ANNALS OF PLANT SCIENCES
ISSN: 2287-688X
OPEN ACCESS
www.annalsofplantsciences.com

Reaseach Article

Spoil characteristics under five years old native woody plantations and unplanted dump in dry tropical environment, India.

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Received: 9/22/2017; **Accepted:** 9/28/2017

Abstract: Present study was conducted to investigate spoil characteristics under 5-yr old high-density plantations of three native trees (*Albizia lebbeck A. procera* and *Tectona grandis*) and one fast growing woody grass (*Dendrocalamus strictus*) species on coal mine spoils and same age unplanted mine spoil dump at the same area. We examined physical characters such as soil bulk density, water holding capacity, soil texture (sand, clay and silt) and chemical characters such as pH, total nutrients (C, N and P) and exchangeable cations (Ca, Mg, K and Na) in chronosequence of spoil depth (0-50 cm) at 10 cm interval under planted stand of each selected species and unplanted dump. A significant effect of plantations on physico-chemical characteristics (except soil bulk density) of mine spoils was found. Among species, *A. lebbeck* exhibited substantial improvement in mine spoil soils followed by *D. strictus*, *A. procera* and *T. grandis* plantation. Although, chemical characteristics especially total concentrations of soil C, N and P and their ratios were significantly different due to species and spoil depth, indicating plantations of all species have abilities to improve soil chemical qualities at young stage of establishment. Compared to unplanted dump, plantation of *A. lebbeck* showed highest concentrations of total nutrients (C, N and P) and exchangeable cations with respect to spoil depth followed by *D. strictus*, *A. procera* and *T. grandis*, which confirms that some species have suitable qualities for the modification of spoil characteristics during rehabilitation process.

Keywords: *Albizia lebbeck*; *Albizia procera*; *Dendrocalamus strictus*; *Tectona grandis*; unplanted dump, UPD; Mine spoil.

Introduction

Coal extraction by surface mining (opencast) process drastically alters the physical and biological nature of the surroundings of mined area (Singh *et al.* 1995; Frouz *et al.* 2017). On the first hand, this industry is to the next of agriculture that posses a significant role to meet our demands in different ways. Most of the natural wealth of the world, for example, precious metals (diamond, silver and gold), comes out through mining activities. But on the other hand, the process of opencast mining posed serious environmental problems which left damaged landscapes, disrupted ecosystems and destroyed microbial communities that are to be a hard task to restore into their original state (Singh *et al.* 1995; Bradshaw 2000; Singh *et al.* 2004a; Vega *et al.* 2005; Jozefowska *et al.* 2017).

The most important preconditions for ecosystem rehabilitation in post mining landscapes are the processes of soil redevelopment (Singh *et al.* 2004a,b; Sourkova e*t al.* 2005; Singh *et al.* 2006; Liu *et al.* 2017). The soil has to be restored in these landscapes with all physico-chemical and biological properties such as texture, bulk density, water holding capacity, pH, exchangeable cations, total nutrient content and availability as well as microbial nutrients and its activity. Once soil fertility is restored, it will be easier for the more desirable species to establish and perpetuate into self sustained ecologically suited design, therefore, soil is considered to be one of the primary agents in determining vegetation development and the importance of soil characteristics in ecological studies cannot be underemphasized (Singh *et al.* 2004b; Singh and Singh, 2006). Since mine spoils are characterized by the loss of soil both in pedological and biological sense. Restoration of such degraded lands is a challenging ecological problem. Moreover, natural recovery in mine spoils is a slow process (Singh *et al.* 1995). A successful restoration programme attempts to accelerate the natural recovery processes to check the soil erosion, to restore the soil fertility and to enhance the biological diversity (Singh *et al.* 2002). The first step in any restoration programme, of course, is to protect the disturbed habitat and communities from being further wasted. Then follow attempts to accelerate the revegetation process for increasing biodiversity and stabilizing nutrient cycling (Singh *et al.* 1995). If planting a desirable plant species on mine spoil can accelerate the process of natural succession, a self-sustaining ecosystem may develop in a short period.

Evidently, Fisher (1995) suggested five general hypotheses for the mechanisms that contribute to the amelioration of degraded lands by planting certain desirable species. The mechanisms involve: first, an increase in the soil organic matter contents as a result of carbon (C) fixation in photosynthesis and its transfer via leaf litter and root turnover to the soil. Second, nitrogen (N) fixation by some leguminous trees results in an increase in soil N content under the tree canopy. Third, a rhizosphere effect of tree on soils resulting in enhanced N mineralization and increased microbial biomass. Fourth, microclimate modification by tree canopies that moderate soil and air temperatures and soil

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http://dx.doi.org/10.21746/aps.2017.6.11.8

moisture regimes, and fifth, nutrient pumping reflecting uptake of nutrients from greater depths by tree roots and accumulation in a smaller volume of surface soil as a result of litter fall.

