IMPACT OF PLANTATION ON ECOSYSTEM DEVELOPMENT IN DISTURBED COAL MINE OVERBURDEN SPOILS

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BANERJEE, S. K., MISHRA, T. K., SINGH, A. K. & JAIN, A. 2004. Impact of plantation on ecosystem development in disturbed coal mine overburden spoils. Eleven nitrogen fixing and one non-nitrogen fixing tree species were planted in coal mine overburden spoils of Bisrampur colliery at Surguja district, Chattisgarh, India in 1993. Their growth performance at one, two, four, six and eight years was recorded. It was observed that after eight years of planting, *Acacia mangium* performed very well in respect to all the growth parameters followed by *A. holoserecia, Dalbergia sissoo, Albizia procera, Pithecellobium dulce, Acacia auriculiformis* and *Gmelina arborea. Acacia nilotica* showed very poor performance. The number of natural colonisers increased with increasing age of the planted species. Nutrient status of the spoils also increased gradually with the increase in age of the plants. Organic carbon increased greatly and, as a result, activities of bacteria, actinomycetes and fungi accelerated. This study indicated that the spoil environment, which is extremely harsh just after mining, could be improved gradually and the ecosystem restored by planting suitable species. Therefore, for early development of the ecosystem, afforestation with suitable leguminous species is recommended.

Key words: Enrichment – nutrient – microorganisms – leguminous species – afforestation

BANERJEE, S. K., MISHRA, T. K., SINGH, A. K. & JAIN, A. 2004. Kesan ladang hutan terhadap pembangunan ekosistem kawasan permukaan lombong batu arang yang rosak teruk. Sebanyak 11 spesies pokok pengikat nitrogen dan satu spesies pokok bukan pengikat nitrogen ditanam di kawasan permukaan lombong batu arang di Bisrampur di daerah Surguja, Chattisgarh pada tahun 1993. Prestasi pertumbuhan pokok-pokok itu dicerap pada tahun pertama, kedua, keempat, keenam dan kelapan. Daripada keputusan, didapati bahawa selepas lapan tahun ditanam, *Acacia mangium* tumbuh paling baik diikuti dengan *A. holoserecia, Dalbergia sissoo, Albizia procera, Pithecellobium dulce, Acacia auriculiformis* dan *Gmelina arborea. Acacia nilotica* menunjukkan prestasi pertumbuhan paling rendah. Bilangan pengkoloni semula jadi bertambah mengikut umur pokok yang ditanam. Status nutrien di kawasan tersebut beransur-ansur meningkat dan akibatnya aktiviti bakteria, aktinomiset dan kulat bertambah dengan mendadak. Kajian ini menunjukkan bahawa persekitaran yang rosak teruk selepas perlombongan dapat dibaiki secara beransur-ansur dan ekosistem dipulihkan dengan menanam spesies yang sesuai. Oleh itu, untuk pembangunan awal ekosistem, penghutanan semula menggunakan spesies legum yang sesuai disarankan.

Introduction

Overburden dumps in mined areas exhibit completely modified ecological system. In addition, the mine spoils lack most of the physical, chemical, nutritional and biological characteristics of undisturbed soils. Natural plant invasion and succession are important parts of vegetation development as well as nutrient enrichment at disturbed sites (Thomson *et al.* 1984). During ecosystem development, colonisation of different plant species is the primary process that leads to soil formation (Bradshaw 1983). When vegetation is established, the improved soil condition promotes plant succession (Schafer *et al.* 1980). The degree of ecosystem development can be assessed by the level of vegetation recovery, nutrient status of the spoils and microbial population (Jha & Singh 1991, Banerjee & Sonkar 1999, Banerjee *et al.* 1999, 2000a,b, Banerjee 2001). The vegetation modifies the spoil development process through phytocycling of biogenic elements. However, this is a slow process and restoration of ecosystem takes a long time. Direct relationship between spoil age and productivity in mine spoil has been reported by many workers (Marrs *et al.* 1981, Roberts *et al.* 1981, Wali & Pemble 1982, Schafer 1984). Planting of suitable species brings appreciable changes in spoil properties due to spoil-plant interaction, ultimately improving the fertility status of the spoils (Banerjee *et al.* 2001). Nitrogen-fixing tree species has been recommended for successful bio-reclamation of mined spoils (Gudin & Syratt 1975). However, not all of this species have the colonising characteristic necessary for germination and establishment on highly degraded areas. In the present investigation, the growth performance of 11 nitrogen-fixing and one non-nitrogen-fixing tree species was studied in the overburden spoils of Bisrampur colliery at Chattisgarh, India. The impact of plantation on the development of spoils in respect to phytosociological, nutritional and biological characteristics was assessed.

