Journal of Environmental Sciences Vol.17, No.1, pp.168—174, 2005

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2005)01-0168-07 **CLC number**: X131 **Document code**: A

Heavy metal concentrations in redeveloping soil of mine spoil under plantations of certain native woody species in dry tropical environment, India

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Abstract: Total concentration of heavy metals(Cd, Cr, Cu, Fe, Pb, Ni, Mn and Zn) was estimated in the redeveloping soil of mine spoil under 5-yr old plantations of four woody species namely: *Albizia lebbeck*, *Albizia procera*, *Tectona grandis* and *Dendrocalamus strictus*. The data recorded in the present study were compared with other unplanted coal mine spoil colliery, which was around to the study site and adjoining area of dry tropical forest. Among all the heavy metals, the maximum concentration was found for Fe and minimum for Cd. However, among all four species, total concentrations of these heavy metals were recorded maximally in the plantation plots of *T. grandis* except for Fe, while minimally in *A. lebbeck* except for Zn, whereas, the maximum concentration of Fe and Zn was in the plantation plots of *D. strictus* and *A. procera*. Statistical analysis revealed significant differences due to species for all the heavy metals except Cu. Among four species, *A. lebbeck*, *A. procera* and *D. strictus* showed more efficient for reducing heavy metal concentrations whereas *T. grandis* was not more effective to reduce heavy metal concentrations in redeveloping soil of mine spoil.

Keywords: *Albizia lebbeck*; *Albizia procera*; *Dendrocalamus strictus*; heavy metals; mine spoil; restoration; *Tectona grandis*

Introduction

As a result of mining and coal combustion, significant areas of land are degraded and existing ecosystems replaced by undesirable waste materials in the form of dumps, tailing dams and ash dams (Piha, 1995). The coal extraction process drastically alters the physical and biological nature of a mined area. Strip mining, commonly practiced to recover coal reserves, destroys vegetation, causes extensive soil damage and destruction and alters microbial communities (Corbett, 1996).

Therefore, there is a need for an increased knowledge of tolerating efficiency of those hardy species chosen for establishment of vegetation cover on coal mined spoil especially for heavy metal concentration. Mining is the second source of heavy metal contamination in the soil after sewage sludge. In the dry tropical region of Indian territory, there are many economically important natural resources including minerals, wildlife, water, timber, forage, and food. Development of these resources often leads to degradation of plant communities, which may require restoration efforts. A total forest area of about 6000 hm^2 is likely to be affected by coal mining in Singrauli area(Singh, 1995). Thus, generation of coalmine spoil threatens the economic, ecological and social sustainability of Indian dry tropics where such industry is in operation.

Mine spoils possess very rigorous conditions for both plant and microbial growth because of low organic matter contents, and other unfavourable physico-chemical characteristics (Jha, 1993; Singh, 1995; 1996; 1999b; 2002). Therefore, primary aim to revegetation is the control of soil erosion through plant cover in the short term and the development of self-sustaining community through colonization of native plants in the long term (Singh, 1995; 2004a). Nevertheless, restoration success depends on the augmentation of biological activity of the surface soil horizons in the long term (Arnold, 1984) as well as development of direct relation with vegetation and soil by which acceleration of structure and functioning could sustain more or less a real shape of that pre-mined natural habitat(Singh, 1995; 1996; 1999b; 2002). Thus, problems of restoration may be potentially solved by re-structuring the vegetation through planting by suitable species and then after by manipulating the rates of nutrient cycling and resource use(Singh, 1995). However, natural recovery process in mine spoil is very slow, it also depends on time and space, and is influenced by geographical and climatic factors and ecological conditions of the site(Jha, 1991; Singh, 1995). On the other hand, in brief, establishment of vegetation on abandoned mined lands is hindered by physical factors such as high temperature, low availability of soil moisture (Richardson, 1967); uncertain structure and unstable slopes due to hilly terrain (Down, 1975a; 1975b); and compaction (Richardson, 1975). Sparse vegetation growth on abandoned mine soils also results from low organic matter, low levels of plant nutrients particularly P (Fitter, 1974) and N (Williams, 1975), K concentration (Chadwick, 1973), and high levels of metals (Al and Mn)(Sutton, 1987; Kost, 1997).

