Tropical Ecology **43**(2): 315-324, 2002 ISSN 0564-3295

Effect of tree plantations on the soil characteristics and microbial activity of coal mine spoil land

RAMAN KUMAR DUTTA & M. AGRAWAL*

Department of Botany, Banaras Hindu University, Varanasi – 221005, India

Abstract: Soil characteristics and microbial activity of vegetated coal mine spoil land under plantations of five exotic tree species were assessed. The data obtained were compared with those of the bare overburden mine spoil and the native forest soils. The results showed an improved soil status under different plantation stands compared to bare overburden. The silt and clay particles in soil were higher among different plantation stands in comparison to bare overburden dump. Bulk density was highest in the plots of *Casuarina equisetifolia* and lowest in *Gravellia pteridifolia* plots. Soil moisture content was also higher under different plantations. Water holding capacity and soil moisture content were highest in the *Eucalyptus hybrid* plots. Organic carbon and total nitrogen concentrations were higher in the plantation stands in comparison to the bare overburden dumps. Available nitrogen (NO_3 – N and NH_4 – N) was highest in the plots of *Eucalyptus hybrid* in all the three seasons. Soil microbial biomass C, N and P were highest in the plots of *Gravellia pteridifolia* and lowest in *Cassia siamea* plots. The plantations enhanced the nutrient status of the degraded mine spoil land. The plant species varied in their ability to modify the soil properties of mine spoil. Among the tree species *Eucalyptus hybrid, Acacia auriculiformis* and *Casuarina equisetifolia* were found to be most suitable for the modification of spoil characteristics during the revegetation process.

Resumen: Se evaluaron las características de, y la actividad microbiana en, una tierra deteriorada por una mina de carbón, pero cubierta de vegetación, bajo plantaciones de cinco especies de árboles exóticos. Los datos obtenidos fueron comparados con los de la sobrecarga de desecho desnudo de la mina y los suelos de bosque nativos. Los resultados mostraron que la condición del suelo es mejor en los rodales de las diferentes plantaciones que en la sobrecarga desnuda. Las cantidades de partículas de limo y arcilla en el suelo fueron más altas entre los diferentes rodales de plantaciones en comparación con el tiradero de la sobrecarga desnuda. La máxima densidad aparente correspondió a las parcelas de *Casuarina equisetifolia* y la mínima a las parcelas de *Gravellia pteridifolia.* El contenido de humedad en el suelo fue también más alto bajo diferentes plantaciones. La capacidad de retención de agua y el contenido de humedad en el suelo fueron mayores en las parcelas de *Eucalyptus hybrid*. Las concentraciones de carbono orgánico y de nitrógeno total fueron más altas en los rodales de las plantaciones en comparación con los tiraderos desnudos de la sobrecarga. El nitrógeno disponible (NO_3 – N y NH_4 – N) tuvo su valor más alto en las parcelas de *Eucalyptus hybrid* en las tres estaciones. El C, N y P del suelo correspondiente a la biomasa microbiana tuvieron sus máximos valores en las parcelas de *Gravellia pteridifolia* y los más bajos en las de *Cassia siamea*. Las plantaciones mejoraron el estado nutricional de la tierra dañada por los desperdicios de la mina. Las especies vegetales variaron en sus habilidades para modificar las propiedades del suelo en el desecho de la mina. Entre las especies arbóreas, se encontró que *Eucalyptus hybrid, Acacia auriculiformis* y *Casuarina equisetifolia* son las más adecuadas para modificar las características del deterioro durante el proceso de revegetación.

**Corresponding Author:* E-mail: madhoo@banaras.ernet.in; r_kdutta@rediffmail.com

Resumo: As características do solo e a actividade microbiológica de um solo de refugo de um mina de carvão revestido com cinco espécies exóticas arbóreas foram investigadas. Os dados obtidos foram comparados com os dos solos nus dos refugos da mina e com os da floresta nativa. Os resultados mostram uma melhoria no status do solo sob coberto nas diferentes parcelas plantadas em comparação com o do solo de refugo nu. As partículas de limo e argila no solo eram mais elevadas entre as diferentes parcelas plantadas em comparação com os depósitos de solo nu de refugo. A densidade global foi mais elevada nas parcelas de *Casuarina equisetifolia* e menos nas de *Gravellia pteridifolia*. O teor em água no solo era também mais elevado nas diferentes plantações. A capacidade de retenção e o teor de água no solo era mais elevado nas parcelas com *Eucalyptus* híbridos. As concentrações em carbono orgânico e azoto total eram maiores nas parcelas plantadas quando comparadas com as dos depósitos de solo nu de refugo. O azoto disponível (NO_3 – N e NH_4 – N) e em todas as estações, era maior nas parcelas de *Eucalyptus hybrid*. A biomassa microbiana no solo C, N e P eram mais elevadas nas parcelas de *Gravellia pteridifolia* e menores nas de *Cassia siamea*. As plantações melhoraram o status nutricional dos solos degradados de refugos de mina. As espécies vegetais variaram na sua capacidade de alteração das propriedades de solos de refugo mineiro. Entre as três espécies, a *Eucalyptus hybrid*, *Acacia auriculiformis* e *Casuarina equisetifolia* mostraram-se as mais adequadas para modificar as características dos refugos durante o processo de revegetacionamento.

Key words: Mine spoil, microbial biomass, N-mineralization, nutrients, revegetation.