In agreement with this, Singh and Singh (1999) reported that a desired species for planting on mine spoils should possess the abilities (i) to grow on poor and dry soils, (ii) to develop the vegetation cover in short time and to accumulate biomass rapidly, (iii) to bind soil for arresting soil erosion and checking nutrient loss, and (iv) to improve the soil organic matter status and soil microbial biomass, thereby enhancing the supply of plant available nutrients. In addition, the species should be of economic importance. On the basis of the effectiveness of above these facts, four species were chosen 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*). Earlier reports on the same plantations evidently proved that certain ideal species have positive tendency to improving soil nutrient level in coalmine spoil. For example, bamboo plantations showed a significant effect on redeveloping soil of coal mine spoil in terms of high rate of accumulating biomass, productivity, litter fall and microbial biomass within a short time (3-5 years) (Singh and Singh, 1999). Rest three planted species (*A. lebbeck*, *A. procera* and *T. grandis*) also showed a substantial role in the same direction within a short period (4-6 years) (Singh *et al.* 2004a, 2004b).

Mine spoil habitats often show heterogeneity condition especially in soil nutrient distribution (Bloomfield *et al.* 1982); and spoil material does not contain organic C derived from recent plant material, but may contain various amounts of fossil C (Barnhisel and Massey, 1969; Roberts *et al.* 1988). In addition, adverse properties of spoil material, such as erosion, toxicity and unsuitable water regime or nutrient deficiency, may reduce plant growth in some post-mining landscapes (Bradshaw and Huttel, 2001; Sourkova *et al.* 2005). Therefore, questions might be arrived such as: (1) are these planted species can rapidly change physico-chemical properties into deeper depth of mine soil (up to 50 cm) or only in the mineral layer (0-10 cm) of spoil? (2) Does the role of leguminous substantially differ from non-leguminous species especially in C and N nutrients in soil of mine spoil? (3) Does variability in physico-chemical properties across soil depth and species exhibiting any trend to understand soil restoration mechanism at least from initial stage of rehabilitation?

Therefore, in present study, we compared the effect of 5-year old planted species with naturally vegetated same age unplanted coal mine spoil dump (UPD) on certain soil physico-chemical characters such as water holding capacity, bulk density, soil texture (sand, silt and clay), pH, total nutrients (C, N and P) and exchangeable cations (Ca, Mg, K and Na) under chronosequence of spoil depth (0-50 cm). In this study, climate, relief, parent materials and time were same for unplanted dump and all plantations, respectively. Therefore, differences found between the soil characters would be comparable due to the effect of vegetation.

Materials and Methods

Description of Study Site

The plantations were situated in the east section of Jayant Block which is located in the North-eastern part of Singrauli Coalfield in the district of Sidhi (Madhya Pradesh, India) between latitudes 24°6'45"-24°11'15"N and longitudes 82°36'40"-82°41'15"E. Due to opencast coal mining operations in the area, huge amount of overburden materials are dumped on adjacent lands. Dump management in this area includes filling of void by overburden. Overburden removed by shovel dampers is dumped over the internal dumps created by draglines and subsequently leveled by dozers. The periphery of the overburden dump is kept sloped at 28° with maximum bench height of 30 m. The rocks are fine to coarse-grained sandstones, white and gray clays with ferruginous bands, carbonaceous shale and coal seams (Singh *et al.,* 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 present on the site showed that the mean monthly minimum temperature within the annual cycle ranges from 6-28°C and mean monthly maximum from 20-40°C. The annual rainfall averages 1069 mm, of which about 90% occurs during late June to early September (Singh *et al.,* 1995; Singh and Zeng, 2008).

Plantations and Sample Plots

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 by planting 7 to 8 months old nursery raised seedlings on east section of mine spoil. Plantation of *T. grandis* was raised by planting 6 to 8 months old nursery-raised seedlings on west section of mine spoil dump. While *D. strictus* plantation was raised by planting eight months nursery-raised seedlings on east section of mine spoil dump. UPD was situated in the east section that is very near to all selected plantations. It had been remained as it is only for comparison, regarded as control site. Total planted area for *A. lebbeck* and *A. procera* was 1.5 ha, each, whereas the same for *T. grandis* and *D. strictus* was about 0.5 ha, each. In case of UPD, the total area was 0.4 ha. For sampling three permanent plots were established for each species.