Mine spoils have a number of physico-chemical irregularities, toxic level of metals is one of them. Recently, the interest in the accumulation of heavy metals in the wasteland soils has been emphasized. According to Dickinson *et al*. (Dickinson, 2000b), trees potentially provide one way of safely, effectively and economically managing low value contaminated land in the medium to long term. Despite concern about toxic effects of soil pollution, it has become

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increasingly apparent that trees frequently survive and grow on soils containing levels of contamination a factor of 10 or 100 × higher than current guidance value. Based on UK regulation and legislation, they further point out that heavy metal contamination of soil is largely based on total metal concentrations, in common with many countries. A soil is contaminated when the concentrations of one or more elements or compounds exceeds baseline and background levels (Dickinson, 1991; 1997; 2000b; Lombi, 1998). Soil trace elements, which include heavy metals and metalloids, are often separated in to those considered to be primarily zootoxic (As, Cd, Cr, Pb, Hg, Se) or phytotoxic(Cu, Zn, Ni, B) (ICRCL, 1987). Although heavy metals have a beneficial effect on living organisms as micronutrients, they become toxic when high concentration levels used up (Alloway, 1995). On the other hand, however it is difficult to identify critical contamination limits for concentrations of heavy metals in the soils, due to physico-chemical and biological variables, which control bioavailability and potential toxicity (Dickinson, 2000b).

Toxic effects of heavy metals have been observed on many higher plants including forest trees (Bazzaz, 1974; Bradshaw, 1983; Dobson, 1995; Dickinson, 2000b) as well as on soil microorganisms(Jackson, 1977). Contamination of mine spoil by heavy metals constitute an important task for establishment and further growth and development of plants on mine spoil. However, it is widely documented that trees provide improved soil conditions, for example aeration, tillage and incorporation of organic matter are known to improve conditions for natural attenuation (Rhykerd, 1999; Singh, 1999b; 2004a; Dickinson, 2000b). Not only this, trees also provide a system for waste disposal of bio-solids whilst also a bio-energy crop(Bardos, 1999). Perhaps, plant species and clones of trees may be used for maximum uptake of pollutants, which can then be harvested and removed leaving behind a pristine soil (Dickinson, 1997; Bañuelos, 1999).

A desired species for planting on mine spoils should possess the abilities: (1) to grow on poor and dry soils; (2) to develop the vegetation cover in short time and to accumulate biomass rapidly; (3) to bind soil for arresting soil erosion and checking nutrient loss; and (4) to improve the soil organic matter status and soil microbial biomass, thereby enhancing the supply of plant available nutrients (Singh, 1999b). In addition, the species should be of economic importance. Taking into account these facts four species were selected for plantation in this study: *Albizia lebbeck* (L.) Benth., *A. procera* (Roxb.) Benth, *Tectona grandis* (L. f.) and *Dendracalamus strictus* (Roxb.) Nees. The selected species are indigenous and possess varied ecological characteristics such as short stature leguminous tree (*A. lebbeck*, *A. procera*), slow growing timber tree (*T. grandis*) and fast growing woody grass(*D. strictus*).

Therefore, our present study reports the impact of these 5-yr old native woody species in modifying the heavy metal concentration in redeveloping soil of mine spoil with the hypothesis that native species can survive well and accumulate more biomass, net primary production as well as more concentration of heavy metals through the various components viz: root, stem, leaf and fine root, respectively.

1 Materials and methods

1.1 Study site

The study was conducted in the east section of the Jayant Block, located in the northeastern part of Singrauli Coalfield (23° 47′—24° 12′ N, 81° 48′—82° 52′ E, and elevation 280—519 m above mean sea level) in India. The rocks are fine to coarse-grained sand stones, white and gray clays with ferruginous bands, carbonaceous shells and coalseams(Singh, 1995). The climate of the area is tropical monsoonal and the year is divisible into a mild winter (November-February), a hot summer (April-June) and a warm rainy season (July-September). Data collected at a meteorological station on the site showed that the mean monthly minimum temperature within the annual cycle ranges from 6—28° and mean monthly maximum from 20—42°. The annual rainfall averages 1069 mm, of which about 90% occurs during late June to early September. The rainfall is characterized by a high degree of inter-annual variation; for example, during the period 1980—1996 it ranged from 673 to 1450 mm/a(Singh, 1995; 1996; 1999b).