Introduction

At the early stages of an ecosystem development, soil acts as a critical controlling component. Without the natural processes of soil development, ecosystems would remain in a degraded condition. Mine spoil heaps are composed of coarse rocks due to the deep coal mining operations and associated coal processing. These spoils are not suitable for both plant and microbial growth because of low organic matter content, unfavourable pH, drought arising from coarse texture or oxygen deficiency due to compaction (Agrawal *et al.* 1993). The other limiting factors for revegetation of mine spoil may be salinity, actidity, poor water holding capacity, inadequate supply of plant nutrients and accelerated rate of erosion (Jha & Singh 1991). During the reclamation of mine spoil, it is often necessary to establish and maintain a vegetative cover without the use of topsoils or other bulky amendments (Rimmer 1982). Pederson *et al.* (1988) observed that the surface material from coal mining in Pennsylvania had a high density and low porosity resulting in low infiltration rates. In addition to soil physical characteristics, the nutrient status of overburden soil is also a major factor limiting plant growth. The cycling of nutrients regulates the sustainability of any plant community. Without cycling, nutrients will be lost or immobilized and the plant community will not be capable of regeneration. Berg & Barrau (1978) suggested that rapid reestablishment of the nitrogen cycle appears to be particularly important, but often difficult to achieve in mine spoil.

In mine spoils, geomorphic system is in disequilibrium due to the destruction between landform and processes, which accelerates erosion rate (Dutta 1999). Destruction of soil properties causes reduced soil productivity. Mine spoils present very regrous conditions for both plant and microbial growth because of low nutrient contents, either coarse texture and compacted structure (Dutta & Agrawal 2000). Natural plant succession is also very slow on coal mine spoil land. Raising of plantations may accelerate this process leading to a self sustained ecosystem in a relatively short period of time (Singh & Singh 1999). Plantations impart a favourable role in the biological reclamation of mine spoil due to modification of the soil characteristics. The present study was, therefore, conducted to assess the impact of plantations of five exotic tree species on soil physico-chemical characteristics and microbial activity, and to recommend the suitable plant species for bioreclamation of mine spoil land.

Materials and methods

Study area

This study was conducted on the mine spoils of Jayant opencast coal mine, Northern Coal Limited situated in the Sidhi district of Madhya Pradesh, India (24° 05′ 55″ – 24° 11′ N latitude, 82° 38′ 10″ – 82° 40′ 45″ E longitude, 300-500 m above sea level). The climate is tropical monsoonic type. During the study period the mean monthly minimum temperature ranged between 13.5 – 34.4°C and mean monthly maximum temperature between 19.0 – 43.5°C in an annual cycle. The annual rainfall was 750 mm. The mean relative humidity varied between 30.4 (May) to 73.3% (July). The climatic data were obtained from the Central Mine Planning and Designing Institute at Jayant.

Natural vegetation and soil

The natural vegetation of the area is tropical mixed deciduous forest type. The undulating, nearly flat area is under cultivation, whereas forest is confined mostly on hilly portions. The soils of the area is shallow, leached, residual, sandy loam, reddish to reddish brown ultisols mainly derived from Kaimur sand stones (Dhandraul orthoquartzite). The native forest soil contains 60% sand, 32% silt and 8% clay with the moisture content of 14.5%. The pH of the soil is 6.9. The bulk density is 1.25 g cm^{-3}, whereas water holding capacity is 45%. Available nutrients are higher in forest soil (NO_3-N, 9.65 μg g^{-1}; NH_4-N, 12.1 μg g^{-1}; available P, 20 μg g^{-1}). The contents of organic carbon, total N and total P are 1.13%, 0.16% and 0.068%, respectively.

Seedlings plantation on mine spoil

Six month old nursery raised seedlings of five exotic plant species i.e. – *Acacia auriculiformis*, A. Cunn, *Casuarina equisetifolia*, JR & Forst, *Cassia siamea,* Lamk, *Eucalyptus hybrid,* Pryor & Johnson and *Gravellia pteridifolia*, R. Br. were planted by the Forest Department of Madhya Pradesh, India in 1990 in previously dug pits (40 cm^3) at a spacing of 2 m x 2 m. Three permanent experimental plots for each species, of size 25 m x 25 m except for *A. auriculiformis* and *C. siamea*, where the plots were 10 m x 10 m were identified. The experiment was started when the plantations were four years old. The plantations have been raised for land rehabilitation because natural colonization is very slow on mine spoil. All the exotic species selected for the present study are commonly grown in India for developing green belts under the social forestry scheme of the Forest Department.

Soil sampling

Triplicate soil samples were collected randomly from each of the three permanent plots using 15 x 15 x 10 cm (depth) monoliths in each of the three seasons, i.e. summer, rainy and winter for the analyses of available nutrients and nitrogen mineralization, other physical and chemical characteristics of soil viz., organic carbon, total nitrogen, total phosphorus, microbial biomass carbon, nitrogen and phosphorus were analysed once only during winter season. The samples from within a plot were thoroughly mixed to yield one composite sample per plot. Large pieces of plant materials were removed and the field moist soil was sieved through 2 mm mesh screen. Each soil sample was divided into two parts. One part held in the field moist condition was used for the measurement of available nutrients (NH_4 – N, NO_3 – N and PO_4-P). The other part was used for the determination of soil moisture, pH, total organic C, Kjeldahl N, total P and microbial biomass analysis.

