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ORIGINAL ARTICLE

Bioreclamation of coalmine overburden dumps—with special empasis on micronutrients and heavy metals accumulation in tree species

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Abstract Major environmental impacts of opencast mining are degradation of landscape and aesthetics of the area by creating huge overburden dumps and deep voids at the mining sites. These overburden dumps are characterised by high rock fragment contents, low moisture retention capacity, higher bulk density, low nutrients, lower pH and elevated metal concentrations. Overburden dumps are reclaimed by tree species for stabilising as well as pollution control and overall improvement of the visual aesthetics. A field study was carried out in the old reclaimed coal mine overburden dumps at KD Heslong project, Central Coalfields, India to study the physico-chemical changes in the reclaimed overburden dumps and determines the magnitude of trace elements accumulation in the planted tree species. Total, bioavailable and acid extractable trace metals concentration in minesoils of overburden dump and topsoil in the mining areas was compared with undisturbed soil. The study showed that tree plantation improves the moisture contents, bulk density, pH and overall nutrient contents of minesoils. The study revealed that lower pH in the minesoils increases the bioavailabity of metals but concentration were found within toxic limits. However, ratio between total and bioavailable metals was found lower in overburden dumps than topsoil due to low pH and lack of organic matter. Out of six tree species studied, *Bambusa* shows highest accumulation of Fe and Cr. Bioaccumulation coefficient for Cr and Zn was found 74 times in *Bambusa* and 83 times in *Dalbergia sissoo*. The results of the study underscore the need for close monitoring of trace elements in reclaimed overburden dumps. Tree species like *Dalbergia sissoo, Eucalyptus, Cassia seamea, Acaccia mangium* and *Peltaphorum* were found to be the best species for bioreclamation of overburden dumps.

Keywords Coalmine overburden dumps · Tree · Bioreclamation · Metals · Bioaccumulation

Introduction

Surface mining causes drastic and immediate soil degradation and decline the soil quality due to stock piling of overburden dumps, creation of large voids and increase in particulate pollution load (Sengupta, 1993). Reclamation of overburden (OB) dumps by vegetation cover is an integral aspect of environmental management in any opencast coalmining project. In 2003–04, India produced about 328 million tonnes (mt) of coal making 3rd largest coal producing country in the world next to China and USA. It has been envisaged that coal demand may further increase to 620 Mt and 780 Mt in the year 2012 and 2017 respectively (Chaoji, 2002). Currently more than 80% of coal demand is being met by opencast mining thus disturbance of land is

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unavoidable. Virtually all surface mining methods produce dramatic change in landscape due to large-scale operation, results in the formation of large OB dumps and huge voids at mining sites.

Mine degraded soils are man-made habitat which experience a wide range of problems for establishing and maintaining vegetation cover. The adverse physicochemical properties tend to inhibit soil forming process and plant growth. In an acidic dumps, along with elevated metal concentration, other adverse factors includes high stone content, lack of moisture, higher compaction, very less soil forming fine materials, shortage of soil forming materials and organic matter (Maiti, 1994; Maiti and Saxena, 1998).

The OB dumps are environmentally very unstable, whether mechanically stable or not, may become sources of pollution when suitable controlling measures are not taken. The major effects are destruction of original habitat and land, air pollution, increase in heavy metal concentrations in the surroundings, water pollution by increasing the suspended solids loads in the water bodies which results increase in turbidity and deteriorates aesthetics (Down and Stocks, 1977; Sengupta, 1993). Restoration of a vegetation cover can fulfil the objectives of stabilisation, pollution control, visual improvement and removal of threats to surrounding population (Wong, 2003). The constraints related to plant establishment, physicochemical properties of mine wastes and choice of appropriate plant species are major issues for the revegetation of mine waste.

Coalmine OB dumps is being restored by the principle of *phytostabilisation*. The normal practice is to choose drought resistant, fast growing trees, which can grow in acidic, nutrient deficient, elevated metal contaminated soils. The effort should be aimed at finding out restoration success of nutrient poor acidic overburden dumps with liming, improvement of organic carbon, N and P status and reduce bio-availability of heavy metals due to elevated acidity.

The present work was undertaken to acquire information about the abilities of plant species growing on OB without any pH correction and accumulation of metals in leaf tissue, which take parts in nutrient cycling. Plant species grown in OB dumps are expected to take up metals and eventually accumulate them. Plants also developed mechanisms to avoid the uptake of trace elements or exclude them. Therefore, plant community established on mine spoils could be useful to minimize the impacts of mining. Thus, considering the diversity of plant responses in acidic dumps having different metals and toxicity levels, it is important to find out tree species, which could be useful for reclamation of OB dumps and overall improvements in soil quality.

Materials and methods

Site description

This study was carried out at KD Heslong surface mine coal project, located in the North Karanpura area of Central Coalfield Limited (CCL) in Ranchi district, Jharkhand. It falls between 23° 39′ 53″ and 23° 42′ 0″ N and longitudes 84° 59′ 15″ and 85° 0′ 3″ E. The topography of the block is undulating and rolling marked by small ridges and valleys. The climate is tropical with very high summer average temperature of 42°C to cold winter of 4°C. The average rainfall amounts to 1450 mm/year. The production was about 6.8 million tonnes per annum (2000–01) and spread over 4.5 km^2. The mining was done by Shovel-dumper combination and the average height of dump dumps varies between 40–50 m and quarry depth between 60–70 m. All the dumps were reclaimed by plantation of timber yielding tree species without any pH correction of the minesoils.

