil or adding manure.

The acutely reduced level of K-concentration in litter could be related to its low biomass accumulation. This reduction might be also due to the incorporation of surface litter in to soil organic matter during ecosystem development. The concentration of litter potassium in the present study falls in line with the findings of Lyngdoh (1995).

The nutrient (N, P, K) accumulation in all the three segments showed a common trend with maximum accumulation in the unmined site and least in the 6-8 year old spoil during both the sampling years. Nutrient accumulation is thought to be directly related to biomass. It is, infact, a cumulative function of biomass and concentration. From the data, it can be inferred that the concentrations did not play much role instead it was plant biomass which played a deterministic role through high biomass accumulation. Among the two major vegetation compartments, maximum accumulation of N, P and K occurred in the belowground parts 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 the sites that were dominated by *Lupinus arborium* and on mature woodland sites.

Soil system is the largest storehouse of both nitrogen and phosphorus but it contains a relatively small amount of potassium compared to the vegetational compartment. Soil in any stable ecosystem generally contains more than 90% of the

total nutrients present in the ecosystem. But, in the present work, the nutrient distributional pattern demonstrated wide variation from the stable ecosystems indicating thereby the unstable and fragile nature of these mine spoils. All the sites inclusive of the control site are sandy in texture with more than 85% sand. The low content of potassium in the soil is due to its leaching down the deeper soil layers (Tukey 1970, Uma Shankar 1991, Lyngdoh 1995).

The present study has direct relevance to reclamation programmes. Nutrient compartmentation studies of these derelict spoils can predict the specific vegetation endpoint which nutrient concentrations need to reach. This information is desirable for any reclamation scheme becoming fruitful. Nutrient accumulation and compartmentalised stores characterise the development of mine spoils. The very high biomass and nutrient allocation to underground parts suggest that the mine spoils have been colonised by hardy plant species which are adapted to grow in disturbed ecosystems and have right strategy required for ecorestoration of these ecosystems.

Table 7.1. Seasonal variation in the accumulation of herbaceous biomass (g/m²) in the live green and standing compartments of the aboveground vegetation on the mine spoils of different ages and the control site.

Site/Species	LG/ SD	Winter 1995	Spring	Rainy	Autumn	Winter 1996	Spring	Rainy	Autumn
Control									
<i>Arundinella khasiana</i>	LG	3.29	5.02	9.90	10.33	3.00	4.75	3.60	8.24
	SD	2.02	3.82	7.29	4.98	2.24	3.20	4.60	7.08
<i>Borreria hispida</i>	LG	1.05	11.02	6.27	4.60	-	1.75	2.32	-
	SD	0.15	0.56	2.31	1.65	-	0.65	1.33	-
Other Monocots	LG	4.26	3.79	4.48	19.13	3.49	3.78	4.74	6.24
	SD	3.18	3.22	8.06	33.24	5.56	1.58	10.66	4.45
Other dicots	LG	0.95	1.39	5.21	13.24	0.18	4.71	0.55	3.27
	SD	0.39	1.27	1.68	4.65	0.78	2.67	0.45	1.05
Miscellaneous fraction	LG	1.10	1.93	1.92	3.65	1.27	4.75	1.63	0.87
	SD	0.77	2.67	0.45	2.21	1.98	1.02	0.88	-
Total	LG	10.65	23.15	27.78	50.95	7.94	19.74	12.84	16.62
	SD	6.51	11.54	19.79	46.73	10.56	9.12	17.92	12.58
12-14 year old spoil									
<i>Arundinella khasiana</i>	LG	2.40	3.68	5.31	6.99	2.02	1.33	3.68	6.10
	SD	1.89	2.15	2.87	5.60	1.50	1.25	1.98	0.33
<i>Borreria hispida</i>	LG	1.09	3.51	2.27	2.50	1.15	1.56	1.29	-
	SD	0.90	0.75	2.00	1.05	0.87	0.83	0.07	-
Other monocots	LG	3.83	5.05	4.72	4.59	2.60	1.66	3.22	6.26
	SD	2.79	4.43	2.72	3.30	1.42	1.94	2.89	4.05
Other dicots	LG	0.81	2.13	3.86	3.04	1.40	1.82	0.86	1.18
	SD	0.50	3.41	0.55	1.02	0.60	1.27	0.35	0.39
Miscellaneous fraction	LG	0.69	0.13	5.18	1.09	0.86	1.14	0.05	0.52
	SD	0.30	-	2.05	3.21	0.34	1.05	-	0.12
Total	LG	8.82	14.50	21.34	37.11	8.03	11.51	9.10	14.06
	SD	6.38	10.74	10.19	14.18	4.73	7.34	5.29	4.89
6-8 year old spoil									
<i>Arundinella khasiana</i>	LG	1.62	4.28	3.25	4.95	1.49	1.60	1.08	4.78
	SD	0.92	2.63	3.66	2.59	0.88	1.42	0.50	2.44
<i>Borreria hispida</i>	LG	0.92	1.78	0.39	3.50	0.78	1.18	0.12	-
	SD	0.36	0.52	0.20	2.78	0.41	0.96	0.10	-
Other monocots	LG	2.17	2.93	4.98	7.59	1.23	1.90	2.58	1.21
	SD	1.55	2.33	3.13	5.37	0.80	0.89	2.44	1.09
Other dicots	LG	0.53	2.61	3.08	2.86	0.62	1.20	1.30	0.67
	SD	0.18	1.96	2.87	2.20	0.25	0.60	4.51	0.50
Miscellaneous fraction	LG	0.41	2.18	4.72	7.76	0.57	1.00	-	1.87
	SD	0.22	0.32	3.31	6.30	0.21	0.20	-	0.70
Total	LG	5.65	18.78	16.42	26.66	4.69	10.88	5.08	5.53
	SD	3.23	11.76	13.17	19.24	2.55	5.07	7.19	2.83

LG: Live green, SD: Standing dead; - indicates absence

Table 7.2. Seasonal variation in the belowground (0-20 cm soil depth) biomass accumulation (g/m²) on the mine spoils of different ages and the control site (\pm SEM).

Site/Comp artments	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
	1995				1996			
Control	298.33 \pm 1.26	284.67 \pm 2.93	320.28 \pm 5.41	372.74 \pm 4.17	330.97 \pm 4.33	342.7 \pm 2.21	357.27 \pm 2.95	420.78 \pm 2.12
12- 14 year old spoil	121.08 \pm 3.60	163.86 \pm 1.17	156.99 \pm 1.92	192.03 \pm 1.83	140.46 \pm 1.36	174.8 \pm 2.34	184.97 \pm 1.83	224.2 \pm 1.01
6-8 year old spoil	30.29 \pm 1.06	59.72 \pm 1.24	69.12 \pm 0.83	77.29 \pm 1.03	88.25 \pm 1.57	46.45 \pm 1.29	52.45 \pm 1.49	92.83 \pm 2.82
0-2 year old spoil	-	-	-		-	-	-	-

" - " indicates absence.

Table 7.3. Seasonal variation in litter (g/m²) accumulation on the mine spoils of different ages and the control site (\pm SEM).

Site/ Compartments	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
	1995				1996			
Control								
Pine needle	41.41	52.90	69.44	59.70	30.22	33.96	80.75	42.33
	± 2.83	± 1.65	± 2.88	± 2.79	± 1.02	± 1.16	± 3.42	± 1.48
Dicots	5.49	1.91	4.53	4.84	2.01	4.65	3.95	11.10
	± 1.79	± 0.52	± 0.28	± 0.65	± 0.65	± 1.71	± 0.20	± 0.82
Monocots	4.29	3.74	3.61	12.28	3.24	9.39	10.10	33.33
	± 1.46	± 0.03	± 0.81	± 1.21	± 0.27	± 1.10	± 1.86	± 1.19
Miscellaneous fraction	5.76	3.32	2.15	5.66	5.10	5.21	5.06	15.00
	± 0.12	± 0.18	± 0.07	± 0.16	± 0.86	± 0.86	± 1.12	± 1.93
Total	56.95	61.87	79.73	82.48	40.57	53.21	99.86	101.76
12-14 year old spoil								
Pine needle	32.90	42.63	47.07	48.12	12.34	27.29	68.05	67.13
	± 2.01	± 1.01	± 2.94	± 2.87	± 0.92	± 1.13	± 2.67	± 3.81
Dicots	3.05	1.68	2.93	3.82	8.96	1.96	2.70	1.87
	± 0.29	± 0.22	± 0.06	± 0.11	± 1.70	± 0.27	± 0.70	± 0.36
Monocots	2.49	2.56	1.39	2.57	3.95	1.58	2.78	2.81
	± 0.16	± 0.13	± 0.18	± 0.09	± 0.18	± 0.13	± 0.18	± 0.42
Miscellaneous fraction	5.57	2.38	6.35	3.67	4.14	4.85	2.49	4.41
	± 1.15	± 0.26	± 0.61	± 0.31	± 0.26	± 0.70	± 0.17	± 0.16
Total	44.01	49.25	57.74	58.18	29.39	35.68	76.02	76.22
6-8 year old spoil								
Pine needle	4.31	8.87	18.36	17.51	2.55	8.29	20.49	29.06
	± 0.86	± 1.16	± 1.19	± 0.93	± 0.57	± 1.15	± 1.32	± 1.86
Dicots	2.60	1.27	2.16	3.22	1.46	2.25	1.89	3.31
	± 0.42	± 0.36	± 0.32	± 0.77	± 0.85	± 1.08	± 0.56	± 0.29
Monocots	1.18	1.29	2.42	2.32	1.93	5.47	3.76	2.43
	± 0.21	± 0.26	± 0.41	± 0.52	± 0.06	± 0.76	± 0.12	± 0.16
Miscellaneous fraction	5.29	5.20	2.41	3.83	3.35	2.72	8.78	3.13
	± 1.02	± 0.84	± 0.28	± 0.39	± 0.08	± 1.01	± 1.56	± 0.96
Total	13.38	16.63	25.35	26.88	9.29	18.73	34.92	37.93

Table 7.4 Primary productivity (Kg/ha) in the aboveground, belowground and litter compartments in the mine spoils of different ages and the controls site.

Site	Aboveground	Belowground	Litter
Control	381	890	435
12-14 year old spoil	242	808	305
6-8 year old spoil	237	646	211

Table 7.5 Nutrient accumulation (Kg/ha) in the coal mine spoils of different ages and the control site.

Compartments	Elements	Control site	12-14 year old spoil	6-8 year old spoil
Aboveground	N	5.03	2.20	1.79
	P	0.20	0.08	0.04
	K	0.79	0.05	0.03
Belowground	N	67.17	31.04	9.81
	P	0.33	0.20	0.02
	K	0.85	0.36	0.10
Litter	N	1.24	2.92	0.86
	P	0.12	0.37	0.08
	K	0.03	0.06	0.01

Table 7.6a. Seasonal variation in TKN concentration (mg/g) in the live and dead compartments of the aboveground vegetation in mine spoils of different ages and the control site.