The size of the sample plots was 25 m × 25 m for *A. lebbeck* and *A. procera*, and 15 × 15 m for *T. grandis* and *D. strictus* and 10 m ×10 m for UPD. At UPD site, a total of 30 herbaceous species representing 12 families was recorded. Beneath plantations, a lower number of species representing 10 families as from UPD site was recorded, being maximum in *T. grandis* (24) and minimum in *D. stricus* (12) plantation plots. While in case of both legume plantations (*A. lebbeck* and *A. procera*) the number of herbaceous species representing 8 families was somewhat similar. However, following species *Aristida adscensionis*, *Bothriochloa pertusa*, *Dactyloctenium aegyptium*, *Tephrosia perpurea* and *Cassia tora* were the most abundant species in the ground vegetation among all plantations as well as in UPD site (Singh, 1999). However, detail study regarding biodiversity reconstruction, rate, species richness, evenness and their association under all native and exotic woody species planted on coal mine spoil is however still under investigation.

Sample Collection and Analyses

Soil samples were collected at random from each of the three permanent plots of each species including UPD using 15 × 15 × 10 cm monoliths for 0-50 spoil depth at 10 cm interval. Six monoliths soil samples collected from within a plot were separated according to the depth variation (0-10, 10-20, 20-30, 30-40 and 40-50 cm) then thoroughly mixed to yield one composite sample per plot separately for each soil depth; this yielded fifteen samples for each plantation. Large pieces of plant materials were removed and the field-moist soil was air dried, sieved through a 2 mm mesh screen, and then used for any physico-chemical analysis.

Water holding capacity was determined using perforated circular brass boxes (Piper 1944). Soil bulk density was determined by using soil corer and measuring the weight of dry soils of a unit volume to each spoil depth at 10 cm interval (Piper 1944). Particle-size distribution (texture) was analysed by using soil sieves of different mesh sizes (Piper 1944). Soil pH was measured in a 1:2.5 mixture of soil and de-ionized water using a glass electrode. Soil organic C was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Allen *et al.,* 1986). Kjeldahl N was determined by microkjeldahl method (Jackson 1958), and samples were analysed for total P by a phosphomolybdic acid blue colour method after triple acid digestion (Jackson 1958). For the analysis of total Ca, Mg, K and Na, spoil soil was digested in the triple acid mixture as above (Allen *et al.,* 1986). Total Na, Mg and K were measured by using a flame photometer (Systronics Mediflame 127) and Ca by a Perkin-Elmer atomic absorption spectrophotometer (373 AAS) following Allen *et al.,* (1986).

Statistical analyses

All the statistical analyses were done using SPSS-PC statistical software (SPSS, version 14.0). To observe effects of species and spoil depth on physico-chemical properties of coalmine spoils, the data were subjected to analyse analysis of variance (ANOVA) through multivariate factorial analysis by general linear model (GLM). Species and spoil depth were used as a main fixed factor and all data for physico-chemical properties were in dependent variables.

Results and Discussion

Effect of Physical Characters on mine spoil

Bulk Density and Water Holding Capacity

Bulk density is a measure of the weight of the soil per unit volume, usually given on an oven dry basis. It is used as a measure of soil wetness, volumetric water content, and porosity. It is also a measurement of the compaction of the degree of compaction of the soil. In this study, the bulk density values showed an increasing trend with increased spoil depth (0-50 cm) but were not significantly different among species and UPD at 0-50 cm spoil depth, being maximum in UPD (1.76 g cm^{-3}) at 30-40 cm and minimum in *A. lebbeck* (1.60 g cm^{-3}) and *T. grandis* plantation (1.60 g cm^{-3}) at 0-10 cm spoil depth (Fig. 1a; Table 1). However, in UPD site, bulk density values (1.61 g cm^{-3}) were somewhat in similar range as it was found in *A. lebbeck* and *T. grandis* plantation (1.60 g cm^{-3}) at 0-20 cm spoil depth; but subsequently become higher (1.72-1.76 g cm^{-3}) when progressively down spoil profile from 20-50 cm (Fig. 1a). Evidently, corresponding values (1.75 g cm^{-3}) reported in fresh mine spoil (Singh *et al.,* 2004a) was above the threshold value as reported by Russell (1977) that root growth is restricted in soils with a bulk density higher than 1.6 g cm^{-3}. Soil bulk density may vary due to textural differences, organic matter content, and cultivation practices (Hausenbuiller 1981). Clay, clay loam, and silt loam soils normally have bulk densities ranging from 1.00-1.60 g cm^{-3} and a range of 1.20-1.80 g cm^{-3} may be found for sand and sandy loams. After establishment of *A. lebbeck* and *T. grandis* plantation, this value became lower than fresh mine spoil and UPD, while in case of *A. procera* and *D. strictus* plantation the values were lower than fresh mine spoil, but were still higher than threshold value of 1.60 g cm^{-3} for better root growth. Although, plantations of native woody species had significant impacts on the physical condition of the mine spoil, the trees had kept the ground covered and reduce evaporation (Singh *et al.,* 1995; Singh *et al.,* 2002). However, the plausible reason for the higher values of soil bulk density with increasing spoil depth might be due to the loosely compaction, heterogeneous mixture of stone and rock fragments, deflocculated soil particles and restricted capillary pores (Singh *et al.,* 1995; Frouz 2017). In agreement with this, however, Bending & Moffat (1999) reported that bulk density commonly exceeded 1.70 g cm^{-3} below 20 cm depth in mine spoil. Delong *et al.,* (2012) have estimated corresponding parameters by four methods under reclaimed rocky mine spoils from Kanawha County, West Virginia, USA reported bulk density under compacted and non-compacted mine soil within range of our study. They further documented that sandstone mine soils, with different compaction degrees, gave similar bulk density values of 1.70 to 1.84 Mg m^{-3}. The native forest soil had a bulk density of 1.05 Mg m^{-3}.