Overburden sampling

Sampling sites were selected after a geo- botanical survey of the area. Minesoils samples were collected from reclaimed and nearby unreclaimed overburden dumps, topsoil from mining sites (undisturbed but polluted due mining activity like dust deposition in the surface) and garden soil (undisturbed soil) as control. The overburden minesoils were collected by random grid method of 10 m × 10 m. From each grid, one composite sample was collected by mixing five sub-samples and reduced the weight approximately to 0.5 kg by conning-quartering method. In case of reclaimed overburden dumps, minesoils were collected from the rhizosphere of the planted tree species. In case of fresh overburden materials, composite sample was collected directly from the dumping area.

At each site a variable number of samples (5 nos) at 0–20 cm in depth were taken. Bulk mine soils samples were collected by split tube coring tool operated manually. Each sample was a composite sample of five

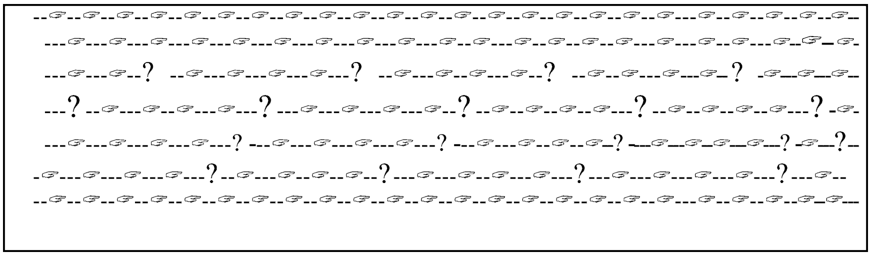


Fig. 1 Schematic scheme of tree plantation in the reclaimed overburden dumps. Each row consists of one type of tree species. Length of row 200 m and spacing between rows 2 m. Every 4th tree was measured for aerial growth and soil sample was taken from the rhizosphere. [☞ = *Dalbergia sissoo*; ? = *Gmelina arborea*; ? = *Cassia seamea*; ? = *Acacia mangium*; ? = *Eucalyptus sp.*].

sub-samples, which were collected, based on surface features (rocky or fine material, colours and textures) and types of vegetation cover. By conning-quartering method sample volume was reduced to 0.5 kg and put in a polythene bag. After collection, the samples were air-dried at the laboratory at room temperature (30–35°C) and lightly crushed with a mortar and pestle and passed through a 2-mm sieve.

Plant sampling

In the reclaimed overburden dumps, tree species were planted in a row-wise and each row covers a length of 200 m and distance between two rows was 2 m (density 2500 tree/ha) (Fig. 1). Ten leaves were collected from each plant (3rd and 5th leaf from apex) growing in the reclaimed OB dumps and put in a plastic bag and brought to the laboratory. Leaf samples were cleaned in abundant freshwater and rinsed with distilled water. The detail composition of tree species used for reclamation of OB dumps are given in Table 1.

Overburden and soil analysis

The percentage of soil fraction was determined by gravimetric method by taking the weight of the fraction passed through the 2-mm sieve divided by the total weight of the sample (Maiti, 2003b). The bulk density was determined by soil core method using 15-cm long and 7-cm diameter core (Maiti, 2003b). Field moisture was estimated by gravimetric method and total organic carbon was estimated by wet oxidation method (Ghosh *et al*., 1983). The pH and electrical conductivity (EC) was determined in soil/water (1:2.5) suspension with a pH meter and Conductivity meter respectively.

Table 1 Common plant species used for the reclamation of OB dumps

Sl. No.	Common name (English name)	Scientific name and family	Relative density (%)
1.	Acacia (Australian Wattle)	*Acacia uriculiformis* A. Cunn. (Mimosaceae, Fabaceae)	10*
2.	Mangium acacia	*Acacia mangium* L. (Mimosaceae, Fabaceae)	20*
3.	Gamhar (White Teak)	*Gmelina arborea* Roxb. (Verbenaceae)	5*
4.	Subabul	*Leucaena leucocephala* L.(Mimoseae, Fabaceae)	5
5.	Karanj (Indian Beech)	*Pongamia pinnata*, Pierrer (= *Derris indica* (Lam), Bennett) (Papilionaceae, Fabaceae)	5
6.	Chakundi (Indian wood tree)	*Cassia seamea* L (Papilionaceae, Fabaceae)	15
7.	Eucalyptus	*Eucalyptus* sp. (Myrtaceae)	5
8.	Sisham (Sissoo)	*Dalbergia sissoo* L. (Papilionaceae)	20*
9.	Neem (Margosa tree)	*Azadirachta indica* A. Juss. (Meliaceae)	5
10.	Radhachura (The Copper Pod or Rusty Shield-Bearer)	*Peltaphorum inerme* L. (= syn. *P. ferrugineum* Benth. *P. pterocarpum*, DC (backer)) (Cesalpineae, Fabaceae)	5*
11.	Bamboo	*Bambusa arundanacea* L. (Poaceae)	5*