Site/Species	LG/SD	1995				1996			
		Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
Control									
<i>Axonopus compressus</i>	LG	12.5	15.2	9.8	8.5	18.6	17.5	9.6	9.7
	SD	9.0	6.3	3.3	4.2	0.20	3.1	7.5	6.5
<i>Arundinella khasiana</i>	LG	18.7	16.5	14.9	16.2	16.5	20.7	18.1	15.7
	SD	8.8	9.3	5.3	9.2	10.7	20.0	19.9	14.0
Other monocots	LG	6.7	25.9	12.1	13.0	8.8	5.0	12.4	12.0
	SD	2.3	23.0	1.3	3.6	3.9	4.0	12.5	1.5
Other dicots	LG	5.2	20.4	12.5	10.5	5.9	23.5	13.7	13.5
	SD	3.1	12.9	2.5	6.5	6.3	3.7	12.5	10.5
<i>Borreria hispida</i>	LG	12.9	9.9	13.0	12.8	18.9	13.9	15.8	14.0
	SD	1.8	6.3	1.0	2.3	7.2	22.4	6.9	2.8
Ferns	LG	8.5	18.5	5.0	4.7	8.2	15.9	5.9	6.2
	SD	6.3	7.1	1.1	1.8	8.1	6.7	3.1	2.0
12-14 year old spoil									
<i>Axonopus compressus</i>	LG	6.2	13.5	10.2	8.5	6.9	17.9	9.6	11.0
	SD	3.5	7.9	2.3	7.2	6.4	12.3	13.3	5.5
<i>Arundinella khasiana</i>	LG	7.2	12.5	11.0	10.7	7.5	18.5	9.6	8.9
	SD	1.8	8.5	0.75	1.9	2.9	4.8	9.4	6.7
Other monocots	LG	4.5	10.8	9.7	11.2	15.5	21.6	18.8	12.2
	SD	2.9	12.0	1.0	2.8	14.3	15.7	3.6	2.6
Other dicots	LG	6.2	19.6	10.3	9.8	7.6	20.5	12.6	12.0
	SD	3.5	5.0	2.5	4.9	10.5	4.7	11.3	8.8
<i>Borreria hispida</i>	LG	6.6	8.4	10.2	3.9	7.6	7.7	10.8	10.0
	SD	5.2	1.6	2.2	1.0	6.3	5.1	4.2	3.2
Ferns	LG	11.2	17.1	6.8	6.4	16.4	14.0	16.4	15.3
	SD	5.0	3.0	1.8	2.2	6.7	6.8	4.8	3.6
6-8 year old spoil									
<i>Axonopus compressus</i>	LG	5.3	6.5	11.2	10.5	9.8	13.9	10.3	4.0
	SD	1.8	2.5	9.5	2.4	3.6	10.0	10.4	25.4
<i>Arundinella khasiana</i>	LG	5.8	11.1	8.9	9.2	8.2	19.6	14.8	14.4
	SD	3.2	2.5	5.8	3.3	7.7	11.2	11.4	11.1
Other monocots	LG	8.1	11.6	11.1	5.5	11.0	14.6	14.2	11.3
	SD	1.6	14.5	9.8	4.6	6.2	13.9	11.9	7.7
Other dicots	LG	6.7	8.9	3.0	8.2	3.0	19.5	3.8	3.4
	SD	3.6	2.9	1.6	2.9	1.5	18.6	2.9	2.2
<i>Borreria hispida</i>	LG	7.7	12.3	12.0	8.7	11.8	15.2	17.6	12.8
	SD	1.2	13.0	10.5	3.1	7.3	7.5	13.7	8.2
Ferns	LG	2.5	15.6	10.8	7.2	9.9	16.5	12.3	16.5
	SD	0.9	2.2	9.1	0.9	4.8	2.0	8.7	10.4

LG: Live green; SD: Standing dead

Table 7.6b. Seasonal variation in the total-P concentration (10^{-2} X mg/g) in the live and dead compartments of the aboveground vegetation on the mine spoils of different ages and the control site.

Site/Species	LG/SD	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
		1995				1996			
Control									
<i>Axonopus compressus</i>	LG	0.26	0.35	0.53	0.65	0.30	0.56	0.69	0.73
	SD	0.12	0.20	0.28	0.30	0.11	0.26	0.34	0.49
<i>Arundinella khasiana</i>	LG	0.43	0.52	0.69	0.84	0.55	0.61	0.78	0.89
	SD	0.21	0.28	0.31	0.52	0.25	0.28	0.35	0.41
Other monocots	LG	0.52	0.59	0.77	0.98	0.57	0.73	0.93	1.09
	SD	0.15	0.24	0.36	0.44	0.25	0.26	0.44	0.75
Other dicots	LG	0.20	0.27	0.38	0.43	0.29	0.32	0.46	0.59
	SD	0.02	0.03	0.02	0.10	0.02	0.06	0.09	0.10
<i>Borreria hispida</i>	LG	0.27	0.33	0.42	0.65	0.32	0.46	0.68	0.70
	SD	0.13	0.18	0.23	0.35	0.19	0.29	0.38	0.50
Ferns	LG	0.02	0.05	0.06	0.10	0.03	0.88	1.00	0.12
	SD	0.01	0.02	0.04	0.60	0.09	0.64	0.70	0.80
12-14 year old spoil									
<i>Axonopus compressus</i>	LG	0.14	0.28	0.48	0.52	0.21	0.38	0.40	0.55
	SD	0.10	0.18	0.23	0.20	0.08	0.19	0.29	0.26
<i>Arundinella khasiana</i>	LG	0.38	0.46	0.56	0.48	0.38	0.39	0.48	0.55
	SD	0.17	0.21	0.26	0.22	0.17	0.18	0.26	0.30
Other monocots	LG	0.41	0.49	0.69	0.57	0.44	0.47	0.64	0.79
	SD	0.13	0.18	0.33	0.21	0.22	0.26	0.36	0.28
Other dicots	LG	0.15	0.19	0.26	0.48	0.26	0.29	0.40	0.56
	SD	0.01	0.02	0.02	0.48	0.09	0.18	0.07	0.51
<i>Borreria hispida</i>	LG	0.21	0.26	0.33	0.38	0.23	0.27	0.45	0.40
	SD	0.09	0.11	0.17	0.11	0.15	0.11	0.27	0.18
Ferns	LG	0.02	0.09	0.45	0.10	0.31	0.52	0.92	0.12
	SD	0.02	0.04	0.03	0.02	0.07	0.28	0.35	0.72
6-8 year old spoil									
<i>Axonopus compressus</i>	LG	0.08	0.13	0.36	0.21	0.07	0.19	0.22	0.36
	SD	0.06	0.10	0.14	0.14	0.03	0.08	0.19	0.12
<i>Arundinella khasiana</i>	LG	0.08	0.08	0.24	0.40	0.22	0.23	0.33	0.44
	SD	0.02	0.03	0.11	0.16	0.08	0.10	0.16	0.28
Other monocots	LG	0.36	0.43	0.25	0.33	0.16	0.18	0.31	0.50
	SD	0.07	0.10	0.11	0.16	0.09	0.13	0.14	0.27
Other dicots	LG	0.18	0.22	0.11	0.33	0.09	0.11	0.18	0.26
	SD	0.05	0.09	0.01	0.05	0.01	0.02	0.03	0.23
<i>Borreria hispida</i>	LG	0.17	0.19	0.19	0.24	0.12	0.16	0.20	0.30
	SD	0.06	0.08	0.06	0.06	0.03	0.05	0.10	0.09
Ferns	LG	0.05	0.07	0.20	0.04	0.29	0.98	0.45	0.38
	SD	0.02	0.02	0.02	0.01	0.12	0.48	0.22	0.18

LG= Live green, SD= Standing dead.

Table 7.6c. Seasonal variation in exchangeable-K concentration ($10^{-3} \times \text{mg/g}$) in the live and dead compartments of the aboveground vegetation on the mine spoils of different ages and the control site.

Site/Species	LG/SD	1995				1996			
		Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
Control									
<i>Axonopus compressus</i>	LG	0.18	0.29	0.34	0.39	0.28	0.44	0.57	0.62
	SD	0.10	0.11	0.21	0.17	0.14	0.18	0.32	0.48
<i>Arundinella khasiana</i>	LG	0.29	0.37	0.36	0.44	0.43	0.51	0.56	0.60
	SD	0.18	0.17	0.19	0.25	0.23	0.20	0.28	0.52
Other monocots	LG	0.27	0.40	0.42	0.28	0.33	0.57	0.61	0.78
	SD	0.15	0.28	0.30	0.17	0.19	0.19	0.36	0.31
Other dicots	LG	0.13	0.17	0.28	0.33	0.21	0.32	0.39	0.49
	SD	0.09	0.20	0.17	0.24	0.14	0.22	0.27	0.27
<i>Borreria hispida</i>	LG	0.11	0.19	0.18	0.28	0.18	0.27	0.32	0.48
	SD	0.05	0.10	0.08	0.17	0.12	0.13	0.18	0.18
Ferns	LG	0.12	0.55	0.20	0.27	0.18	0.22	0.31	0.39
	SD	0.12	0.11	0.10	0.20	0.09	0.11	0.14	0.12
12-14 year old spoil									
<i>Axonopus compressus</i>	LG	0.16	0.18	0.28	0.23	0.20	0.32	0.43	0.57
	SD	0.09	0.10	0.20	0.18	0.11	0.21	0.32	0.32
<i>Arundinella khasiana</i>	LG	0.17	0.19	0.18	0.33	0.31	0.39	0.40	0.59
	SD	0.11	0.09	0.10	0.25	0.18	0.17	0.19	0.40
Other monocots	LG	0.20	0.21	0.36	0.20	0.27	0.47	0.50	0.42
	SD	0.10	0.13	0.19	0.09	0.19	0.10	0.16	0.20
Other dicots	LG	0.09	0.09	0.17	0.28	0.15	0.30	0.26	0.39
	SD	0.10	0.08	0.09	0.13	0.09	0.12	0.13	0.18
<i>Borreria hispida</i>	LG	0.07	0.12	0.12	0.15	0.12	0.18	0.28	0.31
	SD	0.02	0.08	0.06	0.10	0.07	0.09	0.18	0.14
Ferns	LG	0.40	0.25	0.14	0.19	0.30	0.14	0.13	0.25
	SD	0.13	0.12	0.08	0.06	0.15	0.05	0.07	0.12
6-8 year old spoil									
<i>Axonopus compressus</i>	LG	0.08	0.10	0.14	0.14	0.13	0.17	0.19	0.22
	SD	0.04	0.06	0.01	0.10	0.09	0.20	0.08	0.14
<i>Arundinella khasiana</i>	LG	0.11	0.08	0.12	0.20	0.18	0.25	0.23	0.30
	SD	0.07	0.07	0.08	0.16	0.10	0.13	0.19	0.17
Other monocots	LG	0.13	0.11	0.18	0.16	0.21	0.36	0.24	0.21
	SD	0.10	0.10	0.10	0.09	0.17	0.10	0.11	0.19
Other dicots	LG	0.10	0.02	0.08	0.13	0.10	0.14	0.15	0.19
	SD	0.06	0.04	0.04	0.11	0.10	0.06	0.07	0.11
<i>Borreria hispida</i>	LG	0.05	0.07	0.09	0.11	0.07	0.09	0.17	0.12
	SD	0.02	0.03	0.03	0.05	0.05	0.03	0.14	0.09
Ferns	LG	0.11	0.13	0.06	0.30	0.16	0.11	0.10	0.13
	SD	0.10	0.08	0.02	0.10	0.110	0.06	0.15	0.08

LG= Live green, SD= Standing dead

Table 7.7a. Seasonal variation in the TKN concentration (mg/g) in the belowground compartment of the vegetation on mine spoils of different ages and the control site (\pm S.E.M).

Site	Depth (cm)	1995				1996			
		Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
Control	0 - 20	20.6 \pm 0.033	16.3 \pm 0.003	18.9 \pm 0.003	22.5 \pm 0.003	21.8 \pm 0.003	13.1 \pm 0.003	21.6 \pm 0.003	22.8 \pm 0.003
12-14 year old spoil	0 - 20	18.2 \pm 0.003	14.4 \pm 0.003	19.1 \pm 0.003	21.8 \pm 0.003	19.1 \pm 0.003	12.9 \pm 0.003	20.6 \pm 0.003	20.1 \pm 0.003
6-8 year old spoil	0 - 20	10.4 \pm 0.003	10.6 \pm 0.003	13.4 \pm 0.003	20.8 \pm 0.003	18.2 \pm 0.003	12.6 \pm 0.003	16.3 \pm 0.003	19.3 \pm 0.003

Table 7.7b. Seasonal variation in the total-P concentration (10^{-2} X mg/g) in the belowground compartment of the vegetation on mine spoils of different ages and the control site (\pm S.E.M.).

Site	Depth (cm)	1995				1996			
		Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
Control	0 - 20	0.048 \pm 0.0003	0.052 \pm 0.0003	0.051 \pm 0.0003	0.15 \pm 0.004	0.14 \pm 0.004	0.024 \pm 0.0003	0.17 \pm 0.0003	0.15 \pm 0.004
12-14 year old spoil	0 - 20	0.032 \pm 0.0003	0.046 \pm 0.0003	0.04 \pm 0.0003	0.12 \pm 0.004	0.13 \pm 0.004	0.042 \pm 0.0003	0.38 \pm 0.004	0.14 \pm 0.004
6-8 year old spoil	0 - 20	0.018 \pm 0.0003	0.042 \pm 0.0003	0.024 \pm 0.0003	0.032 \pm 0.0003	0.078 \pm 0.0002	0.0042 \pm 0.0004	0.016 \pm 0.0002	0.012 \pm 0.0003

Table 7.7c. Seasonal variation in the exchangeable-K concentration (10^{-3} X mg/g) in the belowground compartment of the vegetation on mine spoils of different ages and the control site (\pm S.E.M.).