Materials and methods

Study site

The study site is in Bisrampur colliery of Surguja district in the state of Chattisgarh, India (Figure 1). The site is located at latitude 23° 10' to 23° 13' N and longitude

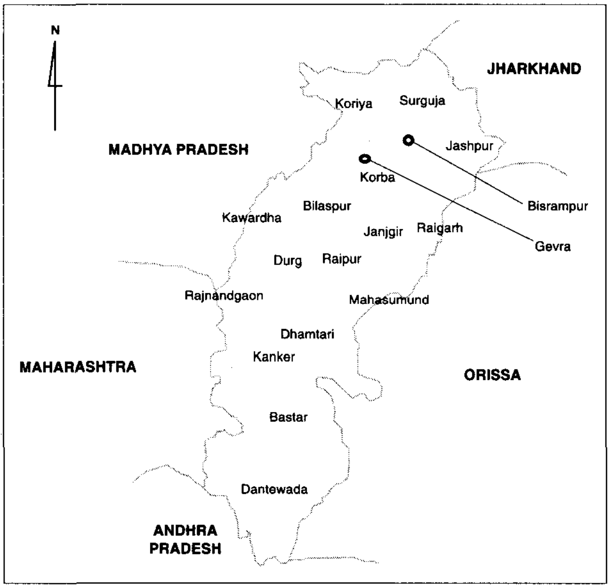

Figure 1 District map of Chattisgarh, India

of 82° 57' to 83° 01' E. Topography of this area is generally undulating. The minimum and maximum elevations range between 203 and 228 m above mean sea level.

Geology and soil

The block in Bisrampur has an area of about 4000 ha and has a single coal seam known as Pasang seam. The thickness of the seam varies from 1.20 to 4.27 m and it occurs at depths varying from 9 to 75 m. The Lower Gondowana formation gives place to the low lying carboniferous area of the Bisrampur coal fields and this again is succeeded further west by coarse sand stone overlying the metamorphic rocks which occur at various places. The carboniferous series contains beds of shale, sand stone and coal seams of varying thickness. At places the coal seam is replaced or represented by carbonaceous shale. The carboniferous series is underlain by Talcher sand stones and greenish needle shales. The natural soils are shallow to moderately deep, acidic (pH 5.8), sandy loam to loam in texture, yellowish brown in colour and fall under Typic Ochraqualf.

Climate

The mean annual rainfall is 1240 mm and mean maximum and minimum temperatures are 32° and 16 °C respectively. The climate of this area is tropical with summer from March till mid June, monsoon from mid June till September and winter from October till February. The dry spell prevails for about eight months.

Vegetation

The natural vegetation of the area is of dry deciduous type dominated by *Shorea robusta.* Other trees present include *Diospyros melanoxylon, Madhuca latifolia, Butea monosperma, Terminalia belerica, Anogeissus latifolia* and *Lagerstroemia parviflora.* High temperature during summer is the main hostile factor in this area, which causes rapid drying and hardening of surface soil, making establishment of vegetation more difficult. The herbaceous vegetation grows rapidly in rainy season and reaches maximum biomass in early October.

Overburden spoil

At the time of study, the overburden spoil was 15 years old. Physical reclamation activities, e.g. easing of slope, top levelling and gully plugging were done in 1991. The height of the overburden dump varied from 10 to 12 m and the slope varied from 10° to 15°. The total area of the dump was 87 ha. The spoils were very coarse and mixed with rock fragments of different sizes. The colour of fresh spoil is grey but it changes to blackish with age. The physical parameters of the spoil before planting are shown in Table 1.

Table 1 Physical parameters of spoil at Bisrampur colliery before planting

Parameter	Value
pH	5.2
Particle size	
> 2 mm	28.4%
2–0.2 mm	55.7%
0.2–0.1 mm	9.6%
< 0.1 mm	6.3%
Bulk density	1.52 g ml^{-1}
Particle density	2.67 g ml^{-1}
Water holding capacity	38.2%
Pore space	41.8%
Aggregates (< 0.25 mm)	34.8%

Methodology

Before plantations were established in the overburden dump, a trial was conducted in a nursery using 57 species in polypots filled with a mixture of overburden spoil and farm yard manure in 1:1 proportion. The performance of seedlings was studied after six months; many species either did not survive or showed very poor growth. On the basis of survival and growth data of this trial, 12 species (11 nitrogen-fixing tree species and 1 non-nitrogen-fixing tree species) showing good growth were selected for field plantation. Block (monoculture) plantations of the 11 nitrogen-fixing tree species, namely, *Acacia catechu, A. nilotica, A. leucophloea, A. mangium, A. auriculiformis, A. holoserecia, Albizia lebbeck, A. procera, Pongamia pinnata, Dalbergia sissoo* and *Pithecellobium dulce* (all Leguminosae) and the one non-nitrogen-fixing tree species, namely, *Gmelina arborea* (Verbenaceae) were raised in 13 ha of dump material in July 1993.