Chemical analysis

Percentage of sand, silt and clay in the soil was determined by the pipette method as described by Piper (1966). Soil pH was measured in a suspension of 1:5 (soil:water; W/V) using a photovolt pH meter with a glass electrode (DPH, Instrument Technique Pvt. Ltd., India). Bulk density, water holding capacity and porosity were determined according to Piper (1966). Organic C was determined by Walkely and Black's rapid titration method described by Allison (1973). Kjeldahl N was determined by the microkjeldahl method (Jackson 1958), NH_4-N was extracted in 2 M KCl and analysed by the phenate method (APHA 1995). NO_3-N was measured by the phenol disulphonic acid method, using $CaSO_4$ as the extractant (Jackson 1958). Bicarbonate extractable inorganic P was determined by the ammonium molybdate stannous chloride method (Sparling *et al.* 1985). The soil was digested in a tri acid mixture of $HClO_4$, HNO_3 and H_2SO_4 (1:5:1), and the digest was analysed for P using phosphomolybdic acid blue method (Jackson 1958).

N–mineralization

N – mineralization was measured by the buried bag technique (Eno 1960). Two fresh field moist, sieved (2 mm) soil samples (150-200 g each) were sealed in large polythene bags and buried in the soil at 15 cm depth in each plot. Coarse root and large fragments of organic debris were removed in order to avoid any marked immobilization during incubation. Nitrate – N and ammonium – N were analysed (as mentioned above) at time zero and after 30 days of field incubation. The increase in the concentrations of ammonium-N and nitrate – N over the course of field incubation is defined as N – mineralization, the increase in nitrate – N only as nitrification and the increase in ammonium – N only as ammonification. All results are expressed on an oven dry soil (105°C, 24 h) basis.

Microbial biomass C, N and P

Field moist soil was pre-incubated by spreading between the two polythene sheets overnight. It was then transferred to polythene bags and incubated for 7 days at 25°C in a air tight container which contained two vials, one with 20 ml distilled water to maintain 100% relative humidity and other with sodalime to absorb CO_2. The cover of the container was opened for a few minutes every day for the aeration. The soil was taken out after one week and mixed thoroughly for analysis of microbial biomass C, N and P by the fumigation extraction method (Brookes *et al.* 1982; Vance *et al.* 1987). The preconditioned soil samples (50 g) were fumigated in a dessicator with purified liquid chloroform ($CHCl_3$) for 10-20 h (Srivastava & Singh 1988) and then chloroform was removed by evacuation. For the estimation of biomass C and N, the soil was extracted with 0.5 M K_2SO_4 (1:4, soil : extractant) but for the estimation of biomass P another soil sample was extracted with 0.5 M $NaHCO_3$ for 30 min. The unfumigated preconditioned soil samples were also extracted.

Microbial C was determined by dichromate digestion following Vance *et al.* (1987). Biomass C was calculated from the equation MBC = 2.64 Ec, where Ec is the difference between C extracted from the fumigated and unfumigated soils (Vance *et al.* 1987). Biomass N was estimated as total N using the Kjeldahl digestion method. The flush of total N (K_2SO_4 – extractable N in unfumigated soil subtracted from that of fumigated soil) was divided by a K^N (fraction of biomass N extracted after $CHCl_3$ fumigation) values of 0.54 (Brookes *et al.* 1985). Biomass P was determined as inorganic P in the $NaHCO_3$ extracts of fumigated and unfumigated soils by the ammonium molybdate-stannus chloride method (Sparling *et al.* 1985). Biomass P was estimated as the difference in $NaHCO_3$ – inorganic P in fumigated soil and the unfumigated soil using the recovery rate (KP) of 0.40 assuming that 40% P in the soil microbial biomass is released as inorganic P by $CHCl_3$ (Brookes *et al.* 1982). All results are expressed on an oven dry soil (105°C, 24 h) basis.

Statistical analysis

The data were statistically analysed using Analysis of Variance and Correlation by using computer software M-STAT on a Personal Computer.

Results and discussion

The data obtained for soil characteristics from mine spoils under different plantations were compared with fresh mine spoil soils. Soil physical properties varied considerably between the plots of different plant species (Table 1). The percentage of sand was lower in plots of different plant species (81.41% – 84.95%) as compared to fresh mine spoil (89.30%), whereas silt (12.35% – 13.60%) and clay (2.70% – 5.02%) percentages were found higher in the planted plots compared to fresh mine spoil (silt 8.2% and clay 2.5%). The variations in sand percentage between different tree species were not statistically significant. However, silt ($P<0.01$) and clay ($P<0.001$) percentages showed significant variations among the plots of different plant species. Significant variations in silt and clay suggest that plantations are capable of changing the soil texture after their establishment and growth in

Table 1. Physical properties of soil around different plant species planted on coal mine spoil and on the fresh mine spoil (Mean ± 1 SE).

Parameters	Fresh mine spoil	*A. auriculiformis*	*C. equisetifolia*	*C. siamea*	*E. hybrid*	*G. pteridifolia*
Texture (%)						
Sand	89.30 ± 2.27	83.95 ± 2.86	84.95 ± 2.00	83.31 ± 4.40	81.41 ± 3.20	82.58 ± 4.28
Silt	8.20 ± 0.22	12.60 ± 0.26	12.35 ± 0.17	13.40 ± 0.20	13.60 ± 0.21	13.00 ± 0.05
Clay	2.50 ± 0.01	3.45 ± 0.01	2.70 ± 0.02	3.29 ± 0.04	5.02 ± 0.07	4.42 ± 0.02
Bulk density (g cm^{-3})	1.45 ± 0.03	1.62 ± 0.04	1.63 ± 0.02	1.61 ± 0.02	1.61 ± 0.04	1.58 ± 0.04
WHC (%)	25.00 ± 1.24	27.98 ± 1.25	30.68 ± 2.10	28.66 ± 2.11	35.01 ± 1.75	30.73 ± 1.33
Moisture (%)	6.83 ± 0.10	7.42 ± 0.14	8.26 ± 0.09	7.52 ± 0.02	8.95 ± 0.04	7.95 ± 0.08
pH	6.40 ± 0.04	6.86 ± 0.07	6.61 ± 0.04	6.86 ± 0.07	6.71 ± 0.06	6.85 ± 0.08
Porosity	45.20 ± 1.20	38.86 ± 2.00	38.49 ± 2.10	39.24 ± 2.00	39.26 ± 1.90	40.34 ± 1.70