Site	Depth (cm)	1995				1996			
		Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
Control	0 - 20	0.29 \pm 0.0003	0.30 \pm 0.0003	0.23 \pm 0.0003	0.20 \pm 0.0003	0.24 \pm 0.0003	0.34 \pm 0.0003	0.20 \pm 0.0003	0.23 \pm 0.0003
12-14 year old spoil	0 - 20	0.19 \pm 0.0003	0.29 \pm 0.0003	0.21 \pm 0.0003	0.19 \pm 0.0003	0.19 \pm 0.0003	0.29 \pm 0.0003	0.18 \pm 0.0003	0.16 \pm 0.0003
6-8 year old spoil	0 - 20	0.13 \pm 0.0003	0.25 \pm 0.0003	0.19 \pm 0.0003	0.15 \pm 0.0003	0.14 \pm 0.0003	0.13 \pm 0.0003	0.08 \pm 0.0003	0.12 \pm 0.0003

Table 7.8a. Seasonal variation in the TKN concentration (mg/g) in the litter compartment of the mine spoils of different ages and the control site (\pm S.E.M.).

Site/ compartments	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
	1995				1996			
Control								
Pine needles	6.20 \pm 0.03	4.8 \pm 0.03	7.70 \pm 0.03	8.9 \pm 0.03	6.8 \pm 0.02	5.2 \pm 0.03	8.1 \pm 0.08	9.8 \pm 0.06
Dicots	4.1 \pm 0.03	4.8 \pm 0.01	8.9 \pm 0.02	7.8 \pm 0.03	4.6 \pm 0.01	6.0 \pm 0.02	8.7 \pm 0.02	8.2 \pm 0.03
Monocots	3.2 \pm 0.03	2.9 \pm 0.05	8.6 \pm 0.04	8.6 \pm 0.03	3.7 \pm 0.03	3.9 \pm 0.08	8.5 \pm 0.03	9.0 \pm 0.03
Miscella- neous fraction	2.7 \pm 0.07	5.8 \pm 0.01	9.2 \pm 0.06	9.8 \pm 0.06	4.7 \pm 0.08	6.4 \pm 0.03	9.5 \pm 0.001	12.5 \pm 0.06
Total	16.1	18.3	34.4	35.1	19.8	21.5	34.8	39.5
12-14 year old spoil								
Pine needles	6.0 \pm 0.02	4.1 \pm 0.01	7.5 \pm 0.02	7.8 \pm 0.03	6.4 \pm 0.16	4.8 \pm 0.03	8.3 \pm 0.03	8.9 \pm 0.01
Dicots	4.5 \pm 0.09	3.4 \pm 0.025	6.2 \pm 0.01	7.5 \pm 0.01	6.4 \pm 0.01	3.8 \pm 0.03	8.2 \pm 0.03	8.5 \pm 0.03
Monocots	2.2 \pm 0.03	3.7 \pm 0.05	5.8 \pm 0.01	7.1 \pm 0.01	4.7 \pm 0.01	3.2 \pm 0.03	7.8 \pm 0.07	8.0 \pm 0.01
Miscella- neous fraction	0.9 \pm 0.07	3.5 \pm 0.01	8.0 \pm 0.03	11.0 \pm 0.03	4.7 \pm 0.12	4.5 \pm 0.01	9.1 \pm 0.03	12.9 \pm 0.03
Total	13.6	14.7	27.5	33.4	22.5	16.3	33.4	38.3
6-8 year old spoil.								
Pine needles	4.2 \pm 0.01	2.9 \pm 0.07	5.5 \pm 0.01	6.6 \pm 0.06	4.9 \pm 0.03	3.7 \pm 0.06	6.5 \pm 0.02	7.8 \pm 0.05
Dicots	1.8 \pm 0.007	2.1 \pm 0.01	4.3 \pm 0.01	5.8 \pm 0.01	7.8 \pm 0.04	3.1 \pm 0.03	6.2 \pm 0.02	6.9 \pm 0.01
Monocots	2.2 \pm 0.006	1.9 \pm 0.03	3.9 \pm 0.02	5.2 \pm 0.01	4.1 \pm 0.03	2.9 \pm 0.02	5.4 \pm 0.02	6.0 \pm 0.01
Miscella- neous fraction	3.0 \pm 0.01	2.5 \pm 0.01	7.5 \pm 0.02	7.5 \pm 0.03	4.4 \pm 0.04	5.3 \pm 0.07	7.8 \pm 0.03	8.4 \pm 0.07
Total	11.2	9.4	21.5	25.1	21.2	15.0	25.9	29.1

Table 7.8b. Seasonal variation in the total-P concentration (10^{-2} X mg/g) in the litter compartment of the mine spoils of different ages and the control site.

Site/ Compartment	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
	1995				1996			
Control								
Pine needle	0.58	0.59	0.66	0.79	0.66	0.78	0.89	0.99
Dicots	0.39	0.47	0.72	0.75	0.47	0.27	0.62	0.78
Monocots	0.28	0.30	0.78	0.82	0.37	0.40	0.99	0.64
Miscellaneous fraction	0.22	0.38	0.82	0.93	0.28	0.55	2.05	1.25
Total	1.47	1.74	2.98	3.29	1.78	2.00	4.55	3.66
12-14 year old spoil								
Pine needle	0.55	0.56	0.70	0.74	0.63	0.63	0.79	0.73
Dicots	0.48	0.53	0.59	0.69	0.51	0.64	0.55	0.56
Monocots	0.42	0.46	0.51	0.64	0.47	0.32	0.64	0.58
Miscellaneous fraction	1.89	0.38	0.82	1.20	2.47	0.48	1.83	2.19
Total	3.34	1.93	2.62	3.27	4.08	2.07	3.81	4.06
6-8 year old spoil								
Pine needle	0.40	0.39	0.49	0.62	0.55	0.56	0.63	0.69
Dicots	0.25	0.33	0.41	0.56	0.38	0.48	0.52	0.33
Monocots	0.20	0.27	0.38	0.48	0.27	0.31	0.47	0.29
Miscellaneous fraction	0.19	0.24	0.59	0.68	0.45	0.19	1.42	0.78
Total	1.04	1.23	1.87	2.34	1.65	1.54	3.04	2.09

Table 7.8c. Seasonal variation in exchangeable-K concentration ($10^{-3} \times \text{mg/g}$) in the litter compartment of the mine spoils of different ages and the control site.

Site/Compartment	Winter	Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn
	1995				1996			
Control								
Pine needle	0.05	0.07	0.08	0.09	0.08	0.10	0.11	0.14
Dicots	0.01	0.07	0.06	0.04	0.02	0.07	0.08	0.06
Monocots	0.01	0.03	0.04	0.02	0.04	0.04	0.03	0.04
Miscellaneous fraction	0.11	0.42	0.56	0.68	0.23	0.50	0.62	0.86
Total	0.18	0.59	0.74	0.83	0.37	0.71	0.84	1.10
12-14 year old spoil								
Pine needle	0.05	0.07	0.06	0.07	0.06	0.09	0.09	0.12
Dicots	0.01	0.05	0.08	0.03	0.03	0.06	0.05	0.06
Monocots	0.01	0.02	0.03	0.02	0.03	0.03	0.04	0.03
Miscellaneous fraction	0.09	0.33	0.50	0.42	0.15	0.36	0.44	0.56
Total	0.16	0.47	0.67	0.54	0.27	0.56	0.62	0.77
6-8 year old spoil								
Pine needle	0.02	0.08	0.05	0.06	0.08	0.04	0.05	0.09
Dicots	0.01	0.03	0.03	0.02	0.01	0.04	0.04	0.04
Monocots	0.01	0.01	0.02	0.01	0.02	0.02	0.03	0.02
Miscellaneous fraction	0.07	0.12	0.21	0.28	0.11	0.19	0.28	0.34
Total	0.10	0.22	0.31	0.37	0.22	0.39	0.40	0.49

Table 7.9. Mean nutrient concentration (mg/g) in the aboveground (live and dead), belowground and litter components in the mine spoils of different ages and the control site (\pm SEM).

Nutrients	Compartments	Live green/Standing dead	Control site	12-14 year old spoil	6-8 year old spoil	0-2 year old spoil
Nitrogen	Aboveground	Live green	12.29 \pm 0.98	11.34 \pm 1.16	10.35 \pm 1.10	-
		Standing dead	7.36 \pm 1.12	5.57 \pm 0.85	6.91 \pm 0.20	-
	Belowground		19.70 \pm 1.21	18.30 \pm 1.09	15.20 \pm 1.42	-
	Litter		6.87 \pm 0.83	6.23 \pm 0.85	4.99 \pm 0.67	-
Phosphorus (10^{-2})	Aboveground	Live green	0.42 \pm 0.05	0.33 \pm 0.03	0.20 \pm 0.03	-
		Standing dead	0.24 \pm 0.04	0.17 \pm 0.03	0.80 \pm 0.02	-
	Belowground		0.10 \pm 0.002	0.12 \pm 0.004	0.03 \pm 0.001	-
	Litter		0.67 \pm 0.12	0.79 \pm 0.21	0.46 \pm 0.06	-
Potassium (10^{-3})	Aboveground	Live green	0.35 \pm 0.04	0.26 \pm 0.03	0.15 \pm 0.02	-
		Standing dead	0.20 \pm 0.002	0.14 \pm 0.002	0.09 \pm 0.001	-
	Belowground		0.25 \pm 0.02	0.21 \pm 0.02	0.15 \pm 0.02	-
	Litter		0.17 \pm 0.11	0.13 \pm 0.08	0.08 \pm 0.002	-

CHAPTER - VIII

GROWTH OF A FEW SELECTED PLANT SPECIES ON MINE SPOILS AFTER CHEMICAL AMENDMENTS

Lands disturbed by mining activity become physically, nutritionally and microbiologically impoverished presenting a very rigorous condition for plant and microbial growth (Jha and Singh, 1993a). Coal mine spoils are no exception. The natural process of ecosystem redevelopment including accumulation of organic matter and nutrients in these derelict habitats is a slow and stochastic process (Bradshaw, 1983; Srivastava *et al.* 1989 and Jha and Singh, 1992). Rehabilitation procedures include pre-mining soil and overburden laboratory analysis, removing and stockpiling of suitable soil materials, reshaping of soil, replacing stockpiled soil material, fertilizing, mulching and seeding or planting appropriate mixture of plant species (Ries *et al.* 1977; Power, 1978) and the use of pulverised fuel ash as a substitute for topsoil etc. Such measures are aimed at restoring the degraded land to their original or fully functional state. The growth of several legumes and grass species help in nutrient build up and amelioration of soil structure by impregnating the parent materials with organic materials and providing substrate for microbial growth (Powell *et al.* 1983; Barnhisel *et al.* 1985).

Suitability of plant species to a particular environmental condition can be determined by analysing their growth and resource allocation pattern. The

importance of studies on resource allocation in the identification of distinct ecological strategies of the species and population, has been emphasised by Harper and Ogden (1970), Tripathi and Harper (1973), Trivedi and Tripathi (1982a) and several other researchers. Most studies on resource allocation in plants are concerned with biomass allocation exclusively, although in many situations, the 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 and Vera, 1977). Several workers have pointed out that mineral elements and biomass are frequently not allocated similarly (Abrahamson and Caswell, 1982) and it has been found that nutrient concentration varies greatly between plant organs and at different growth stages.

The field observations have revealed that *Arundinella khasiana* (Poaceae), *Borreria hispida* (Rubiaceae) and *Axonopus compressus* (Poaceae) can grow very well on the coal mine spoils. The leguminous species *Trifolium repens* (Fabaceae) though not recorded on either the control site or the mine spoils grows rather relatively well in the coal mine area. The over-riding importance of *Trifolium repens* in nitrogen enrichment of drastically disturbed ecosystems such as this need hardly be emphasised as evidenced by the wealth of information available on it the world over. It is probable that *T.repens* has not had the chance of reaching the

spoils. Once it arrives there, it might grow successfully. Hence an experiment was designed to study the growth response and resource allocation of the above - mentioned three species on coal mine spoils of 0-2 year and 6-8 year age in the green house condition with lime, nitrogen and potassium amendments.

It maybe pointed out that the information generated on this aspect may have long term implications for any future restoration endeavour aimed at revegetating the mine spoils using these plant species.