Other physical properties such as water holding capacity showed a significantly increasing trend with respect to spoils depth thus values were substantially higher among different plantations compared to UPD (Fig. 1b; Table 1), being maximum in *A. lebbeck* (400.9 g kg^{-1}) at 40-50 cm spoil depth and minimum in UPD (215.2 g kg^{-1}) at 0-10 cm spoil depth (Fig. 1b). Therefore, analysis of variance (ANOVA) indicated significant differences due to species and depth but their interaction (species × spoil depth) was not significant varied (Table 1). Perhaps, plant growth on spoils may be limited due to lack of available moisture (Sutton & Dick 1987; Zhou *et al.,* 2017). Spoil materials often have reduced water infiltration and water holding capacity compared to un-mined soil. In the present study, significant improvement in water holding capacity of the soil was observed as a result of establishment of plantations. This improvement was maximum in the case of *A. lebbeck* and *A. procera* plantations. Toy and Shay (1987) argued that water holding capacity of the soils could be higher due to an increase in silt and clay contents. In agreement with this, plantation of *A. lebbeck* resulted higher percentage of silt while *A. procera* resulted higher clay contents compared to other plantations. Therefore, the plantations of both *A. lebbeck* and *A. procera* reflected higher quantity of water holding capacity in the soil.

Particle Size Distribution

Like bulk density, soil texture is also important as silt and clay can promote the formation of organic-mineral complexes in the soil layer. In this study, the percentage of sand was lower in the plantation of *A. lebbeck* (77.57-64.63%) compared to UPD site (78.27-70.57%), while the plantations of other three species (*A. procera*, *T. grandis* and *D. strictus*) showed higher range than UPD site at 0-50 cm spoil depth (Fig. 1c). Opposite to sand, percentage of silt was higher in the plantation of *A. lebbeck* compared to UPD plot at 0-50 cm spoil depth (Fig. 1d). However, corresponding values varied among plantations in the following order: *A. lebbeck* (14.10-13.60%) <*D. strictus* (9.13-6.30%) < UPD (7.58-9.92%) < *A. procera* (6.31-12.15%) < *T. grandis* (5.53-9.97%) (Fig. 1d). Whereas clay percentage also varied among plantations, being highest in UPD plot (22.03%) at 30-40 cm spoil depth while lowest in *A. lebbeck* (8.33%) at 0-10 cm spoil depth (Fig. 1e). However, values recorded at 0-50 cm spoil depth were substantially lower in the plantation of *A. lebbeck* compared to UPD plots followed by *T. grandis, D. strictus* and *A. procera* (Fig. 1e). Therefore, statistical analysis (ANOVA) exhibited significant differences due to species and spoil depth for sand, silt and clay, while interactions (species × spoil depth) were significant for silt and clay only (Table 1).

The particle size of soils on mined sites was generally finer relative to UPD sites, and clay tended to be translocated to lower horizons by soil formation over time (Wali 1999; Ciarkowska *et al.,* 2017). It is one of the most permanent soil physical properties, and is a major factor governing the successful reestablishment of vegetation on reclaimed slopes (Toy and Shay 1987). Nevertheless, it influences soil moisture relations, erosion characteristics, bulk densities, nutrient contents, and nutrient availability. In the fresh mine spoil corresponding contents (sand, silt and clay) were reported as about 80%, 9% and 11%, respectively from the same site area (Singh *et al.,* 2004a ; Dolhopf *et al.,* 1981) suggested that mine soils with clay contents greater than 40% might adversely affect reclamation success due to low permeabilities and infiltration rates, structural problems, and compaction problems. They also reported that mine soils with the sand content of greater than 70% might not contain sufficient water for plant production. Soils with high contents of medium fine and very fine sands are very susceptible to wind erosion and soils with a high proportion of very fine sands and silts are susceptible to erosion by water (Hausenbuiller 1981). However, in present study, significant variations due to soil texture (sand, silt and clay) among these plantations indicated that these species have capability to change the spoil texture after their establishment and growth in coming periods.