due course. The texture of mine spoils are drastically disturbed due to irregular pilling of overburden materials. The naturally revegetating mine spoil of five years age showed percentages of sand, silt and clay as 61, 25 and 14% (Jha & Singh 1991).

Particle size distribution is a major factor in governing a successful revegetation on reclaimed land as it influences water holding capacity, bulk density, soil moisture availability and nutrient contents as well as availability. The bulk density was found to be maximum in the *C. equisetifolia* (1.63 g cm^{-3}) and minimum in *G. pteridifolia* (1.58 g cm^{-3}) plots, but the variations among different plots were not statistically significant. The values obtained for bulk density of reclaimed soil were higher than the native forest soil, but lower than the fresh mine spoil. The WHC is maximum in *E. hybrid* plots which is directly correlated with the texture of the soil of plantation stand. The values of WHC reported for the green belts of these species vary between 45.1 to 50.1% (Yadav 1997). The increment in WHC in comparison to fresh mine spoil may be attributed to the establishment of plant cover. The plantations have decreased the porosity, which may be attributed to the fragmentation, redistribution and aggregation of particles due to vegetation development and consequent soil processes in different plots.

Soil moisture content among plots of different plant species (7.42 – 8.95%) was lower than that recorded for the native forest soil (14.5%) but higher than that in fresh mine spoil (6.83%). Prasad & Pandey (1985) also reported lack of moisture retention capacity of mine spoil at Amarkantak in India. The lack of moisture retention of about 25% was also reported for most of the coal mine spoil in Pennsylvania (Pederson *et al.* 1988). The moisture content observed in the present study was higher in comparison to the five years old naturally revegetated mine spoil soil of nearby area (4.6%) as reported by Jha & Singh (1991). The present study indicates a positive relationship between soil moisture content and height of the tree species (*A. auriculiformis* r = 0.90, $P<0.01$; *C. equisetifolia* r = 0.91, $P<0.01$; *C. seamea* r = 0.90, $P<0.01$; *E. hybrid* r = 0.89, $P<0.01$ and *G. pteridifolia* r = 0.90, $P<0.01$). Soil pH showed significant variations among plots from different plant species ($P<0.01$). The pH values recorded during present experiment (6.61 – 6.86) are not toxic and more close to neutral. The increase in pH due to plantations suggests that the organic matter input modifies the pH of the soil. Since the plant species are dicotyledenous, these may release more base cations like Ca^{2+} into the soil and thus increase the pH of the soil more than the fresh mine spoil. Richart *et al.* (1987) also observed that the change in pH of opencast spoil was directly related to the tree growth.

The organic carbon content was maximum in the plots of *A. auriculiformis* (0.60%) and minimum in *C. siamea* (0.47%) plots. Soil oranic carbon content recorded during the present study is very low in comparison to that reported in the topsoil stock piles of four years old mounds at Cumbria and Staffordshire, U.K. (Williamson & Johnson 1990). The lower level of organic carbon in mine spoil soil might be due to the disruption of ecosystem functioning (Stark 1977), depletion of

Table 2. Selected chemical characteristics of soil around different plant species planted on coal mine spoil and on the fresh mine spoil (Mean ± 1 SE).

Parameters	Fresh mine spoil	*A. auriculiformis*	*C. equisetifolia*	*C. siamea*	*E. hybrid*	*G. pteridifolia*
Organic C (%)	0.46 ± 0.02	0.60 ± 0.03	0.58 ± 0.02	0.47 ± 0.03	0.51 ± 0.01	0.55 ± 0.02
Total N (%)	0.028 ± 0.0002	0.062 ± 0.0003	0.057 ± 0.0012	0.047 ± 0.0005	0.051 ± 0.0008	0.058 ± 0.0014
Total P (%)	0.010 ± 0.0001	0.015 ± 0.0004	0.017 ± 0.0004	0.0098 ± 0.0001	0.011 ± 0.0003	0.014 ± 0.0008
Available P ($\mu g\ g^{-1}$)	3.15 ± 0.04	3.60 ± 0.06	4.20 ± 0.06	3.40 ± 0.06	4.00 ± 0.06	4.0 ± 0.06