MATERIALS AND METHODS

In March, 1997, soil samples were collected from the upper 20cm layer of 10 (ten) 50 x50 cm quadrat from the mine spoils of 0-2 and 6-8 years of age from Bapung in the Jaintia Hills district of Meghalaya. Soil samples from the given site were bulked to make composite sample and these were then brought to the laboratory. The soil samples were sieved with a .2mm mesh sieve. The soil moisture content was determined for each sample and raised to an uniform level. Polybags measuring 20.5 cm in length and 15.5 cm in diameter which were used in place of earthen pots were filled with 500 g of soil for growing the plants. The polybags were provided with an outlet for water flow at the bottom having a cotton plug for preventing microbial infection to the plant. The experimental design comprised 2 soil types x 4 treatments (3chemical amendments+ control) x 3species x 3harvests x 3replicates thus involving a total of 216 plants. For this purpose, three plant

species were chosen; the first two being dicot species, viz., *Trifolium repens* and *Borreria hispida*, and the third species being *Arundinella khasiana*, a member of the monocot group. Seedlings of 3-leaf stages of these species which had just started sprouting were chosen for transportation in the polybags. The mean dry weight of the seedlings was 50mg for *T. repens*, 63 mg for *A. khasiana* and 48 mg for *B. hispida*. A constant density of 3 plants per polybag was maintained for each plant species. Planting of seedlings was done on the 4th April, 1997. The polypacks were completely randomised and kept in a polythene roofed net house. Soils from both the spoils were subjected to different chemical amendments to study the response of plants to such treatments and the plausible role played by these chemicals in the restoration of such degraded ecosystems into productive sites which may facilitate vegetation development. The chemical amendments chosen for this purpose included (i) lime i.e. $\text{Ca}(\text{OH})_2$, (ii) murate of potash i.e. KCl , (iii) diammonium phosphate (DAP) i.e. $(\text{NH}_4)_2\text{HPO}_4$ to serve as the source of calcium, potassium and nitrogen respectively. 25ml of 1mM solution of each amendment was applied to each polybags earmarked for chemical amendments. Deionised water was sprinkled on plants at regular interval.

Harvesting was done at 45 days interval corresponding to 45, 90 and 135 days after planting i.e. on 19 May, 4 July and 19 August. At each harvest, root length, shoot length, number of leaves, leaf area, leaf weight and biomass of each

component plant part was determined for each species. For determination of root biomass, roots were thoroughly washed to remove adhering soil particles and oven-dried to constant weight at 80°C and weighed. All the plant parts were later analysed for their N concentration.

Total Kjeldahl nitrogen (TKN) of each component part of plants grown in soils subjected to different chemical amendments was determined by micro-kjeldahl semi-distillation method. Total nitrogen concentration was used in calculating nitrogen accumulation in these plants. Analysis of nitrogen was performed in triplicates and the values were expressed on dry weight basis.

Description of 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 found to be primary colonisers during mine spoil reclamation. *Trifolium repens* has been selected for the present study because it is the only legume which though not found on the mine spoils is a dominant species in the grassland of Bapung. Besides, it assumes added importance because of its abundant nodules through which it can fix nitrogen which is so vital for plants growing in nutrient-poor systems. *Arundinella khasiana*, a dominant grass, and *Borreria hispida*, a dicot plant which occur commonly in grassland, forest, roadside

and mine spoil vegetation. *A. khasiana* has abundant fibrous roots which can help in binding the unstable soil of the mine spoils. *B. hispida* is a hardy plant which grows quite well on mine spoils and their vicinity.

***Trifolium repens* Linn.**

It is a perennial prostrate herb. Some populations are provided with V-shaped white markings on the leaflets while some are devoid of such markings. It propagates with the help of stolons which root at the nodes. It has trifoliate glabrous leaves with long petiole arising from the nodes of the stolons. Flowers are white, ovary is 6mm long with 4 ovules, stigma is capitate, fruits are 2-4 seeded pods enveloped in the calyx tube and seeds are ovoid, smooth and 2 mm across.

T. repens starts its growth in February with rise in temperature. Sporadic rain received in March-April stimulates the growth of a large number of leaves. Flowering usually commences in the last part of April reaching its peak in May-June. Flowering and seed setting continue up to August, although sporadic flowering occurs throughout the year. Even during winter months, few flowers are seen here and there.

***Arundinella khasiana* Nees.**

This plant species, a perennial herb belongs to Poaceae. The plants have robust culms up to 2m long with scabrid, serrulately convolute or flat leaves. The plant shows the presence of ligule ridges of hairs. There are spikelets of 6-7mm.

5-nerved lanceolate glumes are present. Upper glumes also present a similar picture. The inflorescence has male lower florets and bisexual upper florets. The flowering and fruiting generally occur during the month of June - December.

***Borreria hispida* Linn.**

It is a perennial herb of the family Rubiaceae. The plant is procumbent and scabrid. This herb is hispid or hirsute in nature with obovate leaves. Spathulate inflorescence is encountered. The flower is whorled with blue or white coloured corolla with pubescent capsule. The flowering period extends from July-October, which is followed by fruiting which takes place during September - December.

Results:

(A) *Trifolium repens*

There was a marked increase in root and shoot length as well as in root, shoot and leaf biomass. The leaf number also increased from H₁ to H₃. Plants grown in soils amended with DAP always registered the best growth. In both the spoils viz., 6-8 years old and 0-2 year old, showed the best growth for *T.repens* in the DAP treatment followed by lime and MOP treatments, and the least growth was observed in the untreated spoil. At H₂ and H₃ the live green biomass recorded a higher value than the standing dead fraction. However, no standing dead or reproductive part was encountered during the first harvest. Apart from the DAP treatment, the response to lime (calcium hydroxide) amendment was quite good as

indicated by the plant growth. There was a noticeably slow rate of increase in biomass and elongation of various organs in the 0-2 year old spoil as compared to the 6-8 year old spoil though in both spoils the peak growth was observed after 135 days. Thus besides the DAP treatment, liming also favoured the growth of *T.repens*. The growth and biomass accumulation were much more in these two treatments as compared to the other treatments applied (Table 8.1a). Mean biomass in the case of *T.repens* ranged from 4.83-6.54 in the 6-8 year old spoil and 4.18-5.02 in the 0-2 year old spoil at the three different harvest times (Table 8.4). Below ground to aboveground biomass ratio (Bg/Ag) exhibited a declining trend (0.71-0.55 in the 6-8 year old and 0.66-0.50 in the 0-2 year old spoil) from H₁ to H₃ (Table 8.4).

Similar to its growth and biomass accumulation, *T.repens* showed the maximum concentration of nitrogen in the mine spoils with DAP amendments (Table 8.1b). In this treatment, nitrogen in the root ranged from 4.80 mg/g at H₁ to 6.23 mg/g at H₃ in the 6-8 year old spoil and 3.72 mg/g at H₁ to 4.26 mg/g in the H₃ in the 0-2 year old spoil. The nitrogen content gradually decreased in the other three treatments in the case of both the spoils. During the first harvest (H₁), root recorded the highest concentration of nitrogen, whereas at the second (H₂) and third (H₃) harvests there was a better apportionment of nitrogen in the stem in the 6-8 year old spoil. In contrast, the concentration of nitrogen was uniformly higher in the root segment over others at all the harvests in the 0-2 year old spoil irrespective of

the amendments applied. The lesser concentration of nitrogen in the leaf parts in comparison to root and stem was evident in both the spoils. Least concentration of nitrogen was recorded in the standing dead fraction in both the spoils and in different amendments. The reproductive part had a little higher nitrogen concentration than the standing dead though it achieved maximum concentration at H₃ in both the spoils. There was a noticeable decline in nitrogen concentration from the 6-8 year old to 0-2 year old spoil in all the plant components at all the harvests.

The accumulation of nitrogen in *T.repens* followed a trend similar to its concentration, it was maximum in the root at H₁ whilst at H₂ and H₃, the stem accumulated maximum nitrogen in both the spoils. The accumulation was highest in the spoils amended with DAP followed by amendments with lime and MOP. The accumulation of nitrogen was least in the standing dead fraction in both 6-8 year and 0-2 year old spoils (Table 8.1c).

(B) *Arundinella khasiana*

This grass recorded a marked increase in the elongation of root and shoot and leaf number from the first to the third harvest in both 0-2 year and 6-8 year old spoils (Table 8.2a). The maximum increase was always recorded in the spoils amended with DAP irrespective at all the three harvests. There was a significant increase in stem length from H₁ to H₃. Both leaf area and number showed gradual increase from H₁ to H₃ in both the spoils. Notwithstanding the pronounced increase

in root, shoot and leaf biomass from H₁ to H₃ in 6-8 year and 0-2 year spoils, there was marginal enhancement in leaf area also from H₁ to H₃. The plant growth was much better in spoils treated with DAP than that in the untreated spoil and in the spoils treated with MOP and lime. The same trend was evident in the 0-2 year old spoil also. The mean biomass declined from H₁ to H₂ but increased again in H₃ in the 6-8 year old spoil, whereas it showed uniform increase (4.35 to 5.83) from H₁ to H₃ in the 0-2 year old spoil. The belowground /aboveground biomass ratio fluctuated from 0.48 to 0.77 in the 6-8 year old spoil, whereas, it ranged from 0.47-0.69 in the case of 0-2 year old spoil (Table 8.4).

The concentration of nitrogen unlike *T.repens* was always higher in the belowground segment of *A.khasiana* in comparison to other organs. It ranged from 1.66 mg/g to 6.82 mg/g in the root region of *A. khasiana* in the 6-8 year old spoil and 1.39 mg/g to 4.24 mg/g in the 0-2 year old spoil. Similarly for shoot, it varied from 1.12 mg/g to 4.83 mg/g and 0.95 mg/g to 4.71 mg/g in the 6-8 year old and 0-2 year old spoils respectively (Table 8.2b). The same trend was seen in the case of other plant components. There was a clearcut decline in nitrogen concentration from the older to younger spoils.

As regards the accumulation of nitrogen in *A.khasiana*, the major portion was allocated in the root region of the plants grown on spoils treated with DAP. The accumulation of nitrogen was maximum in this treatment followed by lime and

MOP treatments. This sequence was much in evidence in the accumulation of nitrogen in the root to stem, leaf, reproductive part and the standing dead in both the spoils and at all the three harvests. The standing dead fraction which was recorded only during H₂ and H₃ had the least N accumulation in both the spoil types (Table 8.2c).

(C) *Borreria hispida*

The elongation of shoot was more than root at all the harvests with spoils having DAP amendments registering a higher value than other treatments. The shoot length ranged from 4.8cm to 10.2 cm and root length from 4.62 to 9.20cm (Table 8.3a). The number of leaves in *B.hispida* was maximum (22) in the 6-8 year old spoil receiving DAP treatment. In other treatments, it ranged from 4 to 15 in number. Though there was not much significant difference in growth and biomass values of different plant components of *Borreria hispida* from H₁ to H₃, the spoils receiving DAP amendments showed a relatively better performance over other amendments in both the spoil types (Table 8.3b).

The biomass of reproductive parts of the plant as well as in the standing dead fraction increased from H₁ to H₃. The biomass accumulation was maximum in the DAP amendment which was followed by the lime treatment and it was least in the untreated spoil. Similarly, in the 0-2 year old spoil, the application of DAP to spoil samples resulted in increased root, shoot and leaf elongation and greater

biomass allocation when compared with other amendments applied. The shoot length was always more than the root from H₁ to H₃. The root and shoot length did not differ much between the 6-8 year old spoil and 0-2 year old spoil. The number of leaves in the 6-8 year old spoil was consistently higher than that in the 0-2 year old spoil. There was a significantly less growth and biomass accumulation in 0-2 year old spoil as compared to the 6-8 year old spoil.

The pattern of nitrogen concentration was similar to that of biomass accumulation, where the peak was achieved during H₃ for root, stem and leaf in spoils amended with DAP. The least concentration was found in the untreated sample in both the spoil types (Table 8.3b). The belowground plant parts had greater nitrogen accumulation at all the harvests compared to the aboveground parts. The minimum accumulation in this was 0.58 Kg/ha in the control at H₁ and the maximum being 4.85 Kg/ha in the 6-8 year old spoil amended with DAP at H₃. Nevertheless, there was a gradual increase in nitrogen accumulation from H₁ to H₃ with respect to all organs analysed. In the 0-2 year old spoil, root had the maximum accumulation of nitrogen which showed an increasing tendency from H₁ to H₃. In both the cases, the standing dead recorded the least accumulation among all the components in both the spoils. There was significantly less nitrogen accumulation in the plants grown on the 6-8 year old compared to the 0-2 year old spoil (Table 8.3c). The mean biomass in *B. hispida* unlike *T. repens* and *A. khasiana* showed

marginal reduction, though from H₁ to H₃ in both 6-8 year old and 0-2 year old spoils. It ranged from 5.11-5.64 mg/g in the former and 4.45-4.53 in the latter. There was a significant but marginal decline in Bg/Ag ratio from 0.65-0.49 in the 6-8 year old and 0.56-0.45 in the 0-2 year old spoils (Table 8.4).