Effect of Chemical Characters on mine spoil

PH ranges of mine spoil

The pH values in the plots of different plantations including UPD at 0-50 cm spoil depth exhibited a neutral range (6.22–7.33) (Fig. 1f). However, ANOVA indicated significant differences due to species only (Table 1). Of all the chemical measurements taken, pH is most useful in mine rehabilitation studies as it is readily determined and is an overall indicator of the nutrient status of the soil. Slight acid to slight alkaline pH provides optimum plant growth conditions, because nutrient availability is greater within this range (Hausenbuiller 1981). Low pH inhibits plant growth because toxic elements such as Al, Fe, Mn may be present in soil solution at pH below 4.0 thereby limiting the successful establishment of some plant species (Barnhisel and Massey 1969; Bradshaw 1997a,b). In the present plantations, pH was not the problem as it is reported from other mining habitats elsewhere, for example lignite mine spoils at Czech (Sourkova *et al.,* 2005) and Germany (Rumpel *et al.,* 2000).

Total exchangeable cations of mine spoil

Concentrations of exchangeable cations (Ca, Mg, K and Na) among plantations did not significantly vary due to spoil depth (Figs. 2a–d; Table 1). However, the values were substantially higher in all plantations than UPD site at surface layer (0-10 cm) (Figs.2a–d). Highest concentration of Ca was found in the surface layer (0-10 cm) of *T. grandis* (0.042 c mol (+) kg^{-1}) and *A. lebbeck* (0.041 c mol (+) kg^{-1}) followed by *A. procera* (0.018 c mol (+) kg^{-1}) and lowest in *D. strictus* (0.015 c mol (+) kg^{-1}) plantation (Fig. 2a). However, a decreasing trend appeared in the values of all plantations from progressively down profile from 0-50 cm spoil depth but there was not any uniformity developed as a whole. Therefore due to this, effect of spoil depth was not significant while effect of species and interaction (species × spoil depth) were significantly different (Table 1). In case of Mg, all species showed a less variation across spoil depth. However, highest concentration was found in *A. lebbeck* (0.017 c mol (+) kg^{-1}) and lowest in *D. strictus* (0.005 c mol (+) kg^{-1}) at surface layer (0-10 cm) (Fig. 2b). While in case of K concentration, all plantations showed a decreasing trend with spoil depth but the values were in less variation even from UPD plots. ANOVA did not indicate significant differences either by species or by spoil depth (Fig. 2c; Table 1). Nevertheless, among plantations, greater concentration was found in A. *lebbeck* (0.004 c mol (+) kg^{-1}) and *T. grandis* (0.004 c mol (+) kg^{-1}) followed by *A. procera* and *D. strictus* at 0-10 cm spoil depth (Fig. 2c).

Na concentrations varied in the range of 0.068 to 0.017 c mol (+) kg^{-1} in *A. lebbeck*, 0.027 to 0.017 c mol (+) kg^{-1} in *A. procera*, 0.045 to 0.016 c mol (+) kg^{-1} in *T. grandis* and 0.059 to 0.018 c mol (+) kg^{-1} in *D. strictus* plantation at 0-50 cm spoil depth (Fig. 2d). ANOVA indicated significant differences due to species only (Table 1).

Table 1. Summary of ANOVA for the effect of species and spoil depth and species × spoils depth interaction on physico-chemical characters of mine spoil.

Soil characters	Species		Depth		Species × depth	
	F4, 50	P	F4, 50	P	F16, 50	P
pH	39.024	0.000	2.192	0.083	0.611	0.860
Bulk density	1.841	0.136	1.652	0.176	0.231	0.999
Water holding capacity	23.578	0.000	16.074	0.000	0.629	0.845
Sand	41.842	0.000	29.633	0.000	0.905	0.568
Silt	85.092	0.000	4.339	0.004	3.989	0.000
Clay	19.442	0.000	15.693	0.000	2.208	0.017
Organic C	310.689	0.000	354.22	0.000	36.352	0.000
Kjeldahl N	101.141	0.000	186.388	0.000	15.785	0.000
Total P	10.099	0.000	42.696	0.000	4.029	0.000
C: N ratio	21.459	0.000	2.662	0.043	2.938	0.002
C: P ratio	47.815	0.000	22.689	0.000	6.868	0.000
Ca	3.795	0.009	2.350	0.067	2.702	0.004
Mg	2.381	0.064	2.470	0.057	2.648	0.004
K	0.326	0.860	1.273	0.293	1.438	0.163
Na	3.631	0.011	1.970	0.113	3.040	0.001