1.2 Stand structure

All the plantations were raised in the month of July—August by planting nursery-raised seedlings in previously dug pits of 40 cm × 40 cm × 40 cm size at a spacing of 2 m × 2 m. Plantations of *A. lebbeck* and *A. procera* were raised in 1990 by planting 7 to 8 months old nursery raised seedlings on 4-yr old dump at sites 1 and 2 situated in east section of Jayant Block. Plantations of *T. grandis* were raised on a 6-yr old dump situated at site 3 in 1990 by planting 6 to 8 months old nursery-raised seedlings. *D. strictus* plantations were raised in 1991 by planting eight months nursery-raised seedlings on a 2-yr old dump at site 4. All the plots were seeded in 1994 at the rate of 6 kg/hm^2 with *Pennisetum pedicellatum* Trin. (local name: Dina Nath grass) for the purpose of enhancing organic matter and controlling soil nutrient runoff through erosion. Total planted area for *A. lebbeck* and *A. procera* was 1.5 hm^2, each, whereas the same for *T. grandis* and *D. strictus* was about 0.5 hm^2, each(Singh, 1999a).

The stocking density at the time of planting was 2500 ind./hm^2 for all species. Of these, about 71%—88% individuals survived after 3 years. In the 5-yr old of all plantation species, average height and diameter were ranged from 2.89—5.25 m, and 4.12—9.29 cm, respectively (Table 1). Leaf litter fall (2.39—10.68 kg/hm^2), above ground biomass(5.37—49.18 t/hm^2) and above ground net primary productivity (3.75—24.70 t/hm^2) values were comparable to the adjacent area of dry tropical natural forest (Singh, 1991).

Table 1 Stand structural characteristics of 5 yr-old planted species on coalmine spoil. Values are means ± 1 standard error

Characters	Species			
	A. lebbeek	*A. procera*	*T. grandis*	*D. strictus*
Stand density, individuals hm^2	2187 ± 14	2208 ± 9	1778 ± 68	2029 ± 29
Height, m	4.02 ± 0.05	3.71 ± 0.23	2.89 ± 0.11	5.24 ± 0.18
Basal diameter, cm	8.96 ± 0.10	9.29 ± 0.25	6.45 ± 0.15	4.12 ± 0.17
Above ground biomass, t/hm^2	38.91 ± 0.51	21.47 ± 1.85	5.37 ± 0.26	49.18 ± 1.73
Leaf litter fall, kg/(hm^2·a)	6.59 ± 0.08	7.26 ± 0.27	2.39 ± 0.10	10.68 ± 0.33
Above ground net primary production in 5th year, t/hm^2	19.40 ± 0.50	16.01 ± 0.79	3.75 ± 0.24	24.70 ± 1.85

Physico-chemical characteristics of fresh mine spoil indicated neutral pH, high bulk density, low water holding capacity(WHC) and poor soil nutrients(Singh, 2004a). In comparison, the soils in plantations had neutral pH(6.58—7.22), slightly lower bulk density(1.60—1.64 g/cm^3), and higher WHC(253.2—286.5 g/kg) and better soil nutrients. The total soil organic C, N, and P ranged from 2.50—7.25, 0.25—0.70 and 0.14—0.20 g/kg; whereas microbial biomass C, N and P varied from 179.98—319.14, 24.65—37.54 and 11.50—16.17 mg/kg, respectively in 5-yr old plantations of present study(Singh, 1999a; 1999b). Sodium concentration in plantations ranged from 0.005—0.068 cmol (+)/kg, of which the lowest values occurred in *T. grandis* and highest values in *A. lebbeck* plantations. For K, values were in the range of 0.003—0.004 cmol(+)/kg with the highest belonging to *A. lebbeck* and *T. grandis* and the lowest to *A. procera* plantations. In all plantations exchangeable Na, and K were higher than fresh mine spoils. Similarly an increasing trend in Mg and Ca concentrations in plantation soils was visible, the values ranging respectively from 0.005—0.017 and 0.018—0.042 cmol (+)/kg (Singh, 1999a; 2004a).