Discussion

Rehabilitation of coal mine spoils is a major problem due to their nutrient deficiency, lack of organic matter, absence of microbial activities and toxic concentration of some elements and also due to exacting edaphic characteristics. Usefulness of the survival and growth performance studies of different leguminous and non-leguminous plant species in rehabilitation of degraded lands has been proved time and again and reported from different parts of the globe (Skeffington *et al.* 1980, Bloomfield *et al.* 1982, Costigan *et al.* 1982, Brenner *et al.* 1990, William *et al.* 1994, Chu and Bradshaw 1996, Singh *et al.* 1996 and William *et al.* 1994).

Despite the variation in the standing state of nutrients in three different spoils (as evidenced from the data presented in Chapters 4 and 7), the effect of spoils on the growth of the three species namely *Arundinella khasiana*, *Trifolium repens* and *Borreria hispida* was not pronounced. Total biomass of *A. khasiana* decreased from H₁ to H₂ and then increased to the maximum at H₃ in the 6-8 year old spoil. The decline in the total biomass at H₂ was due to the decrease in

aboveground biomass attributable to senescence and shedding of leaves. However, the total biomass showed an overall increase from H₁ to H₃. An important feature of biomass allocation pattern in *A. khasiana* is the allocation of high energy towards the belowground part in comparison to the aboveground parts such as leaf and stem. The extremely reduced allocation of biomass was noticeable in the reproductive organs, which suggested the least dependence of the species on sexual reproduction for population growth. An increase in aboveground biomass (leaf + stem) indicates gradual resource transfer from belowground to the aboveground organs to maximise photosynthesis. In coal mine spoils, the slow rate of nutrient uptake is probably due to high acidity of the mine spoils which inhibits root growth (Marschner, 1991). The greater allocation of biomass towards the stem and leaves may be related to the need of the plant to grow taller and develop photosynthetic apparatus for efficient assimilation.

The greater biomass of *Trifolium repens* at all the harvests and in both the spoils compared to *Arundinella khasiana* and *Borreria hispida* is probably due to the better growth of its extensively proliferating root system especially from the stolons and due to its nodulating habit . The total biomass of *T. repens* declined from H₁ to H₃ in both the spoil types. The belowground/ aboveground (Bg/Ag) biomass ratio was maximum at H₁ ~~only to decline gradually from H₂ to H₃~~. The same trend was observed in the case of *A. khasiana* and *B. hispida*. The

belowground/aboveground ratio in all the spoils and species was lesser than one (<1).

The allocation of dry matter in *T. repens* was more towards the roots than in other parts at all harvests and in soils of both the spoils. This is a mechanism to maximise nutrient intake through a larger root system (Chapin III, 1980) rather than through a high nutrient absorbing capacity (Nye 1977, Nye and Tinker, 1977).

Among the aboveground parts, more biomass was allocated towards the stem. The negligible proportion of biomass allocation in reproductive parts pointed towards the decreased reliance of the plant on sexual reproduction.

In the case of *B. hispida* too, there was a greater allocation of biomass towards the root than either the stem or leaf. Unlike the other two species, the biomass of the reproductive parts was recorded only during the third harvest in both the spoils. There was a noticeable decrease in biomass from the 6-8 year old spoil to the 0-2 year old mine spoil. This could be due to more severe nutrient impoverishment in the 0-2 year old spoil. The total biomass declined from H₁ to H₃ in both 6-8 year and 0-2 year old spoils and so was the case with the aboveground/belowground ratio through the harvests.

Though biomass accumulation in *A. khasiana*, *T. repens* and *B. hispida* increased through the harvests, the belowground/aboveground ratio declined from H₁ to H₃ in both the spoil types for all the three species indicating gradual increase

in allocation to belowground parts with the passage of time .

The nitrogen concentration as well as accumulation in different plant organs varied significantly between the spoils and harvests. In all the species, the concentration of nitrogen was found to be higher in root than the stem and leaf parts. The increase in N concentration in all the plant segments was observable from the first to the third harvest. The plants grown in soils amended with DAP showed far better growth and increased N concentration as compared to the other treatments. The control set recorded the least values. There was a gradual increase in N concentration from the 0-2 year old to 6-8 year old spoil.

In all the three species, minimum nitrogen was observed in the leaves in both the spoils. This probably points to their low metabolic activities, eg. chlorophyll synthesis, protein synthesis. At H₃, the concentration attained its maximum level in the leaf probably due to the flush of new growths as reported by Sarma (1985) and Uma Shankar (1991). The depletion in the concentration of plant nitrogen occurred in 0-2 year old spoil due to the decreased level of soil nitrogen in the younger spoil and due to the increase in plant growth (Van Andel and Vera 1977, Boral 1993).

There was a significant variation in nitrogen accumulation from species to species, with *T. repens* recording the maximum accumulation followed by *A. khasiana* and *B. hispida*. The accumulation of the nitrogen was maximum in the

legume root followed by the stem and leaf. The maximum accumulation of nitrogen in *T. repens* was probably due to much greater biomass accumulation and higher concentration of nitrogen in some of its organs compared to other two species. *B. hispida* had the least accumulation of nitrogen, which was probably due to its low biomass and low nitrogen concentration.

The analysis of nutrient allocation on the basis of biomass alone (Harper 1977) does not give a complete picture. Studies of Saxena and Ramakrishnan (1983) and Sarma (1985) suggest that nutrient allocation is equally important particularly for reproductive growth.

The best response of all the three plant species to the DAP treatment suggests that nitrogen is in short supply in coal mine spoils and needs replenishment. It has been suggested that minimum soil capital of nitrogen to generate a self-sustaining ecosystem is 750 kg ha^{-1} (Dancer *et al.* 1977, Roberts *et al.* 1981). Legumes would appear to provide the only economically feasible answer of nitrogen deficiency on the mine spoils, since they readily fix the atmospheric nitrogen and accumulate more than 100 kg N ha^{-1} on derelict lands (Dancer *et al.* 1977). But they require after care in the form of application of lime and phosphorus if their growth is to be maintained (Bradshaw *et al.* 1977). The application of mulch, lime and fertilizers has been a standard practice in reclaiming mined lands. Studies have shown that mulching enhances establishment and growth

of vegetation on disturbed lands (Dyer *et al.* 1984), whereas light and fertilizer application influence the species diversity. Hansson *et al.* (1982) found increased yield after lime application in the first one year which subsequently fell below the required level; it was reported that continued doses of lime were needed for maintaining the increased yield.

It may be concluded that *T. repens* and *A. khasiana* are better suited for reclamation of mined lands than *B. hispida* by virtue of their faster growth rate, horizontal stolons, adventitious roots and their capacity to reproduce by both sexual and vegetative means. Besides these attributes, *T. repens*, being a legume can nodulate and contribute to nitrogen build up in the mined lands by fixing atmospheric nitrogen.

Table81a. Growth of *Trifolium repens* in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Growth parameters	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6 - 8 year	Root length (cm/plant)	5.50	7.90	6.80	6.30	6.20	8.60	8.20	6.90	6.90	9.50	8.90	7.40
	Stem length (cm/plant)	5.90	7.70	6.90	6.50	6.50	9.10	8.30	7.90	7.10	10.5	9.20	8.50
	No. of leaves/plant	3	12	9	6	9	15	12	9	9	18	15	12
	Leaf area (cm ²)	2.22	3.74	3.53	2.90	2.57	4.15	4.00	3.15	3.11	4.23	3.58	3.33
	Root weight (g/plant)	6.60	9.20	8.80	8.00	6.90	10.70	9.40	8.80	7.80	11.80	10.20	9.30
	Stem weight (g/plant)	6.90	8.80	8.20	7.20	6.30	9.70	9.20	6.80	7.40	10.50	9.90	7.50
	Leaf weight (g/plant)	2.90	4.60	3.70	3.60	3.50	4.80	4.30	3.90	3.70	5.20	4.80	4.20
	Biomass of reproductive parts (g/plant)	-	-	-	-	0.88	2.80	2.60	1.50	1.70	3.50	2.90	2.20
Standing dead biomass (g/plant)	-	-	-	-	0.80	1.70	1.20	0.75	1.20	2.60	2.20	1.30	
0 - 2 year	Root length (cm/plant)	3.70	6.20	5.20	5.00	3.90	6.90	5.80	5.60	4.80	8.30	6.70	6.20
	Stem length (cm/plant)	4.10	5.70	5.30	4.70	4.80	7.00	6.20	5.50	5.30	7.90	6.80	6.40
	No. of leaves/plant	6	9	9	6	6	12	12	9	6	15	15	12
	Leaf area (cm ²)	1.20	2.72	2.21	1.90	1.70	3.14	3.09	2.40	2.11	4.25	3.39	3.20
	Root weight (g/plant)	5.20	7.20	6.00	5.60	6.30	7.70	7.50	6.90	7.20	8.40	8.00	7.50
	Stem weight (g/plant)	4.00	7.90	6.30	6.10	5.50	8.90	8.30	7.00	6.30	9.80	9.20	7.80
	Leaf weight (g/plant)	2.40	3.33	3.20	3.00	2.80	3.53	3.40	3.28	2.99	4.13	3.61	3.47
	Biomass of Reproductive parts (g/plant)	-	-	-	-	1.70	2.20	2.00	1.90	1.40	2.90	2.60	2.00
Standing dead biomass (g/plant)	-	-	-	-	1.00	1.50	1.00	1.20	0.55	2.50	2.30	1.20	

Table 8.1b. Nitrogen concentration (mg/g) of various plant parts of *Trifolium repens* grown in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root	2.27	4.80	4.68	3.35	2.92	5.58	4.88	3.69	3.22	6.23	5.45	4.02
	Shoot	1.72	3.48	2.72	2.50	3.66	6.86	6.62	5.00	4.20	8.25	6.88	5.63
	Leaf	1.11	3.11	2.665	1.88	1.48	4.41	3.92	2.22	2.92	6.62	4.72	2.70
	Reproductive parts	-	-	-	-	0.89	3.27	2.72	2.00	1.05	3.45	2.83	2.21
	Standing dead	-	-	-	-	0.63	1.88	1.62	0.83	0.90	2.12	1.55	0.99
0-2 year	Root	1.85	3.72	3.68	3.11	2.18	3.93	3.77	3.55	2.53	4.26	3.83	3.79
	Shoot	1.13	2.80	2.63	1.54	1.55	3.67	2.89	1.86	1.88	4.44	3.37	2.51
	Leaf	0.75	2.41	2.11	1.14	1.23	2.65	2.42	1.69	1.46	3.42	2.82	2.32
	Reproductive parts	-	-	-	-	0.65	1.72	1.59	1.05	1.07	2.13	1.85	1.10
	Standing dead	-	-	-	-	0.48	1.33	1.08	0.70	1.00	1.57	1.49	1.20

Table 8.1c. Nitrogen accumulation (kg/ha) in *Trifolium repens* in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root (belowground)	1.49	4.41	4.11	2.68	2.01	5.97	4.58	3.25	2.51	7.35	5.55	3.74
	Stem	1.19	3.06	2.23	1.80	2.31	6.65	6.09	3.40	3.11	8.66	6.81	4.22
	Leaf	0.32	1.43	0.98	0.68	0.52	2.12	1.69	0.87	1.08	3.44	2.27	1.13
	Shoot (aboveground)	1.51	4.49	3.21	2.48	2.53	8.77	7.78	4.77	4.19	12.10	9.08	5.35
	Reproductive parts	-	-	-	-	0.08	0.92	0.71	0.30	0.18	1.21	0.82	0.49
	Standing dead	-	-	-	-	0.05	0.32	0.19	0.06	0.11	0.55	0.34	0.13
0-2 year	Root (belowground)	0.96	2.68	2.20	1.74	1.37	3.03	2.83	2.45	1.82	3.58	3.06	2.84
	Stem	0.45	2.21	1.66	0.94	0.85	3.59	2.39	1.30	1.18	4.35	3.10	1.96
	Leaf	0.18	0.80	0.68	0.34	0.34	0.94	0.82	0.55	0.44	1.41	1.02	0.81
	Shoot (aboveground)	0.63	3.01	2.34	1.28	1.19	4.53	3.21	1.85	1.62	5.76	4.12	2.77
	Reproductive parts	-	-	-	-	0.11	0.38	0.32	0.19	0.15	0.62	0.48	0.22
	Standing dead	-	-	-	-	0.05	0.19	0.11	0.08	0.06	0.39	0.34	0.14