soil organic pool (Parkinson 1979) and also due to the loss of litter layer during mining which is an integral storage and exchange site for nutrients. Total nitrogen also followed a similar trend for species wise variation as that of organic carbon (Table 2). The total N conent in soil around different plantations (0.047-0.062%) is comparable to the results of Srivastava & Singh (1988) who found 0.078% total N in twelve years old naturally vegetated over burden. Srivastava *et al.* (1989) found lower concentration of total N in 5 year old mine spoil (20 $\mu g\ g^{-1}$) in comparison to forest soil (75 $\mu g\ g^{-1}$). Higher values of total N in comparison to fresh mine spoil is due to the organic matter accumulation in soil by roots and leaching of N from the herbaceous vegetation of the plots. The total N is also positively correlated with the height of the plants (*A. auriculiformis* r = 0.88, P<0.05; *C. equisetifolia* r = 0.81, P<0.05; *E. hybrid* r = 0.89, P<0.01 and *G. pteridifolia* r = 0.87, P<0.05). *C. siamea,* a nitrogen fixing species, showed lowest N content in the soil due to lower growth and nodulation (Dutta 1999). Total phosphorus content varied significantly among different plant species (P<0.05) with maximum concentration in *C. equisetifolia* plots, however, the variations in available P were not significant. Development of vegetation cover enhanced the natural soil cycle and thus showed higher values of total P compared to fresh mine spoil. The values of available P found during present study is comparable to the reported value of Srivastava *et al.* (1989) for 5 years old naturally vegetated coal mine spoil, but lower in comparison to the bamboo plantation on the same coal mine spoil (Singh & Singh 1999).

The concentrations of NO_3-N and NH_4-N were maximum during summer followed by winter and minimum during rainy season (Fig. 1), the maximum concentration being found in the plots of *E. hybrid* and minimum in *G. pteridifolia.* Nitrate-N content did not show significant variations between different seasons and tree species. However, NH_4-N varied significantly between seasons (P<0.01) and plantations (P<0.01). The concentration of inorganic nitrogen (NH_4-N and NO_3-N) in soil was higher under plantations in comparison to bare overburden dump. This increase may be attributed to the input through litterfall (Dutta & Agrawal 2001), and to the microbial activity causing transformation of inorganic N forms around roots of plant species. The concentrations of inorganic N observed during the present study are comparable to the reported values of Singh & Singh (1999) (NO_3-N, 1.2 $\mu g\ g^{-1}$; NH_4-N, 3.7 $\mu g\ g^{-1}$) in the bamboo plantation on the same mine spoil. The increase in inorganic N during summer reflects decrease demand by plants or may partly be due to upward movement of water. Greater amount of NH_4-N during the dry period may be due to soil drying which results in the release of free ammonium and aminoacids (Birch 1958). The decrease in inorganic N during rainy season is due to higher demand for these nutrients by the plants, which grow vigorously during this period (Singh *et al.* 1989).

Ammonification and nitrification rates were maximum during rainy season and minimum during summer season (Table 3). Both these parameters did not vary significantly between the plots of different plant species, but the season wise variation was significant for nitrification (P<0.001). Net mineralization also showed a similar seasonal pattern. Net mineralization varied significantly both between the plantations (P<0.01) and seasons (P<0.05). The plots of *E. hybrid* (6.19 $\mu g\ g^{-1}\ mo^{-1}$) showed maximum net mineralization and *G. pteridifolia* (5.01 $\mu g\ g^{-1}\ mo^{-1}$) minimum during rainy season. The highest ammonification and nitrification rates during rainy season may be ascribed to adequate moisture and favourable tem-