*Leaves were collected for total digestion of metals

Available macronutrients and micronutrients

Available nitrogen was determined by the alkaline potassium permanganate method (Keeny and Bremer, 1966), available phosphorus by Bray's method (Bray and Kurtz, 1966), available potassium was extracted by neutral 1(N) ammonium acetate solution (soil-to-extractant ratio of 1:10) and determined by Flame photometer (Jackson, 1973). Available micronutrients cations, viz. iron, manganese, copper and zinc were extracted with diethylene triamine pentaacetic acid – calcium chloride, soil-to extractant ration, 1:2 (0.005 M DTPA – $CaCl_2$, pH 7.3) (Lindsay and Norvell, 1978) and analyzed by atomic absorption spectrophotometer (GBC, 902 Australia). Among tested extractant DTPA is one of the most common, although its effectiveness varies with different trace elements. The ratio of DTPA extractant to minesoils was 1:2 and shaking time was kept for 2 h. For acid extractable fraction 1N HNO_3 acid was used as extractant (1:10; w/v; acid: minesoils) and shacked for 2 h in a rotary shaker. The HNO_3 is stronger extractant and extracts metals from all fractions, except the insoluble residual fraction (Lavado *et al.*, 2000). Total metal content was determined by digesting 0.5 g of sample using concentrated HNO_3 and HCl (3:1) in a microwave.

Total metal content of leaves

Leaf samples were dried at 105°C for 12 h and grounded with a mortar and pestle. A homogenized sample of 1 g (nearest 0.001 g) was dissolved with a mixture of HNO_3, HF and $HClO_4$ (5:1:1) (Allen, 1989).

Statistical analysis

Analysis of variance was computed using the Microsoft EXCEL (analysis Toolpak) by single way ANOVA method. Mean of each sample was compared with each other by considering least significance difference (LSD) and significance differences was estimated at $P < 0.05$. The LSD (<0.05) was calculated for different soil parameters and analysis of variance value depicted by different letters for reclaimed and unreclaimed overburden dumps, topsoil in the mining areas, fresh overburden materials and control garden soils.

Results and discussion

Tree growth

The biological reclamation work was carried out during the year 1996–97 comprising of eleven tree species (2500 plants/ha). After six years, tree growth has been measured in terms of aerial height and observed that out of 11 tree species, 5 species were found growing satisfactorily. *Dalbergia sissoo* grows satisfactorily in the dumps followed by *Eucalyptus* and *Cassia seamea* (Table 2). Newly introduced plant like, *Acacia mangium* also grows well and remain evergreen. *D. sissoo* and *Gmelina arborea* are deciduous and sheds all the leaves at the end of January and green coverage of the dump during summer season because of growth of *A. mangium,* and *Cassia seamea.*

Physico-chemical properties

Table 3a depicts the physico-chemical properties of reclaimed OB dumps and topsoil of the mining area. Minesoils undergoes rapid changes in the physical and chemical properties as a result of accelerated pedogenic weathering process. Soil fraction (<2 mm size) is an important parameter and influences the surface properties of the dump and growth of plants. There was no significant difference was observed in soil fraction between reclaimed and unreclaimed overburden dumps and both the cases, it was found less than 50%, whereas

Table 2 Average growth of tree species in the reclaimed dump

		Average height (m)	
Sl No.	Name of species (No. of plants studied, *n*)	Min-max	Average (CV)
1.	*Dalbergia sissoo* ($n = 40$)	4.6–1.0	2.72 ± 1.05 (38.6)
2.	*Gmelina arborea* ($n = 35$)	3.0–0.5	1.98 ± 0.88 (44.5)
3.	*Cassia seamea* ($n = 35$)	3.2–1.0	2.27 ± 0.79 (34.8)
4.	*Acacia mangium* ($n = 35$)	2.6–1.2	1.66 ± 0.80 (47.9)
5.	*Eucalyptus sp.*($n = 20$)	3.4–2.6	3.20 ± 0.32 (28.7)

Table 3 **(a)** Physico-chemical analysis of reclaimed and unreclaimed overburden dumps soils, fresh overburden and topsoil ($n = 10$). Letters represents analysis of variance (ANOVA)

Sampling locations	Soil fraction (%)	Bulk density (Mg m^{-3})	Field moisture (%)	pH (1:2.5)	EC (dSm^{-1}) (1:2.5)
ROB	44.4c	1.76ab	6.08a	4.93a	0.093b
UOB	46.9bc	2.04a	3.24b	4.55a	0.860a
TS	56.2ab	1.45b	6.88a	5.07a	0.073b
FOB	64.8a	na	na	4.81a	0.259b
5% LSD	11.7	0.39	1.23	0.68	0.257

Values with different letter indicates significant difference at $p < 0.05$
ROB = Reclaimed overburden dump; UOB = Unreclaimed overburden dump; TS = Top soil collected close to mining face; FOB = Fresh overburden materials; CS = Garden soil (Control) n = number of samples. na = not analysed

in topsoil and fresh OB materials it was 56% and 65% respectively. The topsoil is mainly of lateritic in nature enriched with boulder materials. Hu *et al.* (1992), are of the opinion that soil with more than 50% stoniness should be rated to be of poor quality. The stone content of the most reclaimed coalmine overburden dumps were reported as high as 80–85%, which is due to geo-mining conditions (Maiti and Saxena, 1998; Maiti and Sinha, 2001). However in the present case, soil fraction was found higher than other mining areas.