1.3 Soil sampling and analysis

Three soil samples were collected at random from each of the three permanent plots using 15 cm × 15 cm × 10 cm monoliths during September 1995. The samples from within a plot were thoroughly mixed to yield one composite sample per plot; this yielded three samples for each plantation species. Large pieces of plant materials were removed and the field-moist soil was sieved through a 2 mm mesh screen. Each soil sample was divided into two parts. One part in the field-moist condition was used for further analysis and other part was used for the determination of dry weight. The concentrations of heavy metals(Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the soil were determined by triple acid digestion method as described in Jackson(Jackson, 1958). The soil was digested in a triple acid mixture of $HClO_4$, HNO_3, and H_2SO_4(1:5:1) and the digest was determined for all corresponding heavy metals by using Atomic Absorption Spectrophotometer (Model 2380, Perkin-Elmer, USA).

1.4 Statistical analysis

All statistical analyses were done using SPSS-PC statistical software (SPSS, 1996). To observe effect of species, data were subjected to analyze analysis of variance. Differences in means were tested using Tukey's HSD as multiple range test.

2 Results and discussion

We do not have data from initial stage of plantations, but we have parallel information on several unplanted areas of coalmine spoils including present research site and adjacent natural forest, that is the good option for comparison(Singh, 1996). However, in this study, climate, relief, parent material and time were the same for all plantations. Therefore, we emphasize only species effect on heavy metal concentration in redeveloping soil of mine spoil.

The concentration of different heavy metals in soil around all selected plant species are shown in Table 2. The values obtained from the plots of all these species are compared with the forest soil and different coal mine spoil colliery of Singarauli area including with the present study site(Table 3). Among the various heavy metals the maximum concentration was found for iron (Fe) that ranged from 20557—27513 mg/kg, while cadmium(Cd) showed minimum concentrations in soil around different plant species (1.33—2.60 mg/kg) (Table 2). However, corresponding values among different collieries were found maximally in Gorbi and minimally in Dudhichua coal mine spoil, whereas for Cd concentration, Jhingurda coal mine spoil showed maximum and Jayant, Kakari and Dudhichua coal mine spoil showed minimum concentration. However, in respect to the mined spoils of various collieries a lower concentration was found in forest soil as well as in present study (Table 3). Cadmium showed a significant variation in soil around different plant species. The maximum concentration of Cd was found in the plot of *T. grandis* (2.60 mg/kg) and minimum in plantation plots of *A. lebbeck* (1.33 mg/kg) (Table 2, 4). Trace elements in the soils may or may not enter the root tissues and then move to the xylem. Some are often transported onwards to the leaves(e.g., Zn, Cd, Co, B and Mo) whilst others(e.g., Cr, Pb, Hg, and Cu) typically have limited mobility to aerial parts of the plants

(Alloway, 1995; Dickinson, 2000b). A tolerated values(15 mg/kg) and toxic levels (3—8 mg/kg) of total Cd concentration was reported in contaminated soils of recreational areas and parks of England (Eikmann, 1991; Dickinson, 2000b). However, opposite to this report, present study resulted a very low concentration among plantations of all species as well as in nearby other colliery spoils. In conformity with this, Dutta and Agrawal (Dutta, 2001) found somewhat similar range (1.06—3.33 mg/kg) under 5-yr old plantations of certain exotic tree species (*Acacia auriculiformis*, *Cassia siamea*, *Casuarina equisetifolia*, *Eucalyptus hybrid and Grevillea pteredifolia*) near to the present research site. Furthermore, in agreement with present study, Alloway (Alloway, 1995) reported a normal range (0.01—2.40 mg/kg) of the corresponding heavy metal concentration from various degraded agricultural soils indicating a favourable concentration for planted species on mine spoil. Figge *et al*. (Figge, 1995) reported more or less under comparable range of Cd concentration(3.8 mg/kg) in abandoned zinc mine site in southwest Kansas of USA. Jastrow *et al*. (Jastrow, 1981) reported somewhat similar range of the Cd concentration(2.7 mg/kg) in the topsoil of coal mine spoil at Colorado, USA. However, compared to agronomic or herbaceous plants, little is known of the influence of Cd on trees plantation and as well as on mature trees. Heavy metal accumulation in the upper layers of forest soil could impair the natural regeneration of forest species, thereby contributing to forest decline, even at relatively low concentrations(Hüttermann, 1999). In general, tree species are not able to exclude heavy metals in soil from their roots, even if toxic levels are reached or exceeded(Kahle, 1993).