Pits of 45 × 45 × 45 cm at a spacing of 2 × 2 m were excavated. Dump material from the pits was mixed with farm yard manure in 1:1 proportion and filled into the pits. Three-month-old seedlings (nursery raised) were then transplanted into the pits. Each block comprised 25 plants and each block was replicated thrice. The blocks were irrigated twice a week during the dry period. Vegetational parameters (height, collar diameter, biomass of each plant component, namely, leaf, stem and branch) were measured after one, two, four, six and eight years. For biomass estimation, plants of average height were felled from each replication and fresh weights of leaf, stem (leading shoot) and branch (other than leading shoot) were determined separately. These fresh samples were then oven dried at 80 °C for the determination of biomass.

The overall performance of the different species was assessed based on the suitability index of mean height growth, mean collar diameter and biomass attained by the species after eight years; 100 points were given to the highest value of each parameter and the total score for each species was then calculated.

Vegetation surveys were conducted using the quadrat method in October after one, two, four, six and eight years of planting. The size of the quadrats were 1 × 1 m for herbs and 5 × 5 m for shrubs. There were five quadrats in each replication. The vegetation data were analysed for frequency and density. The relative frequency, relative density and relative dominance were calculated following Phillips (1959); for dominance, shoot biomass data were used instead of basal area. The importance value index (IVI) was the sum of relative frequency, relative density and relative dominance.

From each replication under each species five surface spoil samples were collected and mixed thoroughly to get a composite sample. Three such samples were drawn for physico-chemical analysis. pH was determined by using glass electrode pH meter in 1:2.5 spoil-water suspension. Organic carbon was estimated by wet digestion method as described in Jackson (1973). Available nitrogen was estimated by alkaline potassium permanganate distillation method (Subbiah & Asija 1956). Total nitrogen of digested sample was estimated by micro-Kjeldahl method (Jackson 1973). Enumeration of microbial community was carried out following serial dilution technique and pour plate method. Throton's, Jensen's and Martin's rose bengal agar media were used for total bacteria, actinomycetes and fungi count respectively as described in Allen (1959). Triplicate plates were prepared for each dilution, which ranged from 1×10^2 to 1×10^6. Samples were incubated at 28 °C for nine days prior to counting.

All statistical analyses were done using SX software. Analysis of variance (ANOVA) was performed using randomised complete block design. Critical difference (CD) was calculated for pair-wise comparison of studied parameters. Variations between different parameters were observed at 5 and 1% significant levels. Correlation matrix (r) was calculated among microorganisms and nutrient characteristics of spoils under different species and its significance was observed at 5 and 1% levels.

Results and discussion

Growth parameters

Table 2 shows the height and collar diameter of the 12 species studied at different years. Maximum height after eight years was recorded in *Acacia mangium* (14.22 m) followed by *Albizia procera* (13.75 m), *D. sissoo* (13.55 m), *P. dulce* (12.92 m), *G. arborea* (12.65 m) and *A. holoserecia* (12.12 m). Minimum height was in *Acacia nilotica* (5.26 m). However, the growth rate during the study period was not uniform for all species. This indicated that growth rate for the species varied from year to year because of adverse edaphic conditions at the site.

Of the six *Acacia* species, *A. mangium* showed the best performance and *A. nilotica* the poorest in terms of height increment. After eight years, collar diameter varied from 10.8 (*A. nilotica*) and 23.9 cm (*A. mangium*) ($p < 0.01$). Total biomass production was maximum in *A. mangium* (91.80 kg $tree^{-1}$) followed by *A. holoserecia* (68.14 kg $tree^{-1}$), *D. sissoo* (51.99 kg $tree^{-1}$), *A. procera* (49.0 kg $tree^{-1}$) and *A. auriculiformis* (35.98 kg $tree^{-1}$) (Table 3). *Acacia nilotica* had the poorest performance with regard to biomass production (2.40 kg $tree^{-1}$).