Average field moisture of all the dumps was found 6% and highest in the reclaimed OB dump, which is similar to topsoil, however there is a significant differences of moisture content between reclaimed and unreclaimed OB dumps soils. The field moisture content in a dump is a fluctuating parameter which is dependent on time of sampling, height of dump, stone content, amount of organic carbon, texture and thickness of litter layers on dump surface (Maiti, 1994). As sampling has been done during winter, average field moisture content was found to be 5%, which may be sufficient for the plant growth. During peak summer (May–June), moisture content in the OB dumps come down as low as 2–3% (Maiti *et al.*, 2002). Low moisture content in the OB dumps may be attributed due to lack organic matter, higher stone content and sandy texture.

The bulk density of reclaimed OB dumps is a function of soil texture and aggregation, types of plant species used, age of reclaimed dumps, and types and amount of heavy equipment used during technical reclamation (Barnshiel and Hower, 1997). Among the three locations, soil bulk density varied in the order unreclaimed soils (2.04 Mg m^3) > reclaimed soils (1.76 Mg m^3) > topsoil (1.45 Mg m^3). The lower bulk density in reclaimed mine soils compared to unreclaimed mine soils is due to higher clay contents, higher organic matter, continuous dense grass and tree cover.

The pH of the OB dump (0–15 cm) was found to be varied from 4.6 to 6.0 and may be categorized as acidic dump. Soil pH in the reclaimed mine soils was close to topsoil for top 15 cm depths. The pH of the topsoil was also found to be acidic in nature, which is due to the geo-climatic condition of the region. At low pH (4.6 to 4.7) along with the availability of micronutrients, bioavailability of toxic metals such as nickel, lead and cadmium also increased (Maiti, 2003a). The EC of the minesoils was found to be 0.2 to 0.05 dSm^{-1}, which may not be a problem for plant growth. The improvement in minesoil quality due to reclamation was evident from the increase in soil pH, which has increased from 4.55 in the unreclaimed dumps to > 4.93 in the reclaimed minesoil for the top 15 cm depths.

Macronutrient status

The major sources of macronutrients (NPK) in the OB dumps are decomposition of organic matter and the major sources of organic matter is the leaf litter accumulation. The average organic carbon (OC) level in reclaimed minesoil was found higher than topsoil due to accumulation and decomposition of leaf litter. This higher level of OC in reclaimed and unreclaimed minesoils compared to topsoil may be due to the deposition of coal dust and presence of carbonaceous shell and coal fraction in the overburden materials (Table 3b).

Available N in the top 15-cm depth was found 30 ppm, which is less than available N present in topsoil (49 ppm). The lower value of available N in OB dumps may be attributed due to lack of microbial activity and mineralisation of organic matter. Available P

Table 3 (b) Nutritional characterizes of reclaimed and unreclaimed overburden dumps soils, fresh overburden and topsoil ($n = 10$). Letters represents analysis of variance (ANOVA)

Sampling locations	OC (%)	Av-N (ppm)	Av-P (ppm)	Na [cmol (+) kg^{-1}]	K [cmol (+) kg^{-1}]	CEC [cmol (+) kg^{-1}]
ROB	1.82a	30.1b	1.20b	0.186a	0.094b	2.04b
UOB	1.53ab	22.4b	0.76b	0.166a	0.099b	1.67b
TS	1.16b	48.5a	3.64a	0.153a	0.134a	4.07a
FOB	0.56c	na	1.20b	0.270a	0.056c	1.99b
5% LSD	0.39	14.0	1.43	0.120	0.030	1.39

Values with different letter indicates significant difference at $p < 0.05$
ROB = Reclaimed overburden dump; UOB = Unreclaimed overburden dump; TS = Top soil collected close to mining face; FOB = Fresh overburden materials; CS = Garden soil (Control) n = number of samples. na = not analysed

was also found lower in comparison to topsoil, which may be due to the fixation of phosphorus by coal shell (Coppin and Bradshaw, 1982) and in acidic pH, it form insoluble iron- aluminum phosphate (Brady, 1985). Exchangeable potassium was found lower in reclaimed minesoils than topsoil. Cation exchange capacity for the topsoil was found significantly higher than minesoils (Table 3b).

Micronutrients and toxic metals status

The concentration of available, acid extractable and total metals such as Fe, Mn, Cu, Zn, Ni, Pb, Co and Cr in reclaimed, unreclaimed minesoils, fresh overburden materials, topsoil and control garden soil are given in Table 4. In acidic pH, bioavailability of trace metals concentration increases which may leads to

Table 4 Micronutrients and heavy metal contents (mg kg^{-1}) of reclaimed and unreclaimed overburden dumps soils, fresh overburden and topsoil ($n = 10$). Letters represents analysis of variance (ANOVA)