Table 2 Heavy metal concentrations(mg/kg) in redeveloping soil of coal mine spoil under 5 yr-old plantations of certain native species

Heavy metals	Species			
	A. lebbeek	*A. procera*	*T. grandis*	*D. strictus*
Cadmium(Ca)	1.33 ± 0.25^{a}	1.63 ± 0.21^{ab}	2.60 ± 0.35^{b}	1.84 ± 0.60^{ab}
Chromium(Cr)	63.20 ± 10.79^{a}	69.93 ± 4.56^{a}	93.09 ± 5.04^{b}	68.15 ± 3.18^{ab}
Copper(Cu)	148.43 ± 34.05^{a}	195.63 ± 15.15^{a}	242.20 ± 41.63^{ab}	184.04 ± 32.89^{a}
Iron(Fe)	20557 ± 786^{a}	23593 ± 1151^{ab}	24630 ± 2074^{b}	27790 ± 593^{b}
Lead(Pb)	42.37 ± 6.37^{a}	47.28 ± 5.15^{a}	42.64 ± 5.06^{a}	68.00 ± 3.11^{b}
Manganese(Mn)	88.32 ± 7.33^{a}	106.31 ± 9.27^{a}	109.17 ± 5.90^{ab}	87.35 ± 11.95^{a}
Nickel(Ni)	54.66 ± 11.58^{a}	70.11 ± 0.41^{a}	81.23 ± 5.47^{ab}	69.34 ± 12.08^{a}
Zinc(Zn)	116.63 ± 5.37^{a}	95.17 ± 13.42^{a}	165.40 ± 4.85^{b}	92.85 ± 3.46^{a}
pH	6.59 ± 0.05^{a}	7.22 ± 0.10^{b}	6.58 ± 0.08^{a}	7.03 ± 0.11^{b}

Notes: Mean values in a row for each species sufficed with different letters are significantly different from each other at $P < 0.05$; values are means ± standard deviation

Table 3 Heavy metal concentrations (mg/kg) in various collieries of Northern Coal India Limited (NCL), Singrauli and adjacent dry tropical forest(source: Singh *et al*., 1996).

	Mine spoil		Forest soil	
	Minimum	Maximum	Minimum	Maximum
Cadmium(Cd)	$2^{j, kh, d}$	18^{jh}	2	10
Chromium(Cr)	28^{b}	473^{a}	44	270
Copper(Cu)	59^{g}	749^{j}	21	538
Iron(Fe)	4025^{d}	57150^{g}	3605	30000
Lead(Pb)	2^{kh}	$107^{j, jh}$	16	99
Manganese(Mn)	29^{d}	772^{kh}	105	500
Nickel(Ni)	8^{j}	153^{jh}	12	112
Zinc(Zn)	39^{d}	380^{g}	66	270

Notes: Values in a mine spoil column for each heavy metal concentration suffixed with different letters are denoted the collieries name; a. Amlori; b. Bina; g. Gorbi; d. Dudhichua; j. Jayant; kh. Khadia; jh. Jhingurda

Table 4 Summary of ANOVA for the effect of species on heavy metal concentrations in redeveloping soil of mine spoil

Heavy metals	Mean square	$F_{3,7}$	P
Cadmium(Cd)	0.88	6.88	0.017
Chromium(Cr)	520.52	10.86	0.005
Copper(Cu)	4467.43	4.27	0.052
Iron(Fe)	21859447.19	11.91	0.004
Lead(Pb)	326.86	11.721	0.004
Manganese(Mn)	356.44	5.26	0.033
Nickel(Ni)	360.89	5.14	0.034
Zinc(Zn)	3180.05	46.65	0.000