Evidently, these cations reported in fresh mine spoils from same area were in lower concentration as from all plantations (Singh *et al.,* 2004a), indicating that values were in substantial amount due to vegetation effect. In the evidence of this, several studies either from mined or un-mined areas showed that the amount of exchangeable cations in the soil can be positively influenced by the tree species composition (Van Breeman *et al.,* 1997; Finzi *et al.,* 1998a; Mohr *et al.,* 2005) or parent materials of the problem sites (Vimmerstedt *et al.,* 1989; Wali 1999). Moreover, this has mainly been attributed to differences in the pH values (Finzi *et al.,* 1998a), leaf chemistry (Filcheva *et al.,* 2000) and decomposability of the plant materials (Mohr *et al.,* 2005). In our study, however, pH was consistent in all plantations with respect to spoil depth even in UPD site; therefore, attribution by pH might be same. But litter chemistry and their decomposition rates substantially varied with planted species. Evidently, a wide variation in the mean relative decomposition rate of the leaf litters of all plantation species was reported (Singh, 1999). *A. lebbeck* showed highest mean relative decomposition rate (2.42 mg g^{-1} d^{-1}) followed by *D. strictus* (2.28 mg g^{-1} d^{-1}), *T. grandis* (2.20 mg g^{-1} d^{-1}) and *A. procera* (2.12 mg g^{-1} d^{-1}) (Singh 1999). Perhaps due to this reason, plantation of *A. lebbeck* reflected greater concentration of all exchangeable cations at surface layer in the mine spoils.

Total Carbon, Nitrogen, Phosphorus and their ratios of mine spoil

Soil organic C, kjeldahl N, total P and their ratios are presented in Figs. 3a–e. These contents showed a decreasing trend with increasing spoil depth, and were significantly higher in all plantations compared to the UPD site (Table 1). Among plantations, however at surface layer (0-10 cm), highest C, N and P contents were found in *A. lebbeck* (C: 7.25-1.63 g kg^{-1}; N: 0.70-0.16 g kg^{-1} and P: 0.19-0.13 g kg^{-1}) and lowest in *T. grandis* (2.5-0.91 g kg^{-1}, 0.25-0.11 g kg^{-1} and 0.18-0.08 g kg^{-1}), respectively (Figs. 3a-c). Although both C: N and C: P ratios did not show any trend according to the depth or species, their values were significantly different due to species and spoil depth (Figs. 3d-e; Table 1). Percent increases in soil C and N contents in all plantations relative to that in UPD were calculated. Among species, plantation of *A. lebbeck* attained 437.0% greatest C and 335.6% N from UPD followed by *D. strictus* (398.5% C and 318.8% N), *A. procera* (211.9% C and 243.8% N) and *T. grandis* (85.2% C and 55.0% N), respectively at surface layer (0-10 cm) of mine spoil. Corresponding increments were reflected a declining trend with increasing spoil depth (0-50 cm) almost in all plantations. Therefore, in this study, higher soil organic C and N values were found in following order: *A. lebbeck* > *D. strictus* > *A. procera* > *T. grandis*. In conformity with this, a high level of their respective primary productivity and biomass accumulation as reported in Singh (1999), Singh and Singh (1999), Singh *et al.,* (2004b). Like N, P is an essential element for plant growth and is one of limiting nutrients in colliery spoils (Bloomfield *et al.,* 1982). In the present study, total P concentration under 0-10 cm spoil depth was 109.8% greater in *A. lebbeck*, 112.0% in *A. procera*, 97.8% in *T. grandis* and 52.2% in *D. strictus* than that under UPD site. However, such changes concomitantly declined with increase of spoil layer up to 20-30 cm while from 30 to 50 cm a little difference was found in the mean concentrations of all plantations including UPD, indicating that the effect of plant species as well as spoil depth on total P are not a key factors to augment in the deeper layer of soil.

C: N ratios indicate the trend toward rehabilitation of mined sites. The C–N relationship is based on the relative fluxes of carbohydrates and nitrogenous compounds during the mineralization of organic matter over time, and its importance in reflecting the dynamics of soil systems has been emphasized in several studies on mine spoil (Wali 1999; Filcheva *et al.,* 2000; Frouz *et al.,* 2001; Bradshaw 1997a, b) as well as from unmined sites (Van Breeman *et al.,* 1997; Finzi *et al.,* 1998b). C: N ratios can be a useful indicator to assess the restoration dynamics of mined systems over time. Wali (1999) reported same ratios in widest range for 1-year old (5–40), while limited range (10–15) for 45-year old naturally vegetated coalmine spoil, comparable to unmined sites. In earlier study, these ratios were significantly changed with stand age, evidently showing an age-related trend and confirming vegetation effect from young stage (Singh *et al.,* 2004a). However, in present study, expressed higher range from UPD in the following order: *A. lebbeck* > *D. strictus* > *T. grandis* > *A. procera*, but did not show any trend with respect to spoil depth. Another ratios (C: P), which reflect changes in both total organic C and total P, however, did not evidently change like C: N ratios; perhaps the mechanisms responsible C: P ratios might vary according to the different levels of ecosystem function and species to species.