Sampling locations	Fe	Mn	Cu	Zn	Cr	Co	Ni	Pb
DTPA extractable metals (1:2)								
ROB	24.2bc	26.4bc	1.94a	3.04a	0.13a	0.47c	1.10a	2.21a
UOB	49.9a	45.7a	1.58ab	2.38b	0.12a	1.11b	0.44b	1.84ab
TS	8.6d	31.9b	1.36b	2.00c	0.09b	1.47a	0.37b	2.24a
FOB	12.4cd	10.1	0.85c	2.9	0.12a	1.17b	0.92a	1.50b
CS	31.6b	18.2cd	0.51c	0.65d	bdl	0.39c	0.11c	2.29a
5% LSD	13.5	12.7	0.42	0.29	0.024	0.25	0.2	0.52
1N HNO_3 extractable metal (1:10)								
ROB	303c	76.8a	10.8a	11.6a	0.48ab	2.28ab	2.43a	6.41ab
UOB	415b	86.1a	7.3b	12.5a	0.56a	2.41a	1.94a	4.36bc
TS	151d	42.0b	6.9b	5.8c	0.63b	1.80b	0.99b	7.67a
FOB	441b	18.0	3.2c	10.1b	0.49b	1.83b	1.80ab	3.53c
CS	1420a	31.8bc	10.4a	3.4d	0.34a	2.45a	2.13a	5.64b
5% LSD	102	20.0	2.4	0.99	0.17	0.51	0.89	1.54
Total metal (Aqua regea)								
ROB	13972b	238b	22.5b	104b	ns	14.6b	16.8b	34.9a
UOB	19672a	256b	22.1b	95.9b	ns	21.2a	1.8c	29.4ab
TS	18148a	170c	24.2b	75.9c	ns	22.0a	28.3a	31.4a
FOB	4720c	88[d]	6.9c	63.9d	ns	7.6c	6.0c	21.3bc
CS	20510a	354a	34.8a	117a	ns	6.7c	15.0b	18.5c
5% LSD	3349	58	6.06	12	ns	6.4	8.8	9.0

Values with different letter indicates significant difference at $p < 0.05$
ROB = Reclaimed overburden dump; UOB = Unreclaimed overburden dump; TS = Top soil collected from the mining face; FOB = Fresh overburden materials; CS = Garden soil (Control); n = number of samples; ns = non significant; bdl = below detection limit.

Table 5 Correlation between bioavailable metals in reclaimed coalmine overburden dumps

	pH	DTPA Fe	DTPA Mn	DTPA Cu	DTPA Zn	DTPA Ni	DTPA Pb	DTPA Co	DTPA Cr
pH	1								
DTPA Fe	−0.538*	1							
DTPA Mn	−0.490*	0.637*	1						
DTPA Cu	0.315	−0.258	−0.193	1					
DTPA Zn	0.520*	−0.628*	−0.597*	0.585*	1				
DTPA Ni	0.289	−0.230	−0.573*	0.547*	0.826*	1			
DTPA Pb	−0.136	0.168	0.623*	0.165	−0.051	0.061	1		
DTPA Co	−0.352	0.022	0.229	−0.617*	−0.650*	−0.663*	0.089	1	
DTPA Cr	−0.070	0.230	0.063	0.069	0.282	0.453	−0.241	0.483*	1

*Significance at $P < 0.05$

the toxicity problems for the growth of plants. The critical metal concentration for the coalmine overburden dumps have not been reported in the literature thus values suggested by Kabata-Pendias and Pendias (1984) was considered for the present study because these values have been used by several workers for the evaluation of phytotoxicity in copper and lead-zing tailings (Alvarez *et al.*, 2003). The critical total soil concentrations have been defined by researches as " the range of values above which toxicity is considered to be possible". Kabata-Pendias and Pendias (1984) considered the following values of the critical soil data: 1500–3000 mg kg^{-1} (Mn), 60–125 mg kg^{-1} (Cu), 70–400 mg kg^{-1} (Zn), 100 mg kg^{-1} (Ni), 100–400 mg kg^{-1} (Pb), 25–50 mg kg^{-1} (Co), 3–8 mg kg^{-1} (Cd) and 75–100 mg kg^{-1} for Cr.

Both bioavailable and acid extractable Fe in reclaimed and unreclaimed minesoils were found higher than topsoil. In control garden soil, the available Fe was found higher in the order of 32 mg/kg. The content of Fe was found to be adequate in the mine soil as they contain more than 4.5-mg kg^{-1} of soil (Lindsay and Norvell, 1978). Available Fe is negatively correlated with pH ($r = -0.538$; $P < 0.05$) and Zn ($r = -0.628$; $P < 0.05$) and positively correlated with Mn ($r = 0.637$; $p < 0.05$) (Table 5). Available Fe constitutes 8% of acid extractable Fe in OB, whereas in case of topsoil and garden soil, it constitutes 13% and 15%. The lower values in case of OB dumps may be due to the facts that OB materials were excavated from a deeper depth. The ratio of available: acid extractable: total in OB dumps was found as 1: 12: 576; in case of topsoil, 1: 7.7: 309 and garden soil as 1: 6.8: 98.

Available-Mn was found to be varied from 16.8 to 32.4 mg kg^{-1} with an average value of 26.4 mg kg^{-1} in reclaimed dumps, whereas in the unreclaimed dumps the value was 46 mg kg^{-1}. However in topsoil Mn was found in the order of 32 mg kg^{-1}. In the fresh overburden materials Mn concentration was found only 10 mg kg^{-1}, which indicates that higher Mn concentration in overburden dumps and topsoil may be due to the deposition of air–borne Mn. Similar trends also were found in case of acid extractable and total concentration. The ratio of available: acid extractable: total Mn for minesoils soil was found 1: 3: 9; for topsoil 1: 1.7: 3.8 and garden soil 1: 1.7: 19.4. The decreasing value of Mn in OB dumps may be perhaps due to formation of Mn-complex with organic matter. Considering the critical concentration of DTPA-Mn of > 1 mg kg^{-1}, there may not have deficiency problems in minesoils. Significant negative correlation with found with pH ($r = -0.490$; $p < 0.05$), Zn ($r = -0.597$) and Ni ($r = -0.573$; $p < 0.05$) and positive correlation with Pb ($r = 0.623$) (Table 5). Correlation studies indicate that Mn is available in acid pH and increase in OC decreases the availability of Mn in overburden dumps.