Consistently, like as Cd, the concentration of chromium (Cr) also varied significantly among plantation species, being maximum in *T. grandis*(93.09 mg/kg) and minimum in *A. lebbeck* (63.20 mg/kg) plantation plots (Table 2, 4). Chromium is one of several heavy metals that cause serious environmental contamination in soil, sediments, and groundwater(Bartlett, 1991; Witmer, 1991). Wastes coming from Cr-related industries have severely contaminated several sites in the USA (Sklar, 1980; Palmer, 1991; Pawlisz, 1997), and the worldwide anthropogenic discharge of Cr in fresh water bodies has been estimated to be 3550 metric tons (Nriagu, 1990). However, value reported from various other colliery spoils near to the present research site was comparable, maximum concentration was reported in Amlori and minimum from Bina coal mine spoil(Singh, 1996; Table 3). Total concentration of Cr was however higher in nearby dry tropical forest than to the present planted species on coal mine spoil (Singh, 1996). Alloway (Alloway, 1995) and Dickinson *et al*. (Dickinson, 2000b) reported a normal range of Cr concentration (9.9—121 mg/kg) in the soils of various agricultural lands through out UK. However, a critical value (100 mg/kg) as well as tolerated value(1000 mg/kg) for the same heavy metal (Cr) was reported from Western Europe (ICRCL, 1987; Angelone, 1992). According to Dickinson *et al*. (Dickinson, 2000b), tolerated value of total Cr concentration, might be suitable for planting species, it can grow favorably well.

The total concentration of copper (Cu) varied from 148.43—242.20 mg/kg, respectively among the plantation plots of all plant species, unexpectedly, this metal was not varied significantly different due to species (Table 2, 4). When concentration values compared with nearby dry tropical forest area and other areas of various coal mind spoil collieries around the present study, maximum concentration (749 mg/kg) was reported in Jhingurda and miniumum concentration (59 mg/kg) in the mine spoil of Gorbi. However, in comparison with plantation plots of present study and forest soils, values were extremely higher around coal-mined spoils of other collieries (Singh, 1996; Table 3). However, Sharma *et al*. (Sharma, 2000) reported very low concentration (4.0 mg/kg) in lime stone coal mine spoil at Indian desert. Whereas Dickinson *et al*. (Dickinson, 2000b) reported a tolerated value of this metal concentration to the plants (600 mg/kg), and a normal range (2—250 mg/kg) was documented by Alloway (Alloway, 1995). Despite of this, Dickinson (Dickinson, 2000a) further documented exceptionally high concentration of Cu metal (1670—9100 mg/kg) under 3-yr old plantations of certain tree species in a metal refinery site in the midlands of England, surprisingly, after passing first growing season of all planted species (nine species) were 94 percent survived suggesting evidence of tolerating capacity of such hardy species.

The concentration of iron (Fe) varied significantly from 20557—27790 mg/kg among plantation plots, being maximum in *D*. *strictus* and minimum in *A*. *lebbeck* plantation (Table 2, 4). When values were subjected for comparison with nearby forest and around other colliery spoils to the present study, a lower concentrations was recorded in the plantation plots of different woody species, indicating the effect of species on redeveloping soil of mine spoil (Table 3; Singh, 1996). However, based on species-specific characters, bamboo plantation (*D*. *strictus*) attained higher growth, biomass, net primary production efficiency followed by other planted species on mine spoil (Singh, 1999b), further suggesting that due to hardiness nature it was unaffected with exceptionally high concentration of iron metal. However, Mench *et al*. (Mench, 2003) reported a lower to extremely higher concentration range (1090—970000 mg/kg) from control to various used combinations in gold mine spoil in Portugal.

In this study, the total concentration of lead (Pb) varied from 42.37—68.00 mg/kg, being the highest concentration in *D*. *strictus* and the lowest like as in other heavy metals in *A*. *lebbeck* plantation plots (Table 2). These differences in species were statistically significant (Table 4). In opposite with present study, other reports which reported a lower range of Pb concentration (24 mg/kg) in tailing soil in Kansas, USA (Figge, 1995), and extremely higher range (8200 mg/kg) in the control site of gold mine spoil in Portugal (Mench, 2003). On the other hand, in comparison with reported concentration range of Pb heavy metal in various coal mine spoil around to the present study site as well as in forest soil, a lower concentration was recorded in the plantation plots of different species (Singh, 1996) indicating rapid accumulation of such heavy metal by species.