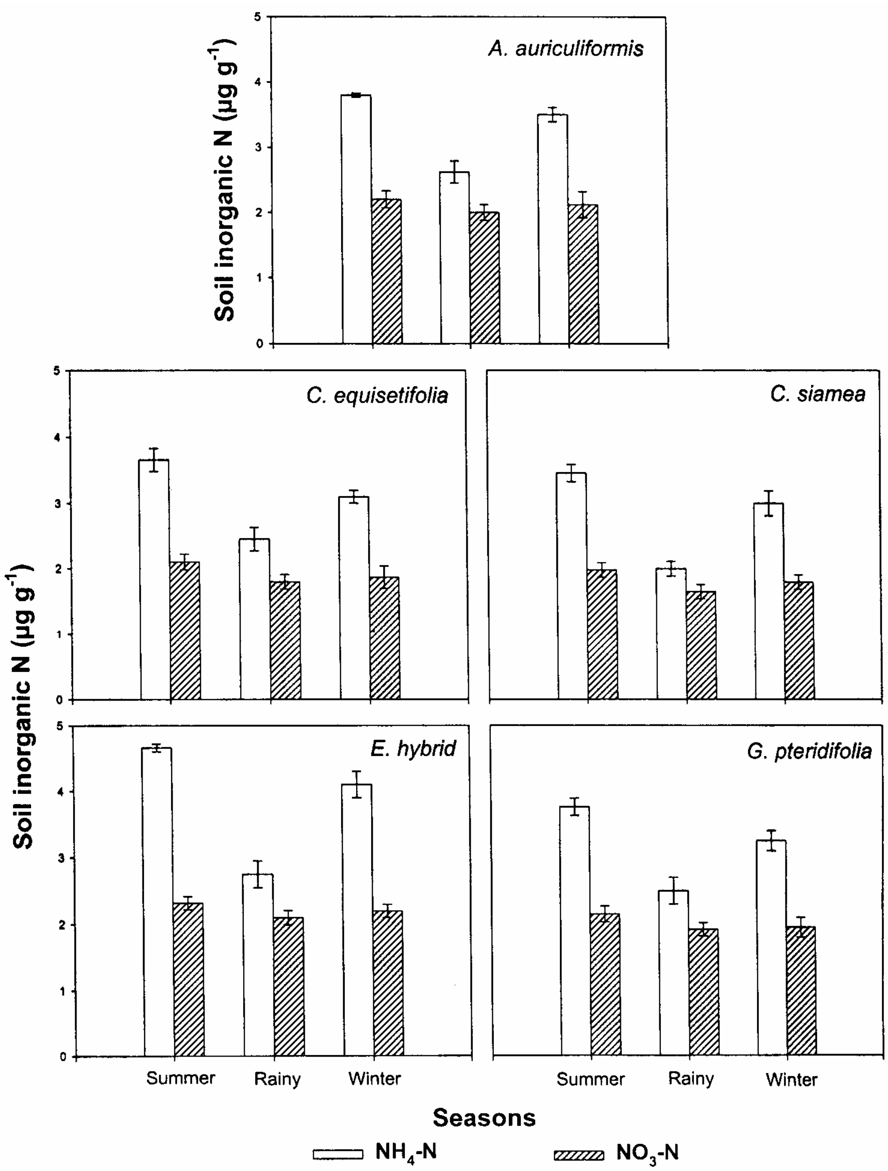

Fig. 1. Seasonal variations in available nitrogen concentration in soil around different tree species planted on coal mine spoil. Vertical bars represent ±1 SE.

perature conditions. But during summer due to limitations of water and high soil temperature, microbial activity may have adversely affected thus reducing the rates of both the processes. The low mineralization rate observed in the present study corresponds to the small pool of soil inorganic N, which is a characteristic feature of immature ecosystem. Higher values of mineral N during rainy season may be due to easily decomposable substrate such as glucose, sucrose, aminoacids and amides (Birch 1958). During rainy season, the dead microbial population provides additional substrate, which further stimulates mineralization. Decrease in N – mineralization in winter and summer may be explained to increased microbial biomass which immobilizes the nutrients and build up their biomass in dry periods (Singh *et al.* 1989).

Variations in microbial biomass C ($P<0.01$), N ($P<0.01$) and P ($P<0.05$) in soil around different plant species were found to be significant. The

Table 3. Ammonification, nitrification and N-mineralization rate (μg g^{-1} mo^{-1}) in soil around different plant species planted on coal mine spoil (Mean ± 1 SE).

Plant species	Seasons	Ammonification	Nitrification	N-mineralization
	S	1.72 ± 0.08	2.70 ± 0.13	4.42 ± 0.21
A. auriculiformis	R	2.02 ± 0.15	3.33 ± 0.18	5.35 ± 0.10
	W	1.87 ± 0.11	2.91 ± 0.07	4.78 ± 0.19
	S	1.71 ± 0.10	2.62 ± 0.08	4.33 ± 0.16
C. equisetifolia	R	2.00 ± 0.10	3.22 ± 0.12	5.22 ± 0.16
	W	1.70 ± 0.03	2.83 ± 0.05	4.53 ± 0.03
	S	1.73 ± 0.03	2.71 ± 0.07	4.44 ± 0.11
C. siamea	R	2.01 ± 0.11	3.29 ± 0.08	5.30 ± 0.16
	W	1.78 ± 0.13	2.87 ± 0.11	4.65 ± 0.12
	S	2.11 ± 0.05	2.98 ± 0.04	5.09 ± 0.10
E. hybrid	R	2.32 ± 0.11	3.87 ± 0.11	6.19 ± 0.11
	W	2.21 ± 0.03	3.07 ± 0.09	5.28 ± 0.06
	S	1.51 ± 0.07	2.60 ± 0.13	4.11 ± 0.03
G. pteridifolia	R	1.91 ± 0.09	3.10 ± 0.11	5.01 ± 0.13
	W	1.62 ± 0.03	2.72 ± 0.05	4.34 ± 0.11

S = Summer; R = Rainy; W = Winter.

values of all these parameters were found maximum in the plots of *G. pteridifolia* and minimum in *C. siamea* plots (Fig. 2). Soil microorganisms act as an important factor in aiding soil formation and revegetation through their activities as decomposers and nitrogen cyclers, nitrogen fixers (symbiotic and asymbiotic) and mycorrhizal symbionts (Visser *et al.* 1983). In the present study, the microbial biomass C ranged between 125.0 – 141.6 μg g^{-1}, biomass N ranged 10.31 – 19.38 μg g^{-1} and biomass P between 3.13 – 6.49 μg g^{-1}. In comparison to these values, Srivastava *et al.* (1989) reported the values of microbial biomass C, N and P in 5 year old naturally revegetated mine spoil as 209 μg g^{-1}, 20 μg g^{-1} and 7 μg g^{-1}, respectively. Several fold higher concentration of microbial biomass is reported for forest soils. Root biomass and above ground plant biomass are considered to be the main source of soil organic matter and the later is highly correlated with microbial biomass (Schnurer *et al.* 1985). Litterfall also acts as a critical regulating component to enrich the microbial biomass on mine spoil soil (Dutta 1999). Microbial biomass C, N and P were highest in *G. pteridifolia* plots which also showed maximum litterfall (Dutta & Agrawal 2001), but the litter decomposition rate was slowest compared to other tree species. A positive and significant correlation was found between litterfall vs MBC (*A. auriculiformis* r = 0.98, P<0.05; *C. equisetifolia* r = 0.99, P<0.05; *C. seamea* r = 0.96, P<0.05; *E. hybrid* r = 0.99, P<0.01 and *G. pteridifolia* r = 0.98, P<0.05); litterfall vs MBN (*A. auriculiformis* r = 0.98, P<0.05; *C. equisetifolia* r = 0.99, P<0.01; *C. seamea* r = 0.99, P<0.01; *E. hybrid* r = 0.97, P<0.01 and *G. pteridifolia* r = 0.98, P<0.05), and litterfall vs MBP; (*A. auriculiformis* r = 0.99, P<0.01; *C. equisetifolia* r = 0.99, P<0.01; *C. seamea* r = 0.98, P<0.01; *E. hybrid* r = 0.97, P<0.05 and *G. pteridifolia* r = 0.87, P<0.05) among the plots of different plant species. It may be because of the humus formation as a result of the decomposition of litter which provides a growing substrate for different microbes in the soil. The reduction in microbial nutrients of the mine spoils is due to the lack of functional top soil layer, less levels of nutrients and lack of active microbial system. Srivastava *et al.* (1989) and Singh & Singh (1999) suggested that soil microbial biomass C, N and P can be taken as a functional index of soil redevelopment.