Zn in reclaimed dump was found in the range of 3.0 to 4.0 mg kg^{-1} with an average concentration of 3 mg kg^{-1}, which is higher than unreclaimed dumps, fresh overburden materials and topsoil in mining areas. However, in natural garden soil available Zn (0.65 mg kg^{-1}) was found significantly lower than mining areas. The HNO_3 extractable and total Zn concentrations also found to follow the same trend, which indicates that Zn concentration is higher in minesoils and topsoils in mining areas than that of natural soils.

Similarly, higher Zn values were also observed in the minesoils of South Eastern Coalfields limited (SECL) in the order of 1.6 mg kg^{-1} (0.7 to 2.8 mg kg^{-1}) (Maiti, 2003a). Considering the critical limit of DTPA-Zn in soil as 0.63-mg kg^{-1}, it may be concluded that minesoils generally have higher level of Zn, which may be to geological nature of rocks.

The available-Cu were found in the ranged from 1.7- to 2.25 mg kg^{-1} with an average value of 1.94 mg kg^{-1} in the reclaimed dumps, which is higher than topsoil and control garden soil. In the fresh overburden materials, available Cu was found only 0.85 mg kg^{-1} and higher values in minesoils and topsoil in the mining areas may be due to deposition air borne Cu on the surface horizon. The concentration of 0.4 mg Cu kg^{-1} of minesoils has been considered as adequate for plant growth (Lindsay and Norvell, 1978), whereas average concentration of available Cu in the normal soil was reported as 1.7 mg kg^{-1} (0.4 to 4.8 mg kg^{-1}) (Tripathy *et al.*, 1994). In OB dumps of SECL, DTPA-Cu was found 0.35 mg kg^{-1} (0.2 to 1.15 mg kg^{-1}) (Maiti, 2003a). Higher level of available Cu in OB dumps may be due to the presence of sulfide minerals in parent rocks. Significant positive correlation was observed between DTPA Zn ($r = 0.585$; $p < 0.05$) and DTPA Ni ($r = 0.547$; $p < 0.05$) and negative correlation with DTPA Co ($r = -0.617$; $p < 0.05$) (Table 5). Higher concentration of Cu in acid extractable and total digestion also indicates that higher Cu concentration in minesoils due to deposition of air borne Cu. The ratio between available: acid extractable: total Cu for mine soil was found as 1: 5.7: 12; topsoil 1: 10: 34.6 and garden soil 1: 20: 68. The ratio indicates that higher availability of Cu in minesoil and topsoil in the mining area than garden soil probably due to the to lack of organic matter and acidic pH.

The average Ni concentration in the reclaimed dump was found 1.1-mg kg^{-1}, which is higher than topsoil and control soil. It has been reported that mobility of Ni increases as pH decreases below 6 (Alloawy, 1990). Higher Ni values in reclaimed OB dumps were perhaps may be due to comparatively higher concentration of Ni present in the OB rocks (28 mg kg^{-1}), acidic pH and deposition as air-borne particulate matter. Available Ni in OB dumps was found negatively correlated with available Co ($r = -0.663$; $p < 0.05$). The ratio between available: acid extractable: total Ni for OB soil calculated as 1: 2.2: 16.4; topsoil 1: 2.7: 75.7 and garden soil 1: 20: 139. The higher availability of Ni in the OB dumps and topsoil in the mining areas was due to acidic pH and lower organic carbon.

There was no significant differences observed between the concentrations of bioavailable Pb in reclaimed OB dumps and topsoil in the mining areas (Table 4). The similar values may be due to the deposition of Pb particulates from vehicular exhaust from mining operations. Lower values of Pb concentrations in the reclaimed dump may be due to chelatization of Pb with organic matter. The ratio between available: acid extractable: total Pb for OB soil as 1: 2.9: 15.9; topsoil 1: 3.5: 14 and garden soil 1: 4: 33.

The concentrations of bioavailable Co was found in the order of topsoil > reclaimed dump > control soil. Lesser value of Co in reclaimed dump and control soil may be due to presence of higher organic carbon. Positive correlation was found between Co and Mn because of its close association with Mn in mineral form. In the reclaimed OB dumps, available Co concentrations have shown significant negative correlation with DTPA Cu, Zn and Ni.

Available and acid extractable Cr in reclaimed OB dumps were found as 0.132 mg kg^{-1} and 0.483 mg kg^{-1} respectively, which was higher than topsoil (0.09 mg kg^{-1}). The higher values in the reclaimed OB dumps may be attributed to the deposition of air borne particulate matter released from heavy earth moving machineries. Significant positive correlation was found between DTPA Co with DTPA Cr in reclaimed OB dumps ($r = 0.483$; $p < 0.05$).