Like other heavy metal concentrations, manganese (Mn) also showed significant variation due to species in this study. Whereas concentration values being maximum (109.17 mg/kg) in *T*. *grandis* and minimum (88.32 mg/kg) in the plantation of *A*. *lebbeck*, respectively (Table 2, 4). Consistently, when compared with reported from other colliery spoil around present study site, the values were not only substantially lower from all collieries even reported from nearby dry tropical forest soil (Table 3; Singh, 1996). Jastrow *et al*. (Jastrow, 1981) reported a similar range for Mn in the topsoil of coal mine spoil in Colorado, USA.

Similarly like cadmium, chromium, copper, iron, lead and manganese heavy metals in the plantation plots of present study, nickel (Ni) was also significantly varied due to species (Table 2, 4). Concentration values were recorded maximally in *T*. *grandis* and minimally in *A*. *lebbeck* plantation plots, respectively. When compared with other reported Ni concentration of various coal mine spoil and adjoining area of forest near to the present study site, the concentration of Ni in all planted species plots was lower. However, Johnson and Eaton (Johnson, 1980) reported a lower concentration of Ni as 19 mg/kg in a coarse soil of Pb-Zn mine in North Wales than to present study. A normal range (7.3—70.0 mg/kg) of Ni concentration in agricultural soils of UK (Alloway, 1995), and tolerated values (250 mg/kg) to the plants was reported by Dickinson *et al*. (Dickinson, 2000b).

Most available soil metals probably become bound outside the roots or in the cell walls and a relatively small proportion is likely to be transported to above ground tissues even for the more mobile metals such as zinc (Dickinson, 2000a; 2000b). In the present study, the concentration of zinc (Zn) was maximum (165.40 mg/kg) in *T*. *grandis* and minimum (95.17 mg/kg) in *A*. *procera* plantation plots (Table 2). Analysis of variance indicated significant differences due to species (Table 4). Rosselli *et al*. (Rosselli, 2003) reported a similar range for Zn concentration (65 mg/kg) in the control soil and exceptionally high range (620 mg/kg) in contaminated soil of Switzerland. Whereas, a tolerating range of Zn concentration (3000 mg/kg) to the planting species was reported by Eikmann and Kloke (Eikmann, 1991), Dickinson *et al*. (Dickinson, 2000a; 2000b).

In this study, the concentrations of all heavy metals except Fe were maximum at *T*. *grandis* plots, which could be correlated with the low potential of biomass accumulation and soil restoring ability. Perhaps, developing levels of soil organic matter and productivity in redeveloping soil of mine spoil can act as an indicator of decreasing concentration of heavy metals(Singh, 1999a; 1999b; 2004a; 2004b). This would further explain that high levels of growth, biomass, productivity and soil biological fertility of plantations exhibit direct effect on the heavy metal accumulation in the redeveloping soil of mine spoil.

3 Conclusions

This study evidently indicated that the mine spoil contains toxic amount of some heavy metals. In addition, plant species differed in their ability to reduce the heavy metal concentration in redeveloping soil of mine spoil. Since these woody species are known to ameliorate the surroundings in which they grow(Singh, 1999a; 1999b; 2004a; 2004b), mine spoil, which is an impoverished and contaminated medium for plant growth, is influenced greatly by the presence of such woody species. Moreover, among all the four woody species *A. lebbeck*, *A. procera* and *D. strictus* showed more efficient for reducing heavy metal concentrations whereas *T. grandis* was not more effective to reduce heavy metal concentrations in redeveloping soil of mine spoil. In conclusion, better soil characteristics and rapid accumulating efficiency for biomass and net primary production of plants can be correlated with the accumulation of heavy metals in the soil.

Acknowledgements: Corresponding author is thankful to Ministry of Coal, Govt. of India, for financial assistance during the course of study. And, gratefully acknowledge to Institute of Applied Ecology of the Chinese Academy of Sciences for providing present financial support through a grant (SLYQY0409).

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(Received for review April 27, 2004. Accepted August 15, 2004)