On the other hand, productivity of a soil and the rate at which soil properties change has great importance to the long-term success of reclamation and other land use management systems (Roberts *et al.,* 1988; Akala and Lal, 2000). Changes in soil properties due to plantation age are initially very rapid and subsequently slower rates are observed; moreover, development of equilibrium may vary between 25-50 years and is seldom seen in short term studies of mine spoil restoration (Anderson 1977). In conformity with this, an earlier study on the same site and plantation species reported a continued increase with stand age in microbial biomass C: total C ratios, indicating that equilibrium state is yet to be achieved (Singh *et al.,* 2004a). In the early period of establishment of the plantations, there was a progressive build-up of organic matter and nutrients because of the faster growth and high allocation of foliage component in the total biomass and production at stand level (Singh and Singh 1999; Singh *et al.,* 2004b). In this study, two species (*A. lebbeck* and *A. procera*) are leguminous in nature, but *A. lebbeck* exhibited better contribution in developing organic matter especially N capital in the soil of mine spoils. While a non-leguminous species (*D. strictus*, a woody grass) showed a remarkable role in the build-up of organic matter through heavy deposition of litter fall (10.7 t ha^{-1} $year^{-1}$ at 5-year age) on plantation floor and greater amounts of fine roots (1.40 t ha^{-1}) in redeveloping soil of mine spoil (Singh and Singh 1999). Being leguminous in nature, *A. procera* did not pay apparent role like *A. lebbeck* even as *D. strictus*, indicating that some non-leguminous species can contribute better performance to improve soil characters during rehabilitation of any degraded ecosystems.

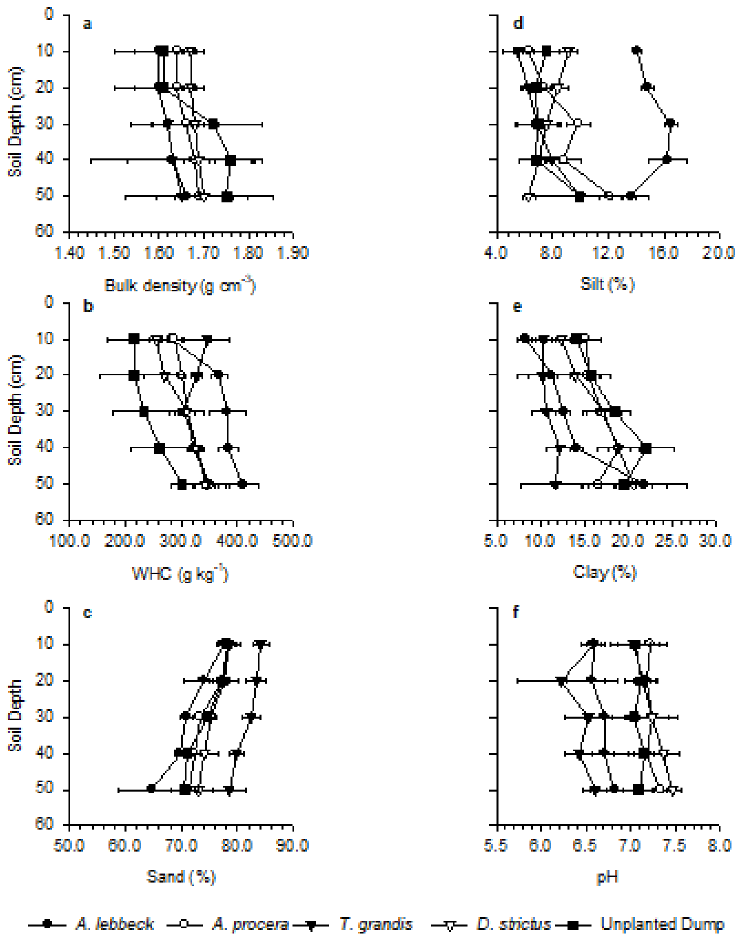

Figure 1. Soil bulk density (a), water holding capacity (b), textural composition such as sand (c), silt (d), clay (e) and pH (e) values under unplanted dump and five-year-old plantations of certain woody species raised on coalmine spoil. Each point in each observation represents the mean of three replicates. Error bars reflect 1 standard deviation.

