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 (FeS₂) 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 uppermost 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??

Low could please see you until next?
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 (± standard error of mean).
Table 4.1. Proportion of sand, silt and clay in the mine spoils and the control site. (± S.E.M.)

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (cm)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0-10</td>
<td>1±0.0</td>
<td>2±0.0</td>
<td>97±0.0</td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>1±0.0</td>
<td>2±0.0</td>
<td>97±0.0</td>
<td>Sandy</td>
</tr>
<tr>
<td>12-14 year old spoil</td>
<td>0-10</td>
<td>8±1.0</td>
<td>6±0.0</td>
<td>86±1.0</td>
<td>Sandy loam</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>10±1.0</td>
<td>7.7±0.0</td>
<td>82.3±1.0</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>6-8 year old spoil</td>
<td>0-10</td>
<td>10±1.0</td>
<td>7.7±1.0</td>
<td>82.7±1.0</td>
<td>Sandy loam</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>9.2±1.0</td>
<td>7.3±1.0</td>
<td>83.0±1.0</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>0-2 year old spoil</td>
<td>0-10</td>
<td>6.5±2.0</td>
<td>4.5±0.5</td>
<td>89±0.0</td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>1±0.0</td>
<td>2±0.0</td>
<td>97±0.0</td>
<td>Sandy</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (cm)</th>
<th>Bulk density (g/cm³)</th>
<th>Porosity (%)</th>
<th>Cation exchange capacity (ml 100g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0-10</td>
<td>1.42±0.003</td>
<td>46.42</td>
<td>11.48±0.08</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>1.25±0.003</td>
<td>52.83</td>
<td>8.51±0.15</td>
</tr>
<tr>
<td>12-14 year old spoil</td>
<td>0-10</td>
<td>1.21±0.003</td>
<td>54.34</td>
<td>2.18±0.19</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>1.17±0.003</td>
<td>55.85</td>
<td>2.10±0.04</td>
</tr>
<tr>
<td>6-8 year old spoil</td>
<td>0-10</td>
<td>1.09±0.003</td>
<td>58.86</td>
<td>1.59±0.11</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>1.02±0.003</td>
<td>61.51</td>
<td>1.24±0.08</td>
</tr>
<tr>
<td>0-2 year old spoil</td>
<td>0-10</td>
<td>1.00±0.003</td>
<td>62.26</td>
<td>0.29±0.05</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.96±0.003</td>
<td>63.77</td>
<td>1.22±0.01</td>
</tr>
</tbody>
</table>
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 (± 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 (± 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 (± 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 (± 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 (± 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 (± standard error of mean).