Table 8.2a. Growth of *Arundinella khasiana* in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Growth parameters	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6 - 8 year	Root length (cm/plant)	3.80	6.80	6.50	5.40	4.70	7.50	7.20	6.30	5.50	7.90	7.80	7.20
	Stem length (cm/plant)	6.60	10.60	9.10	8.70	8.80	12.80	10.50	9.90	10.70	16.20	14.70	12.80
	No. of leaves/plant	3	6	5	5	7	9	9	9	9	11	10	9
	Leaf area (cm ²)	2.00	3.20	3.00	2.20	2.90	4.60	4.10	3.40	3.40	5.20	4.70	4.10
	Root weight (g/plant)	5.50	8.80	8.30	7.70	6.60	10.40	9.20	7.90	8.90	13.30	12.70	9.30
	Stem weight (g/plant)	4.90	7.60	6.50	5.50	6.50	9.70	8.30	7.70	7.30	11.30	9.90	8.00
	Leaf weight (g/plant)	3.10	4.50	4.00	3.50	3.80	5.50	5.00	4.20	4.80	6.70	6.10	5.60
	Biomass of reproductive parts (g/plant)	-	-	-	-	1.60	2.90	2.20	1.80	1.20	3.50	2.90	2.10
Standing dead biomass (g/plant)	-	-	-	-	2.50	3.50	3.10	2.20	3.90	5.90	4.20	2.80	
0 - 2 year	Root length (cm/plant)	2.80	5.40	5.20	4.70	4.50	6.80	6.40	6.90	5.40	7.60	6.90	6.60
	Stem length (cm/plant)	6.30	9.20	9.60	8.40	8.20	11.90	10.20	10.00	10.10	13.60	12.20	11.60
	No. of leaves/plant	2	5	5	3	5	9	7	5	6	12	9	8
	Leaf area (cm ²)	1.80	2.80	2.30	2.00								
	Root weight (g/plant)	4.40	6.20	5.70	5.00	5.60	8.50	8.10	6.80	8.40	11.60	10.70	9.10
	Stem weight (g/plant)	3.30	5.50	5.10	4.30	5.60	7.90	7.50	6.90	6.30	9.70	8.20	7.70
	Leaf weight (g/plant)	2.20	3.80	3.60	3.10	2.70	4.90	3.90	3.80	3.10	6.80	4.70	3.80

Table 8.2b. Nitrogen concentration (mg/g) of various plant parts of *Arundinella khasiana* grown in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root	1.66	3.90	3.80	3.05	2.52	5.77	5.41	3.49	3.17	6.82	6.45	4.28
	Shoot	1.12	2.50	2.68	2.10	1.63	4.05	3.92	3.21	2.44	4.83	4.11	3.77
	Leaf	1.09	2.42	2.28	1.92	1.53	3.13	2.69	2.51	2.11	4.46	3.29	3.02
	Reproductive parts	-	-	-	-	0.66	2.00	1.89	0.81	0.95	1.28	1.32	0.75
	Standing dead	-	-	-	-	0.51	1.30	1.18	1.02	0.60	1.63	1.39	1.12
0-2 year	Root	1.39	3.09	3.00	2.73	2.41	3.80	3.36	2.92	2.83	4.24	3.86	3.77
	Shoot	0.95	2.22	2.14	1.87	1.39	3.63	3.29	2.23	2.20	4.71	3.75	3.55
	Leaf	0.83	1.99	1.79	1.61	1.30	2.30	2.09	1.91	1.66	3.46	2.56	2.36
	Reproductive parts	-	-	-	-	0.44	2.01	1.77	0.63	0.75	2.28	1.89	0.69
	Standing dead	-	-	-	-	0.38	1.20	1.11	0.88	0.52	1.51	1.28	1.00

Table 8.2c. Nitrogen accumulation (kg/ha) in *Arundinella khasiana* in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root (belowground)	0.91	3.43	3.15	2.35	1.66	6.00	4.98	2.76	2.82	9.07	8.19	3.98
	Stem	0.55	1.90	1.74	1.16	1.06	3.93	3.25	2.47	1.78	5.46	4.07	3.02
	Leaf	0.34	1.09	0.91	0.67	0.58	1.72	1.35	1.05	1.01	2.99	2.01	1.69
	Shoot (aboveground)	0.89	2.99	2.65	1.83	1.64	5.65	4.60	3.52	2.79	8.45	6.08	4.71
	Reproductive parts	-	-	-	-	0.11	0.58	0.42	0.15	0.11	0.45	0.38	0.16
	Standing dead	-	-	-	-	0.13	0.46	0.37	0.22	0.23	0.96	0.58	0.31
0-2 year	Root (belowground)	0.61	1.92	1.71	1.37	1.35	3.25	2.72	1.99	2.38	4.92	4.13	3.43
	Stem	0.31	1.22	1.09	0.80	0.78	2.87	2.47	1.54	1.39	4.57	3.08	2.73
	Leaf	0.18	0.76	0.64	0.49	0.35	1.13	0.81	0.73	0.51	2.35	1.20	0.89
	Shoot (aboveground)	0.49	1.98	1.73	1.29	1.13	4.00	3.28	2.27	1.90	6.92	4.28	3.62
	Reproductive parts	-	-	-	-	0.62	0.54	0.35	0.10	0.17	0.68	0.51	0.15
	Standing dead	-	-	-	-	0.11	0.36	0.29	0.17	0.21	0.85	0.51	0.26

Table 8.3a Growth of *Borreria hispida* in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine Spoil age	Growth parameters	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6 - 8 year	Root length (cm/plant)	4.60	6.50	6.30	5.80	4.90	8.20	6.90	6.10	5.30	9.20	7.30	6.60
	stem length (cm/plant)	4.80	8.20	7.80	6.50	4.90	9.30	8.20	7.70	5.80	10.20	8.70	7.90
	No. of leaves/plant	4	8	8	6	6	14	10	8	8	22	15	10
	Leaf area (cm ²)	2.20	4.10	3.90	2.80	2.80	5.70	4.30	3.70	3.30	6.40	4.90	4.20
	Root weight (g/plant)	4.30	8.30	8.20	5.80	5.20	9.00	8.20	5.90	5.80	11.20	8.70	7.90
	Stem weight (g/plant)	4.20	6.50	6.00	5.60	4.80	7.40	7.20	5.80	5.50	8.60	7.70	6.30
	Leaf weight (g/plant)	2.80	6.30	5.80	3.90	3.20	7.20	6.80	4.30	4.40	7.50	6.90	5.40
	Biomass of reproductive parts (g/plant)	-	-	-	-	-	-	-	-	1.10	2.50	2.70	1.20
Standing dead biomass (g/plant)	-	-	-	-	0.65	2.80	2.60	1.60	0.45	3.60	2.80	1.90	
0 - 2 year old spoil	Root length (cm/plant)	3.30	5.90	4.90	4.50	3.90	6.70	5.30	5.00	4.80	7.80	6.30	5.40
	Stem length (cm/plant)	4.10	7.50	7.50	6.20	4.80	8.80	7.70	7.50	5.20	9.90	8.30	7.90
	Root weight (g/plant)	3.70	5.90	5.40	4.60	4.40	7.80	6.60	5.70	4.50	8.90	8.30	5.90
	Stem weight (g/plant)	3.70	5.80	5.20	4.40	4.40	6.40	6.20	5.70	4.50	8.90	8.30	5.90
	No. of leaves/plant	4	6	6	4	4	8	8	8	4	12	8	6
	Leaf area (cm ²)	2.00	3.60	3.60	3.30	2.50	4.10	4.30	3.60	2.80	4.70	4.50	3.70
	Leaf weight (g/plant)	2.20	5.00	4.80	3.60	2.60	5.60	5.20	3.80	3.10	6.60	5.80	4.40
	Biomass of reproductive parts (g/plant)	-	-	-	-	-	-	-	-	1.10	1.90	2.20	1.60
Standing dead biomass (g/plant)	-	-	-	-	2.00	2.20	1.90	1.80	1.80	3.50	2.40	1.90	

Table 8.3b. Nitrogen concentration (mg/g) of various plant parts of *Borreria hispida* grown in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root	1.34	3.05	2.87	2.28	1.43	3.49	3.21	2.42	1.52	4.25	3.42	2.60
	Shoot	1.19	2.40	2.00	1.62	1.33	3.27	2.82	1.78	1.45	3.81	3.29	2.16
	Leaf	1.20	1.88	1.70	1.45	1.28	2.66	2.36	1.69	1.42	3.02	3.03	1.92
	Reproductive parts	-	-	-	-	-	-	-	-	0.38	0.83	0.72	0.51
	Standing dead	-	-	-	-	0.52	1.11	1.00	0.98	0.60	1.42	1.30	1.12
0-2 year	Root	1.19	2.76	2.55	2.03	1.28	2.92	2.63	2.28	1.39	3.77	2.83	2.34
	Shoot	0.97	1.95	1.71	1.36	1.15	2.24	1.89	1.49	1.24	3.51	2.32	1.72
	Leaf	1.00	1.63	1.21	1.05	1.11	1.98	1.69	1.31	1.38	2.38	2.02	1.59
	Reproductive parts	-	-	-	-	-	-	-	-	0.75	0.88	0.92	0.21
	Standing dead	-	-	-	-	0.38	0.63	0.56	0.48	0.50	0.89	0.64	0.60

Table 8.3c. Nitrogen accumulation (kg/ha) in *Borreria hispida* grown in soils/amended soils from 0-2 year and 6-8 year old mine spoils.

Mine spoil age.	Plant parts	After 45 days growth (H ₁)				After 90 days growth (H ₂)				After 135 days growth (H ₃)			
		Control	DAP	Lime	MOP	Control	DAP	Lime	MOP	Control	DAP	Lime	MOP
6-8 year	Root (belowground)	0.58	2.53	2.35	1.32	0.74	3.14	2.63	1.43	0.87	4.85	3.32	1.77
	Stem	0.49	1.56	1.20	0.91	0.64	2.42	2.03	1.03	0.79	3.28	2.53	1.36
	Leaf	0.34	1.18	0.99	0.56	0.41	1.92	1.60	0.73	0.63	2.27	2.09	1.04
	Shoot (aboveground)	0.83	2.74	2.19	1.47	1.05	4.34	3.63	1.76	1.42	5.55	4.62	2.40
	Reproductive parts	-	-	-	-	-	-	-	-	0.04	0.21	0.19	0.06
	Standing dead	-	-	-	-	0.34	0.31	0.26	0.16	0.03	0.51	0.36	0.21
0-2 year	Root (belowground)	0.44	1.63	1.38	0.93	0.56	2.27	1.73	1.29	0.63	3.35	2.35	1.38
	Stem	0.36	1.13	0.89	0.59	0.54	1.43	1.17	0.73	0.61	2.74	1.53	0.86
	Leaf	0.22	0.82	0.58	0.38	0.29	0.91	0.88	0.49	0.49	1.57	1.17	0.69
	Shoot (aboveground)	0.58	1.95	1.47	0.97	0.83	2.84	2.05	1.22	1.10	4.31	2.70	1.55
	Reproductive parts	-	-	-	-	-	-	-	-	0.08	0.26	0.20	0.03
	Standing dead	-	-	-	-	0.08	0.14	0.11	0.86	0.09	0.29	0.15	0.11

Table 8.4. Total biomass per plant and belowground/aboveground ratio (Bg/Ag) in three different species grown on amended soils

Harvests	Total biomass/ Bg/Ag ratio	<i>Trifolium repens</i>		<i>Arundinella khasiana</i>		<i>Borreria hispida</i>	
		6-8 year old spoil	0-2 year old spoil	6-8 year old spoil	0-2 year old spoil	6-8 year old spoil	0-2 year old spoil
H ₁	Total biomass	6.54	5.02	5.83	4.35	5.64	4.53
	Bg/Ag ratio	0.71	0.66	0.77	0.69	0.65	0.56
H ₂	Total biomass	4.83	4.18	5.23	4.52	5.17	4.49
	Bg/Ag ratio	0.59	0.51	0.48	0.47	0.52	0.52
H ₃	Total biomass	5.50	4.69	6.52	5.83	5.11	4.45
	Bg/Ag ratio	0.55	0.50	0.51	0.52	0.49	0.45

CHAPTER IX

GENERAL DISCUSSION

Coal mine spoils of Jaintia Hills in Meghalaya represent highly degraded habitats, which have come into being due to extensive extraction of coal by unscientific method of surface mining and rat hole mining. An in-depth study of the biological and edaphic attributes of the coal mine spoils undergoing recovery has provided an insight into the extent of damage caused and the changes taking place in various structural and functional characteristics of these degraded ecosystems during the process of recovery.