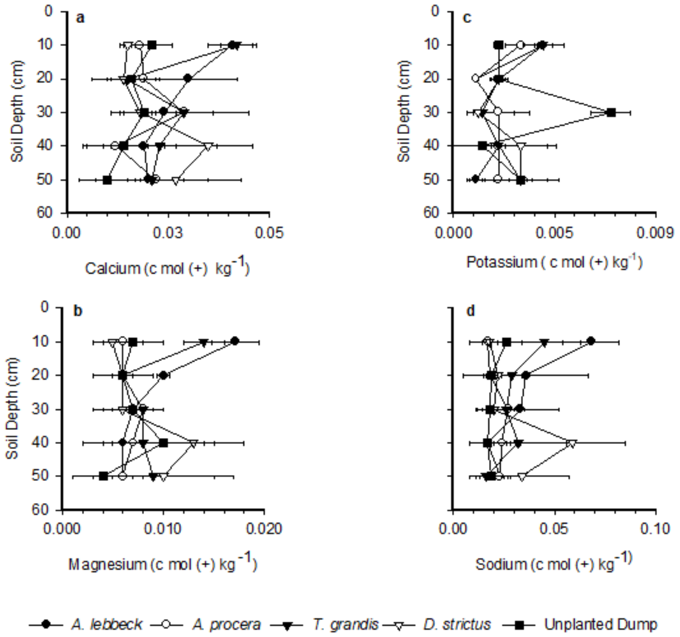

Figure 2. Concentrations of exchangeable cations Ca (a), Mg (b), K (c) and Na (d) under unplanted dump and five-year-old plantations of certain woody species raised on coalmine spoil. Each point in each observation represents the mean of three replicates. Error bars reflect 1 standard deviation.

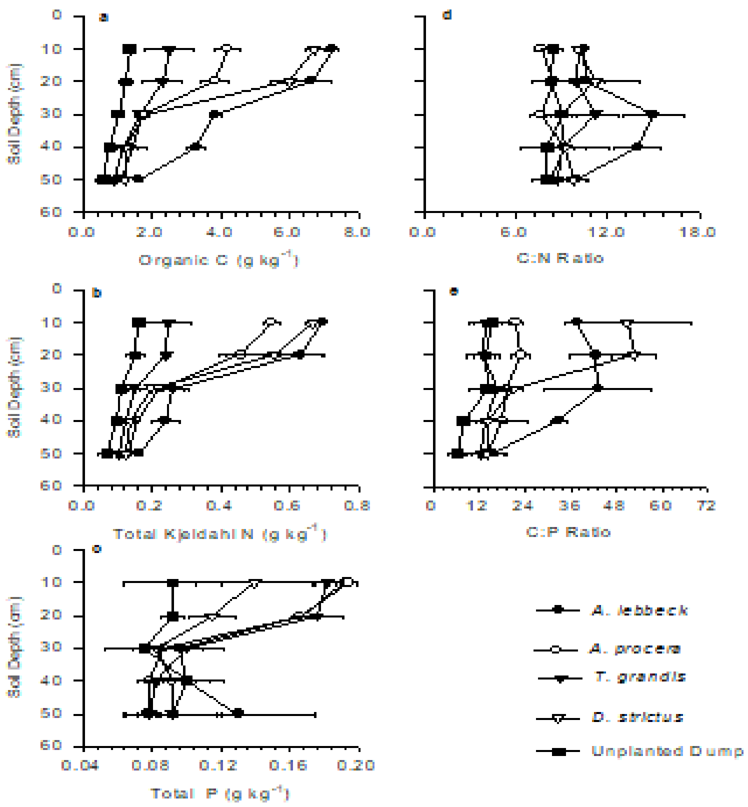

Figure 3. Total soil organic C (a), total kjeldahl N (b), total P (c) and their ratios (C: N and C: P) (d and e) under unplanted dump and certain indigenous woody plantations on coalmine spoil. Each point in each observation represents the mean of three replicates. Error bars reflect 1 standard deviation.

Conclusions

In comparison to naturally vegetated dump, all plantations showed substantial effects to improving physico-chemical qualities of mine spoil within a short period except for soil bulk density. Among plantations, physical characters were maximally improved by *A. lebbeck*, and followed by *D. strictus* and *A. procera*. For example, silt and clay composition in soil texture with respect to spoil depth was better in *A. lebbeck* plantation. Not standing with this, in case of chemical characters, plantation of *A. lebbeck* showed greater values in terms of qualities and quantities in the assessment of spoil characteristics such as total C, N, P and exchangeable concentration followed by *D. strictus*, *A. procera* and *T. grandis*, respectively.

In conclusion, each species has different capacity to improve soil characters during mine spoil restoration. But permanent rehabilitation of coalmine spoil requires the presence of many species. For example, slow growing non-leguminous timber species (*T. grandis*), fast growing woody grass (*D. strictus*) and N-fixing *Albizia* (*A. lebbeck*, *A. procera*) planted in mixed stands can be more potential as for productivity and lead to faster soil redevelopment at least at young stage of rehabilitation process. Therefore, the effects involved in mixed stands are worthwhile further study.

Acknowledgements

Author is thankful to the University Grants Commission, Government of India, for financial assistance through Major Research Project (MRP) to commence Ecological Research on degraded ecosystems.

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Cite this article as:

A.N. Singh: Spoil characteristics under five years old native woody plantations and unplanted dump in dry tropical environment, India *Annals of Plant Sciences 6.11 (2017) pp. 1763-1771.*

doi: http://dx.doi.org/10.21746/aps.2017.6.11.7

Source of support: University Grants Commission, Government of India
Conflict of interest: Nil