Accumulation of heavy metals in planted tree species

The metal accumulation in the leaves of the tree species was mostly found within the normal range except for few tree species as shown in Fig. 2. The critical plant concentration is the level above which toxicity effects may occur in plnats. Kabata-Pendias and Pendias (1984) proposed the following range values of the critical plant data: 300–500 mg kg^{-1} (Mn), 20–100 mg kg^{-1} (Cu), 100–400 mg kg^{-1} (Zn), 10–100 mg kg^{-1} (Ni), 30–300 mg kg^{-1} (Pb), 15–50 mg kg^{-1} (Co), 5–30 mg kg^{-1} (Cd and Cr). Plant like *Peltaphorum* accumulated beyond 500 mg kg^{-1} of Mn, where as *Acacia, Peltaphorum* and *Dalbergia* accumulates greater than 100 mg Zn kg^{-1} but well below the upper toxic limits of 400 mg Zn kg^{-1}. Element like Cu was found to be accumulated well below

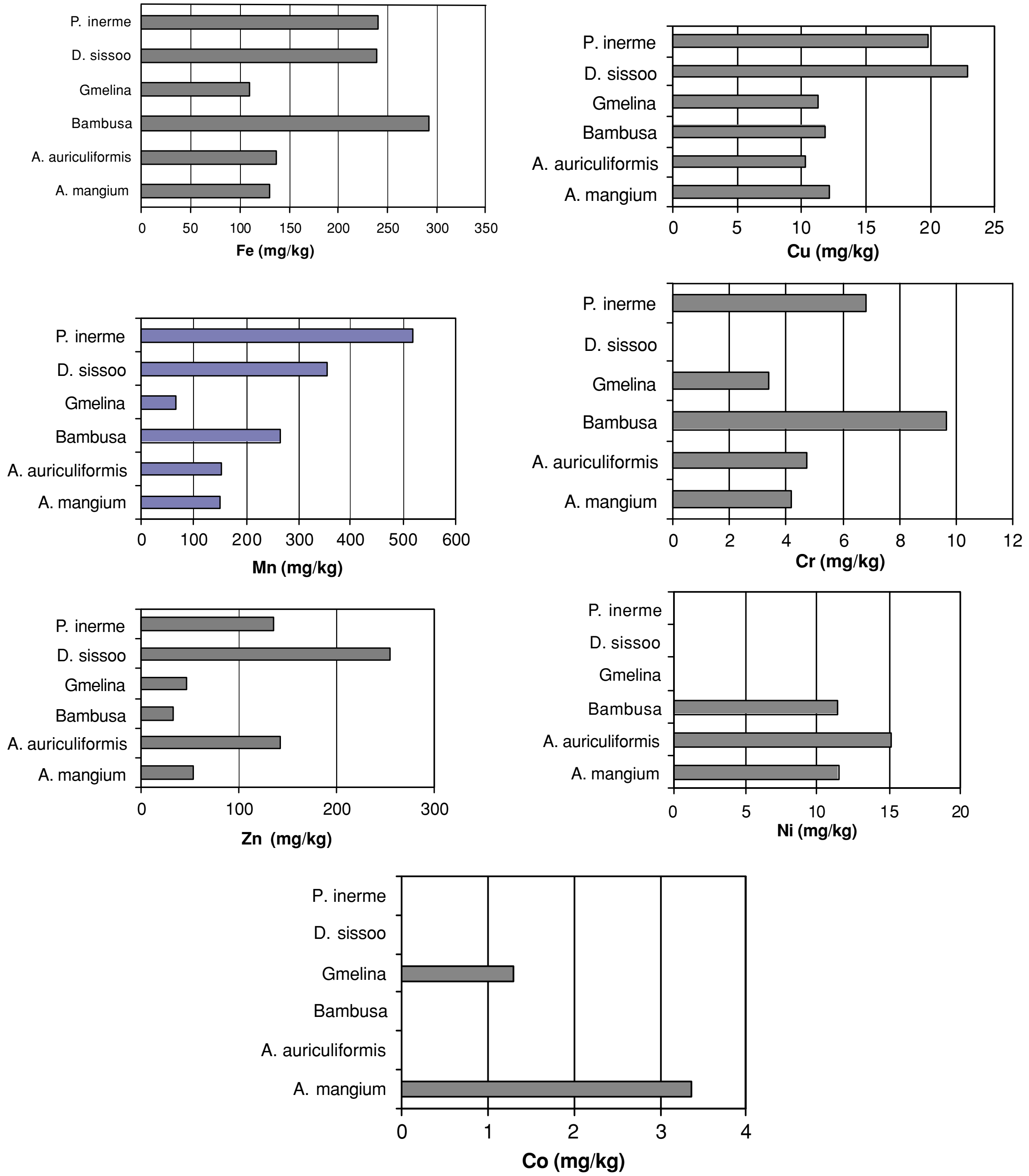
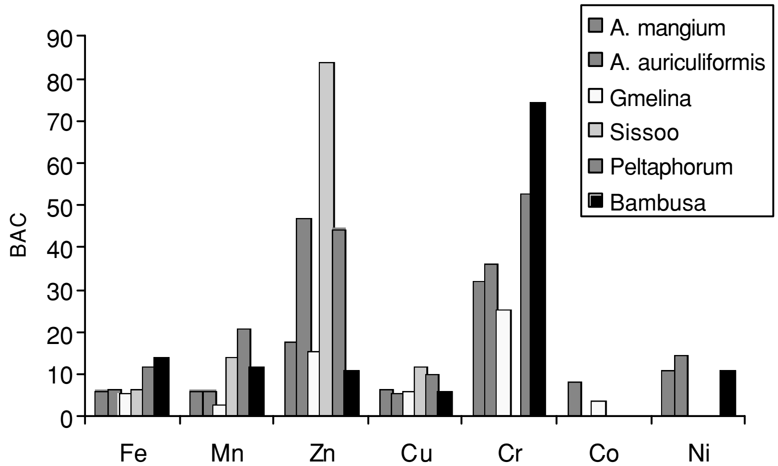


Fig. 2 Metal concentration in the leaves of plants growing on coalmine overburden dumps (mg/kg dry wt.)