The extremely hostile conditions for plant growth and development in the coal mine spoils have been explicitly revealed in the foregoing chapters. The major constraints encountered in the recovery of these spoils are generally moisture stress, acute acidity and deficiency of organic matter and nutrients (Iverson and Wali ,1992). The moisture stress could be due to the exposed surface, sandy texture and paucity of litter on the spoils resulting in elevated soil temperature and enhanced rate of evaporation from the soil surface (Richardson,1975). The severe acidity observed in the mine spoils of Jaintia Hills conforms with the reports of Chadwick (1973), Johnson and Bradshaw (1979) and Baig (1992). There was a gradual improvement in these conditions as the spoils grew older.

Soil reaction, moisture content and water holding capacity and soil nutrient

levels are thought to be related to the organic matter content and rate of N, P and K accumulation. In the present study the organic matter content, nutrient accumulation, pH and soil moisture content increased with an increase in spoil age. The inadequate amount of organic carbon in the mine spoils as observed in the present study agrees with the findings of similar studies carried out elsewhere. The organic carbon content is always expected to be very low in the youngest coal mine spoil (i.e. 0-2 year old spoil) as it was a heap of soil particles brought to the soil surface from deeper horizons which are generally devoid of any organic matter. Initially the young spoils do not have any vegetation, litter and microbial activity. Lyngdoh (1995), Down and Stocks (1977), Thomas *et al.* (1985) also reported low level of organic carbon in mine spoils and attributed it to the delay in vegetation establishment on the mine spoils. The concentration of phosphorus and potassium was extremely low in all the sites which hampered plant colonization and subsequent succession. This is supported by the findings of Lyngdoh (1995), Uma Shankar *et al.* (1993) and Safaya and Wali (1979). A similar trend was discernible for exchangeable-K concentration also. Like P and K, soil nitrogen content was also very low in mine spoils and improved with the age of the spoil. The increase in nutrient concentration with increase in spoil age could be attributed to the colonization by plant species and gradual withering of the spoils. (Cornwell and Stone, 1968; Reeder and Berg 1977a; Uma Shankar *et al.*, 1993 and Lyngdoh 1995).

Some nitrogen input is also expected from the rain water. High C/N ratio found in the study has also been reported by Baig (1992).

The unfavourable habitat conditions prevailing on the coal mine spoils under study might have helped in the invasion and growth of only hardy plant species. The rhizome bearing plants such as *Dicranopteris linearis*, *Axonopus compressus*, *Cyanotis vaga*, *Arundinella khasiana*, *Imperata cylindrica* are the important colonisers of the mine spoils studied. These species also bear fibrous roots which play a vital role in binding the soil particles and absorbing whatever little moisture and nutrients are available to them. This characteristic helps early colonising plants grow on the coal mine spoils. In the present investigation, the therophytes have been found to be the dominant group and the population of perennial plants are more than the annuals indicating adaptation of the community to stressed environments. The increase in species number and families with increasing spoil age is in conformity with the reports of Cornwell (1971) and Mishra *et al.* (1971). The young mine spoils are characterized by low species diversity and high dominance as also reported by Odum (1985) who attributed the decreasing diversity and increasing dominance to stress. The spoil conditions gradually improved with the increase in the age of the spoil. The increase in spoil age also caused an enhancement in plant density, basal cover and species number. The plant biomass and productivity also increased with the amelioration of spoil conditions. Toky and

Ramakrishnan (1983) and Arunachalam *et al.* (1995) have reported increase in species content, species density and biomass with increase in age of the forest stand growing on a site which had experienced disturbance.

Both aboveground and belowground production was significantly higher on the unmined control site. The productivity on the control site was much greater than on the spoils. Unlike the aboveground compartment, the belowground and the litter compartment exhibited an increase from the first to the second sampling year. The increase in primary productivity with increasing age of the spoils clearly indicates that the spoils had undergone recovery with the passage of time and the conditions had become favourable for plant growth and development.

The variation in concentration of N, P and K in the plant materials from site to site was presumably due to the difference in the species composition of the vegetation growing on them (Chapter-V) and due to the difference in the standing state of nutrients on these sites (Chapter-VII). The concentration was 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). This also accounts for the higher concentration of these nutrients in the live biomass of the dominant species at all the sites.

The belowground compartment registered higher TKN concentration. As observed in the case of root biomass accumulation, the unmined site recorded a

greater TKN concentration than the mine spoils. The N, P and K accumulation and input varied significantly with seasons, sites and plant organs. Among these three essential nutrients, K was present in the least quantity in all the compartments. The higher N, P and K accumulation in the live fraction is clearly due to their higher concentration in the live parts and greater quantity of live biomass. The same argument holds true for the higher N, P and K accumulation in the aboveground compartment than the belowground and litter compartments. Monocots had a higher concentration of TKN, total-P and exchangeable-K in comparison to dicots and ferns in the aboveground compartment. The belowground compartment also had a higher TKN concentration whereas total-P and exchangeable-K were present in meagre amounts. The litter fraction had a higher concentration of TKN followed by total-P and exchangeable-K though pine needles, a dominant component of litter recorded the maximum concentration of these three elements in comparison to monocot, dicot and miscellaneous fractions.

The least concentration of TKN, total-P and exchangeable-K in the vegetation compartments and litter was observed on, the 6-8 year old spoil. The youngest coal mine spoil (aged 0-2 year old) initially did not show the presence of any vegetation but towards the fag end of the study the process of colonisation by some ferns and mosses started colonising the spoil. Out of these colonisers, the fern *Dicranopteris linearis* was most conspicuous. This fern is found to be a dominant plant coloniser

in most mine spoils because of its creeping rhizome bearing fibrous roots on its under surface which helps it withstand stresses.

Of the four ecosystem compartments, more amounts of N and P were concentrated in the vegetation compartments than in the soil but exchangeable-K did not show much variation between the compartments. The low concentration of exchangeable-K in all the compartments could be due to its higher mobility than N besides its loss with rain water as the study area experiences a very heavy rainfall. In addition to this loss, transportation of litter from the barren spoils also results in its removal leaving only the belowground detritus through which K can be returned.

Microbial population was very low in the mine spoils due to their nutrient deficiency and thin vegetation cover. The higher bacterial and fungal population (including Yeast) in the unmined site than the disturbed spoil sites could be due to a significant drop in organic-C content of the spoil subsequent to mining (Martin and Focht, 1975). However, the organic carbon builds up with increasing age of the spoil (Chapter VI). The decline in the level of nutrients, aeration and root accumulation might have contributed to the reduction in bacterial and fungal population in the sub-surface (10-20 cm depth). The youngest (0-2 years old) mine spoil being barren due to the absence of any vegetal cover and litter was exposed to direct sunlight and recorded low relative humidity and very low organic carbon content. Consequently it recorded the lowest bacterial and fungal population which conformed with the

reports of Thompson *et al.* (1999) and Miller and Cameron (1976). As revealed by the fungal similarity index data, there is a gradual colonization of the mine spoils by fungal species, and in the long run the microbial communities become similar to that of unmined site during natural recovery. This is confirmed by the fact that the fungal community of 12-14 year old spoil was akin to the unmined control site.

The soil respiration showed a declining trend from the control to the youngest spoil and from the surface soil to the sub-surface soil layer. This agrees with results of Stroo and Jencks (1982). The same trend was also evident in the case of soil microbial biomass (SMB), dehydrogenase enzyme activity (DHA) and N-mineralization rates in the spoils under study. The impact of mining was manifested in the much reduced rate of dehydrogenase enzyme activity in all the mine spoils regardless of seasons. However, with the increase in mine spoil age, the dehydrogenase enzyme activity showed some enhancement which indicated that mine spoils were indeed undergoing some recovery. The higher rate of enzymatic activity in the surface soil layer has also been reported by Schinner and Gurschler (1978). The higher level of SMB in the uppermost layer of soil as also corroborated from the reports of Maithani *et al.* (1997), could be due to a large allocation of soil organic carbon to the microbial biomass pool. This allocation to the SMB pool is a sign of gradual ecosystem recovery (Maithani *et al.* 1997). The N-mineralization rate which is also an indicator of restoration (Fyles and McGill, 1987), increased with

the age of the mine spoils.

Despite the variation in the standing state of nutrients in two different spoils, the effect of spoils on the growth of three species namely *Arundinella khasiana*, *Trifolium repens* and *Borreria hispida* was not much pronounced. The belowground to aboveground biomass ratio showed a declining trend with the age of the spoil. *A. khasiana* showed maximum allocation of biomass towards the belowground part initially and least allocation in the reproductive organs. The gradual increase in the aboveground biomass indicates apparent resource transfer from the belowground to the aboveground organs to maximise photosynthesis. It is possible that high acidity in coal mine spoils not only inhibits root growth but also slows down the nutrient allocation (Marschner 1991). *T. repens*, because of its extensive stolons, proliferating root system and nodulating habit recorded the maximum biomass out of the three species studied at all the harvests, though there was a reduction in biomass values from H₁ to H₃ in both the spoil types. There was also a similar reduction in belowground to aboveground biomass ratio. At all the harvests, *T. repens* showed maximum biomass allocation to the roots, which could be aimed at enhancing nutrient intake. *B. hispida* also showed a pattern similar to *T. repens*. The accumulation of biomass particularly in the case of *B. hispida* decreased from the 6-8 year to the 0-2 old mine spoil. The 0-2 year old spoil was impoverished in nutrients which impaired plant growth.

Out of the fertilizer treatments applied, DAP (diammonium phosphate) caused better growth and enhanced N-concentration in plant parts of all the three plant species grown under controlled conditions. Sequentially, lime and MOP (murate of potash) followed DAP. The control set without any amendments recorded the least values for various growth parameters measured at all harvests and in both the spoil types. The 0-2 year old spoil recorded a lesser concentration of nitrogen than the 6-8 year old spoil.

In all the three plants, leaves had the least nitrogen concentration in both the spoils. It increased in H₃ with the flush of new growth as also reported by Sarma, (1985). In all the three species, N-accumulation was maximum in the root followed by stem and leaf. Of the three species *B. hispida* showed the least biomass and N-accumulation, indicating that it is not preferable for coal mine restoration.

The findings of the present study on the physico-chemical, vegetational and microbiological parameters speak of the natural recovery taking place in the nutrient poor coal mine spoils with the passage of time. With the increase in age of the coal mine spoils, there was an improvement in soil properties, vegetation cover and microbial population in natural course. The gradual amelioration of the spoil ecosystem health with time is evident from the following findings:

* Soil pH, moisture, water holding capacity, bulk density, soil texture, organic

matter improved with increase in spoil age.

* The N, P and K concentrations in soil as well as plant parts increased with increasing spoil age.

* Vegetational parameters like species richness, density, basal cover, persistence and sociability improved with time.

* Plant species number showed an upward trend with the increase in mine spoil age.

* Calculation of relative performance index (RPI) of plant species revealed the adaptational ability of the plants to grow on the harsh mine spoil habitat with increase in mine spoil age thereby indicating a slow but natural recovery. Species similarity index also confirmed the same trend.

* The increase in the population of filamentous fungi, yeast and bacteria apart from fungal species number speak of mine spoil recovery.

* Microbial biomass-C content and dehydrogenase enzyme activity, CO₂ evolution and N-mineralization rates increased with increase in spoil age. The gradual increase in these attributes with increase in spoil age was linked with soil ecosystem recovery and can be used as indicator of ecorestoration of mine spoils.

* Biomass, primary productivity and nutrient (N,P&K) concentration in the above ground, belowground and litter segment increased with increasing mine spoil age which also indicates that there has been a certain degree of ecosystem recovery with the passage of time.

May not happen in
reality

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* Higher belowground to aboveground biomass ratio and enhanced biomass accumulation in the below ground compartment of vegetation in the older spoil also reflected that there was a stabilizing trend with time.