Conclusions

Among different plant species, the physical characteristics are maximally improved by *E. hybrid, A. auriculiformis* and *C. equisetifolia*. In soil texture, maximum silt and clay was found in the plots of *E. hybrid*. Bulk density was higher in *C. equisetifolia* followed by *A. auriculiformis* and lowest in *G. pteridifolia* plots. WHC was also highest in the plots of *E. hybrid*. Moisture content also followed a similar trend. In chemical characteristics,

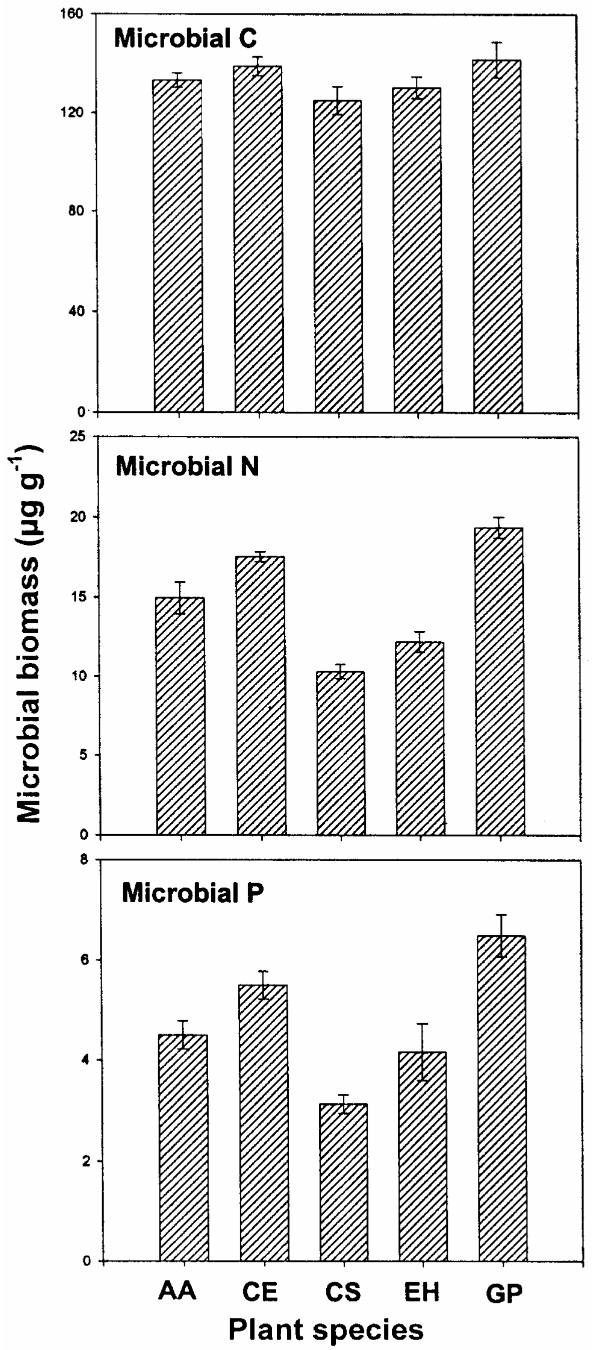

Fig. 2. Microbial biomass C, N and P in different plots of tree species planted on coal mine spoil. Vertical bars represent ±1 SE. (AA = *A. auriculiformis*, CE = *C. equisetifolia,* CS = *C. siamea*, EH = *E. hybrid* and GP = *G. pteridifolia*).

total N content was higher for *A. auriculiformis*, a nitrogen fixing species, whereas *C. siamea* showed lowest N content in soil. Organic C and total P also followed a similar trend. These characteristics can be due to the lower growth and poor nodulation of *C. siamea* plants (Dutta 1999). *C. equisetifolia*, a non-leguminous nitrogen fixing species showed highest available P content and a higher N level in the soil. At any given season, both forms of available nitrogen were maximum in the plots of *E. hybrid*, which also showed maximum ammonification, nitrification and also net N – mineralization rates. Microbial biomass C, N and P varied considerably between the plantations of different tree species.

This study clearly indicates that the plantations on mine spoil modify the soil physico-chemical characteristics up to several folds, but the plant species differed in their ability to modify the same. The plantations of different species have maintained the nutrient regeneration due to addition of organic matter and its further decomposition. Increasing availability of organic matter also enhanced N – mineralization, and hence the supply of plant available nutrients. The enhancement in plant available nitrogen due to plantations will be further helpful in soil-nutrient cycling. The study further suggests that *E. hybrid, A. auriculiformis* and *C. equisetifolia* have maximum favourable impact on modifying physical, chemical and biological properties of mine spoil.