20 mg kg^{-1} except *Dalbergia,* which accumulates 23 mg Cu kg^{-1}. Accumulation of Ni and Cr were found well within the critical concentration but concentration of Pb was found below detection limits. Average Fe concentration in leaf tissue was found 192 mg kg^{-1}, which was about 8 times more than DTPA-Fe in OB dumps.

Metal accumulation in plants can be evaluated using a simple index, defined as biological accumulation coefficient (BAC = metal content in

Fig. 3 Bioaccumulation coefficient of different metal in the tree leaves



plant/DTPA-extractable metal) (Dinelli and Lombini, 1996; Alloway, 1995; Maiti, 2004, 2005). Bioaccumulation coefficients for different metals in different tree species were presented in Fig. 3. BAC of Fe for different tree species were found as follows as *Bambusa (14)* > *Peltaphorum (12)* > *A. mangium* = *A. auriculiformis* = *Dalbergia* = *Gmelina* (6). Total Mn in leaf tissue was found in the range of 69–517 mg kg^{-1} with an average of 252 mg kg^{-1}. Accumulation of Mn varied from 6 to 20 times within the six tree species. Bioaccumulation coefficient (BAC) of Mn for tree species were found as *Peltaphorum* > *D. sissoo* > *Bambusa* > *A auriculiformis* = *A mangium* > *Gmelina*.

Average total Zn concentration in leaf tissue was found 110 mg kg^{-1} and BAC of Zn for plant species growing in dumps were found in the following magnitude-*D. sissoo (83)* > *A. auriculiformis (47)* > *Peltaphorum (44)* > *A. mangium (17)* > *Gmelina (15)* > *Bambusa (11)*. Cu being a less mobile metal in plants, the total Cu concentration in leaves were found in the range of 10.23 to 22.93 mg kg^{-1} with an average concentration of 15 mg kg^{-1}. BAC of Cu in all six-plant species was found in the range of 5.3 *(A. auriculiformids)* to 11.9 (*D. sissoo*).

Absorption of Ni by the plants increases as the exchangeable fraction in soil increases. However, liming and additions of organic matter to the soil, results the decrease of both extractable Ni and the amount taken up by plants (Alloawy, 1990). Within a plant, Ni is considered to be a highly mobile element, and suggested that it behave in a similar fashion to Zn. Only three-tree species showed Ni concentration in leaves (11–15 mg kg^{-1}), and species like *Gmelina, Dalbergia* and *Peltaphorum* showed below detection limit. Reasons may be, some plants can also develop mechanisms to avoid uptake of trace elements or exclude them (Baker, 1981). The BAC of Ni in plants was found as follows: *A. auriculiformis (14)* > *A. mangium* = *Bambusa (10)*.

Concentration of Cr in plant-available form is extremely small in the majority of soil, and this lack of solubility is reflected in the low concentrations of the elements in the plants (McGrath and Smith, 1990). Study conducted in nine different crop plants showed that 98% of either Cr (III) or Cr (VI) absorbed by the plant was retained in the roots and suggested that plants, which accumulate higher amounts of Fe, also accumulate higher amounts Cr (McGrath and Smith, 1990). In the reclaimed OB dumps maximum accumulation of Fe was found in *Bambusa* (292 mg kg^{-1}), which also showed highest accumulation of Cr out of six species. Average total Cr in the leaf tissue was found 6 mg kg^{-1} except for *D. sissoo*. The BAC of Cr was found highest amongst all the trace elements studied in dumps and the value of accumulation coefficient were found as *Bambusa (74)* > *Peltaphorum (52)* > *A. auriculiformis (36)* > *A. mangium (32)* > *Gmelina (25)*.

Uptake of Co by plants is a function of the concentration present in the soil solution and its uptake increases as the soil pH decreases (Alloawy, 1990). Only leaves of *A. mangium* and *Gmelina* showed traces of Co. The Pb element was not detectable in leaf tissue, because it is highly immobilized in the root and root bark portions in plant (Maiti, 2000).

Conclusions

The following are the significant findings emerging from the present study:

1. Among the 11 tree species planted during the bioreclamation programme, the superior species are *Dalbergia sissoo, Eucalyptus, Cassia seamea* and *Acacia mangium,* all are introduced species.
2. Major limiting factors for bioreclamation of dumps are higher stone contents, lower field moisture, acidity, lower organic matter, nitrogen and phosphorus.
3. Improvement of field moisture, bulk density, pH, organic carbon, macronutrients (NPK) and CEC in the minesoils as a direct effect of bioreclamation.
4. The elevated concentration of metals in the minesoils of overburden dumps and topsoil of mining areas may be due to deposition of air borne particulates matters and geochemistry of overburden strata.
5. Acidic nature of minesoils in OB dumps increases bioavailabilty of trace elements (micronutrients) but it is not going to cause any toxicity problems.
6. Out of six species studied, maximum accumulation of Fe was observed in *Bambusa*, which also shows highest accumulation of Cr. Bioaccumulation coefficient of Cr and Zn was found 74 times in *Bambusa* and 83 times in *Dalbergia sissoo*. All these metals are going to transfer to the ecological food-chain, hence some ameliorative measures is required, such as liming at the top 15 cm to bring down the pH.

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