An attempt has been made to predict the time span required for these degraded coal mine spoils to recover to the level of unmined control site. As has been revealed in the preceding chapters, the concentrations of nutrients as well as other physico-chemical conditions were more favourable in the surface soil layer (0-10 cm.depth) and the root proliferation and the microbial activity were also more in this layer. Therefore, mean seasonal values of various edaphic, vegetational and microbial parameters pertaining to the surface layer of all the sites under study were taken into consideration and subtracted from the control site values. Accordingly, the percentage recovery in respect of physico-chemical characteristics like WHC and CEC was slow in comparison to the soil organic carbon which showed a steep increase exhibiting a faster recovery between 8th and the 14th .year of spoil age. The organic carbon content in the 14 year old mine spoil attained a level which was closer to the control site. The numbers of both fungal and higher plant species approached a level that was similar to the unmined site. This also indicated that the coal mine spoils under study may take about 14 years for their restoration to the level of the unmined site.

Microbe-mediated processes like soil respiration, N-mineralization and

How fast
compare with
previous studies

?? // high rainfall may cause
... // the

How to actually
predict the pattern
of recovery ??

dehydrogenase enzyme activity are sensitive and suitable indicators of mine spoil recovery.

The findings of the present study clearly suggest that the pattern of recovery in coal mine spoils with respect to its physico-chemical and biological attributes is predictable. The recovery of the mine spoils under study is quite fast, indicating that even without any external management intervention, the spoils can recover in a relatively short span of time. This is presumably possible owing to high rainfall and availability of propagules of colonising plant species in the vicinity of the spoils. The results also suggest that the parameters studied can be used as indicators of the ecosystem health of such habitats. The selected parameters and the methodologies adopted for the purpose of studying natural reclamation of coal mine spoils seem to be quite appropriate and the data generated in the present study, could be useful in predicting recovery trends in degraded lands such as the coal mine spoils of Jaintia Hills in Meghalaya. This study could certainly pave the way for developing a suitable package of possible management interventions for accelerating the recovery process of such ecosystems.

SUMMARY

Extensive coal mining activity has led to shrinking of land base and creation of a landscape dotted with mine spoils. The pitfalls of such activities are felt in the impairment of soil, vegetation and microbial processes in these ecosystems. The present study analyses the structural and functional changes in the plant and microbial communities and edaphic characteristics of naturally recovering coal mine spoils of three different ages (0-2, 6-8 and 12-14 years) located in Jaintia Hills of Meghalaya, India. A nearby unmined forest stand served as control.

The physico-chemical characteristics of soils sampled from the mine spoils of different ages were determined and attributes of the plant community developing on these mine spoils were analysed with a view to understand the pattern of natural recovery in mine spoils. In order to obtain an all encompassing picture of the degraded coal mine spoils, an in-depth analysis of the soil microbial parameters viz., the bacterial and fungal population count, dehydrogenase activity, respiration, N-mineralisation rates and microbial biomass content were measured. Pattern of growth and resource allocation in three herbaceous species viz. *Trifolium repens*, *Arundinella khasiana* and *Borreria hispida* were analysed by growing them in pots containing the soils collected from the mine spoils of 6-8 year and 0-2 year age under controlled conditions in order to determine their suitability for mine spoil reclamation. The salient findings of the present study are as under:

The soils were sandy in texture and acidic in reaction. pH of the mine spoils was lower than the soils of the control site. Porosity of the youngest spoil was far greater than the control site. The water holding capacity (WHC) of the soil increased with the spoil age. On all sampling dates, the soil moisture content was maximum in the control and minimum in the 0-2 year old spoil. The cation exchange capacity (CEC) was low at all the sites, but the control site soil invariably showed higher CEC than the spoils.

The contents of organic carbon, total Kjeldahl nitrogen (TKN), available-P and exchangeable-K increased significantly with increasing spoil age. The concentration of phosphorus and potassium was very low in all the sites.

The total number of higher plant species recorded on the mine spoils was far less than that on the control site. There was an increase in species number with the age of the spoils. *Osbeckia stellata*, *Cyanotis vaga*, *Arundinella khasiana*, *Hypochaeris radicata*, *Axonopus compressus*, *Imperata cylindrica* and *Paederia foetida* occurred on all the four sites. *Gnaphelium luteo-album*, *Oxalis corniculata* and *Polygonum capitatum* were present only on the mine spoils. The fern species *Dicranopteris linearis* was the only plant which grew not only on the control site and older spoils (12-14 and 6-8 year old spoils), but was also the primary colonizer in the 0-2 year old spoil. On all the four sites, perennials were more in number than

the annuals. The unmined control site had more of annuals, perennials and shrubs in comparison to the mine spoils. Only two (2) perennials were recorded on the youngest (0-2 year old) spoil. On the control site, chamaephytes were more dominant than other life forms. A similar trend was observed in the case of 12-14 year old spoil unlike the 6-8 year old spoil which had a higher percentage of hemicryptophytes closely followed by the chamaephytes. The two species recorded on the 0-2 year old spoil belonged to the hemicryptophytic form.

Density and importance value indices (IVI) of different plant species showed significant seasonal variation. *Axonopus compressus* m showed maximum plant density followed by *P. begonifolia* on the control site. The important species growing on the four study sites are:

Control site : *Axonopus compressus*, *Arundinella khasiana*, *Paederia foetida*, *Plectranthus striatus*, *Pratia begonifolia*, *Paspalum orbiculare*, *Lantana camara*, *Melastoma sp.*, *Commelina bengalensis*, *Eupatorium adenophorum*, *Impatiens khasiana* and *Dicranopteris linearis*.

12-14 year old spoil : *Imperata cylindrica*, *Commelina bengalensis*, *Paederia foetida*, *Houttuynia cordata*, *Oxalis corniculata*, *Borreria hispida*, *Pratia begonifolia*, *Drymeria cordata*, *Dicranopteris linearis*, *Crossocephalum crepidiodes*, *Osbeckia stellata* and *Polygonum capitatum*.

6-8 year old spoil : *Axonopus compressus*, *Arundinella khasiana*, *Paederia*

foetida, *Dicranopteris linearis*, *Gnaphelium luteo-album* and *Centella asiatica*.

0-2 year old spoil : *Dicranopteris linearis* and mosses.

P. begonifolia, *A. compressus*, *E. adenophorum*, *D. linearis* and *P. foetida* recorded high IVI in the control as well as in the mine spoil sites. Seed production and vegetative propagation were generally poor. *Arundinella khasiana*, *Imperata cylindrica*, *Dicranopteris linearis*, *Eupatorium adenophorum* and *Lantana camara* occupied high position on all the sites with regard to their relative performance index (RPI) and could be useful in the reclamation of mine spoils. The index of floristic similarity (IFS) was maximum in the control site and least in the younger spoil. The number of plant species as well as the number of families to which they belonged increased with the increase in mine spoil age.

Population of bacteria, filamentous fungi and yeast increased with the increasing age of the mine spoils. The microbial population exhibited a marked seasonal and depth-wise variation. It was minimum in the 0-2 year old and maximum in the control site with increasing depth. The microbial population decrease substantially. Similar to higher plant species population, fungal population was also maximum in the control site and minimum in the youngest (0-2 year old spoil). The 12-14 year old spoil harboured 16 species and 6-8 year old spoil 12 species. Altogether 21 species were isolated. *Aspergillus heimalis*, *Sporobolomyces* (Yeast) were common to all the sites, whereas *Absidia cylindrospora* and

Scopulariopsis sp. were found only in the control site, *Helminthosporium* sp. and *Penicillium brevicompactum* were recorded only in the 12 -14 and 6-8 year old spoils respectively. The fungal similarity index showed that the control and the 12-14 year old spoil were more similar than the others. N-mineralisation rates, microbial biomass-C content, soil respiration and dehydrogenase activity declined with decrease in spoil age.

There was a gradual but significant increase in the plant biomass with increase in the spoil age. The control site had a greater biomass than the spoils. A distinct seasonality was observed in the aboveground and belowground biomass accumulation and production. Litter mass also demonstrated a similar trend. All the values showed a conspicuous increase with spoil age. *Axonopus compressus* among monocots and *Dicranopteris linearis* among fern species contributed maximum to the overall production and accumulation. The total primary production increased significantly with the increasing age of the mine spoil. The production of litter also followed a similar trend. The production of root in the oldest spoil (12-14 year) was quite close to that in the control site. Nutrient input and accumulation showed a trend similar to that of the biomass production. There was a significant seasonal and site-wise variation in TKN concentration of the aboveground phytomass. The concentration of total-P and exchangeable-K exhibited seasonal variation and a gradual increase with the increase in the age of spoils. The concentration of total-P

and exchangeable-K was very low in the root biomass. The TKN concentration in roots was, however, quite high during autumn season and low during winter. Maximum concentration of total-P in roots was recorded during rainy season, whereas, exchangeable-K concentration was highest during spring. The N, P and K concentrations showed a slight increase from the first to the second sampling year.

The concentration of TKN in the pine needle fraction of the litter was higher during autumn and low in spring. Similar trend was noticed for the total-P concentration as well. There was no definite trend in the exchangeable-K concentration. The exchangeable-K concentration increased from a low during winter to a high in autumn .

Trifolium repens (leguminous species) grown in soils from mine spoils under controlled conditions, showed a marked increase in shoot and root length and leaf number from the first (H_1) to the third (H_3) harvest. The plants grown in soil from the 6-8 year old spoil always exhibited better growth than the plants grown in soil from the 0-2 year old spoil. Plants responded more favourably to DAP than other treatments like calcium hydroxide (lime) and murate of potash (MOP). Apart from showing a better extension growth, *T.repens* also had a larger production of root and shoot biomass . The total biomass was variable but the Belowground /Aboveground biomass ratio exhibited a declining trend from H_1 to H_3 . The DAP treatment also promoted the accumulation of nitrogen in roots of *T.repens*. At the

Can a prediction
be made?

time of the third harvest (H_3), *A.khasiana* recorded a marked growth in root and shoot length as well as an increase in leaf number. Both the spoil types responded favourably to the DAP treatment and the plants grown in the DAP amended soils showed an increase in biomass accumulation besides showing a high concentration and accumulation of N sa compared to the other treatments. In contrast to *T.repens* and *A.khasiana*, *Borreria hispida* did not present any better picture. At H_3 , there was a pronounced increase in N-concentration and accumulation in the belowground compartment. The belowground/aboveground biomass ratio increased with increasing spoil age. All the plant species showed a better growth and nutrient accumulation in the 6-8 year old spoil than the 0-2 year old spoil.

The study revealed that coal mining has adversely affected the soil, vegetation and soil microorganisms in the coal mining affected areas of Jaintia Hills district of Meghalaya. Such habitats do not permit proper plant growth and development. The study further revealed that it would take several years for the mine spoils to restore naturally. The present study on the ecological and microbiological processes in coal mining affected areas has led to the following conclusions :

i) The estimation of organic-C, TKN, available-P and exchangeable-K, and calculation of C/N ratio have proved useful in the assessment of the status of ecosystem health and recovery pattern of the mine spoils.

ii) Analysis of soil microbial parameters like population counts , soil respiration , nitrogen mineralisation have helped in the understanding of the effects of mining on the biological activity of the soils .

iii) Phytosociological parameters such as floristic composition , IVI and RPI can be used as important tools for predicting the suitability of mine spoil habitats for plant growth and the information gathered on these aspects would be helpful in revegetating the mine spoils.

The present study has revealed that the analysis of soil and vegetation characteristics provides a holistic view of the structure and function of degraded ecosystems and when done in a time sequence, it would depicts the pattern of recovery of such ecosystems. It emerges that the natural recovery of mine spoils are reasonably fast and predictable. Based on the results of the study, it could be argued that the rate of ecorestoration can be enhanced by growing plant species such as *Trifolium repens*,(a nitrogen fixer), *Arundinella khasiana*,(a soil binder) and *Dicranopteris linearis*,(a versatile coloniser). There is a need for undertaking a detailed study on the potential of these species for ecorestoration of the spoils. The study also reveals that fertilizer amendments could be tried for accelerating the ecorestoration of these coal mine spoils. The present study indicates that under the conditions prevailing in the Jaintia Hills area, the mine spoils are likely to recover over a span of time, to the level of the undisturbed site. However, in order to bring

about faster revegetation and ecorestoration of these spoils, suitable management interventions may be required. This study certainly provides the baseline data and scientific informations) which could be utilized by the planners and managers interested in the rehabilitation of lands affected with coal mining.

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