Acknowledgements

We thank Ministry of Coal, Govt. of India, for the financial support to this experiment. We are also thankful to Ministry of Environment & Forest for the financial support. RKD thanks the Council of Scientific and Industrial Research, New Delhi, for Research Associateship.

References

Agrawal, M., J. Singh, A.K. Jha & J.S. Singh. 1993. Coal-based environmental problems in a low rainfall tropical region. pp. 27-57. *In*: R.F. Keefer & K.S. Sajwan (eds.). *Trace Elements in Coal Combustion Residues*. Lewis Publishers, Boca Raton.

Allison, F.A. 1973. *Soil Organic Matter and its Role in Crop Production*. Elsevier, Amsterdam.

APHA (American Public Health Association). 1995. *Standard Methods for the Examination of Water* *and Wastewater*. American Public Health Association, Washington, DC.

Berg, B. & E.M. Barrau. 1978. Management approaches to nitrogen deficiency in revegetation of sub alpine disturbances. Information Series. **28**. pp. 174-181. *In*: S.T. Kenny (ed.) *Proceedings of High Altitude Revegetation Workshop Number 3:* Colorado State University, Fort Collins, Colorado.

Birch, H.F. 1958. The effect of soil drying on humus decomposition and nitrogen availability. *Plant and Soil* **10**: 9-31.

Brookes, P.C., A. Landman, G. Pruden & D.S. Jenkinson. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biology & Biochemistry* **17**: 837-842.

Brookes, P.C., D.S. Powlson & D.S. Jenkinson. 1982. Measurement of microbial biomass phosphorus in soil. *Soil Biology & Biochemistry* **14**: 319-329.

Dutta, R.K. 1999. *Performance and Impact of Selected Exotic Plant Species on Coal Mine Spoil.* Ph.D. Thesis. Banaras Hindu University, Varanasi, India.

Dutta, R.K. & M. Agrawal. 2000. Reclamation of mine spoils: a need for coal industry. pp. 239-250. *In*: Arvind Kumar & P.K. Goel (eds.) *Industry, Environment and Pollution*. Technoscience Publications, Jaipur, India.

Dutta, R.K. & M. Agrawal. 2001. Litterfall, litter decomposition and nutrient release in five exotic plant species planted on coal mine spoils. *Pedobiologia* **45**: 298-312.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polythene bags. *Soil Science Proceedings* **1009**: 277-279.

Jackson, M.L. 1958. *Soil Chemical Analysis*. Constable, London.

Jha, A.K. & J.S. Singh. 1991. Spoil characteristics and vegetation development of an age series of mine spoils in a dry tropical environment. *Vegetatio* **97**: 63-76.

Parkinson, D. 1979. Soil microorganisms and plant roots. pp. 449-478. *In*: A. Burges & F. Raw (eds.) *Soil Biology*. Academic Press, New York.

Pederson, T.A., A.S. Rogowski & R. Pennock. 1988. Physical characteristics of some mine spoils. *Soil Science Society American Journal* **44**: 131-140.

Piper, C.S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay.

Prasad, R. & R.K. Pandey. 1985. Natural plant succession in the rehabilitated bauxite and coal mine overburden of Madhya Pradesh. *Journal of Tropical Forestry* **1**: 310-320.

Richart, S.I., J.H. Nancy, T. David, R.T. John, S. Mark & Z. Kothleanc. 1987. Old field succession on a Minnesota sand plain. *Ecology* **68**: 12-26.

Rimmer, D.L. 1982. Soil physical conditions on reclaimed spoil heaps. *Journal of Soil Science* **33**: 567-579.

Schnurer, J., M. Clarholm & T. Rosswal. 1985. Microbial biomass and activity in agricultural soil with different organic matter contents. *Soil Biology & Biochemistry* **17**: 611-618.

Singh, J.S., A.S. Raghubanshi, R.S. Singh & S.C. Srivastava. 1989. Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. *Nature* **338**: 499-500.

Singh, Anand Narain & J.S. Singh. 1999. Biomass, net productivity and impact of bamboo plantation on soil redevelopment in a dry tropical region. *Forest Ecology & Management* **119**: 195-207.

Sparling, G.P., K.N. Whale & A.J. Ramsay. 1985. Quantifying the contribution from the soil microbial biomass to the extractable P levels of fresh and air dried soils. *Australian Journal of Soil Research* **23**: 613-621.

Srivastava, S.C. & J.S. Singh. 1988. Carbon and phosphorus in the soil biomass of some tropical soils of India. *Soil Biology & Biochemistry* **20**: 743-747.

Srivastava, S.C., A.K. Jha & J.S. Singh. 1989. Changes with time in soil biomass C, N and P of mine spoils in a dry tropical environment. *Canadian Journal of Soil Science* **69**: 849-855.

Stark, N.M., 1977. Fire and nutrient cycling in a douglas fir/larch forest. *Ecology* **58**: 16-30.

Vance, E.D., P.C. Brookes & D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology & Biochemistry* **19**: 703-707.

Visser, S., J. Fujikawa, C.L. Griffiths & D. Parkinson. 1983. Effects of surface mining on the microbiology of a prairie site in Alberta, Canada. *Canadian Journal Soil Science* **63**: 177-189.

Williamson, J.C. & D.B. Johnson. 1990. Determination of the activity of soil microbial population in stored and restored soil at opencast coal sites. *Soil Biology & Biochemistry* **22**: 671-675.

Yadav, R.S. 1997. *Analysis of Air Pollution Problem around Opencast Coal Mine and its Impact on Vegetation.* Ph.D. Thesis. Banaras Hindu University, Varanasi, India.