The suitability indices based on mean height growth, mean collar diameter and biomass attained by the species after eight years are given in Table 4. *Acacia mangium* obtained the highest total score of 300 followed by *A. holoserecia* (240.63), *D. sissoo* (234.76), *Albizia procera* (214.92), *P. dulce* (186.20), *Acacia auriculiformis* (178.20) and *G. arborea* (170.46). The lowest score was observed in *A. nilotica* (84.79). Prasad and Shukla (1985) have reported satisfactory performance of indigenous species such as *Pongamia pinnata, A. nilotica, A. catechu* and *D. sissoo* in the overburdens of Dhanpuri coal mine. Gupta *et al.* (1994) selected suitable species for biological reclamation of coal mine overburden in Talcher (Orissa) and observed that *P. dulce* exhibited the best growth followed by *Simaruba glauca, Cassia siamea* and *D. sissoo.* Rehabilitation of mined land is site specific and the same species may not

Table 2 Height (m) and collar diameter (cm) of plants at different years

Species	Age (year) 1		2		4		6		8	
	Height	Collar diameter	Height	Collar diameter	Height	Collar diameter	Height	Collar diameter	Height	Collar diameter
Acacia nilotica	0.44	0.8	1.16	4.7	2.05	8.3	4.30	9.2	5.26	10.8
Albizia lebbek	0.38	0.9	1.86	5.2	3.99	9.5	6.05	9.9	8.05	11.8
Acacia leucophloea	0.27	0.7	2.26	6.3	4.13	12.1	6.25	13.6	9.10	15.0
Pithecellobium dulce	0.36	1.0	3.46	3.9	6.07	12.6	9.65	13.9	12.92	15.5
Albizia procera	0.43	0.7	3.99	4.6	8.70	12.4	11.85	13.6	13.75	15.5
Pongamia pinnata	0.36	0.8	1.00	2.8	3.01	10.2	4.55	10.8	5.05	12.2
Gmelina arborea	0.48	1.1	3.55	3.6	7.18	9.9	10.25	10.7	12.65	12.8
Dalbergia sissoo	0.54	0.8	4.65	6.9	8.94	16.2	10.85	17.6	13.55	19.8
Acacia mangium	1.18	1.0	4.90	7.2	9.28	19.4	11.55	21.0	14.22	23.9
Acacia catechu	0.34	0.7	2.02	4.0	4.93	11.8	6.25	12.7	7.35	13.3
Acacia holoserecia	0.94	0.8	3.76	5.8	7.76	16.2	9.26	17.2	12.12	19.4
Acacia auriculiformis	0.74	0.7	2.96	4.7	6.42	12.3	8.53	14.7	10.44	15.7
SEM (±)	0.056	0.057	0.153	0.053	0.229	0.381	0.274	0.504	0.353	0.676
CD (1%)	0.16	0.16	0.43	0.15	0.64	1.07	0.77	1.42	0.90	1.90

SEM = standard error mean, CD = critical difference

Table 3 Biomass (kg tree^{-1}) of different species at different years (oven dry basis)

Species	Age (year) 1		2		4		6		8	
	Branch + stem	Leaf	Branch + stem	Leaf	Branch + stem	Leaf	Branch + stem	Leaf	Branch + stem	Leaf
Acacia nilotica	0.12	0.02	0.26	0.05	0.80	0.10	1.27	0.22	2.06	0.34
Albizia lebbek	1.26	0.04	2.29	0.07	9.29	0.32	13.29	0.52	21.02	0.84
Acacia leucophloea	0.42	0.03	0.74	0.07	2.69	0.25	3.91	0.38	6.41	0.63
Pithecellobium dulce	1.75	0.18	3.42	0.32	9.80	0.92	14.89	1.38	25.63	2.36
Albizia procera	2.48	0.33	4.63	0.61	17.73	1.58	26.98	2.53	44.78	4.22
Pongamia pinnata	0.36	0.19	0.61	0.32	2.24	1.09	3.37	1.58	5.52	2.63
Gmelina arborea	1.42	0.23	2.70	0.42	8.47	1.08	13.38	1.67	22.76	2.89
Dalbergia sissoo	2.73	0.38	5.52	0.78	16.54	1.65	27.12	2.69	47.26	4.73
Acacia mangium	4.16	1.02	7.78	2.12	29.54	5.10	47.26	7.90	79.32	12.48
Acacia catechu	0.88	0.07	1.59	0.13	5.84	0.34	8.76	0.58	13.75	1.02
Acacia holoserecia	2.78	0.82	6.36	1.56	18.36	4.76	35.52	6.86	57.88	10.26
Acacia auriculiformis	1.82	0.48	4.96	0.92	9.72	2.22	18.76	3.42	30.32	5.66
SEM (±)	0.101	0.036	0.137	0.042	1.127	0.081	1.670	0.161	3.776	0.621
CD (1%)	0.238	0.102	0.384	0.117	3.167	0.227	4.693	0.452	10.610	1.744

SEM = standard error mean, CD = critical difference

Table 4 Suitability index of different species after eight years

Species	Diameter score	Height score	Biomass score	Total score
Acacia nilotica	45.19	36.99	2.41	84.79
Albizia lebbek	49.37	56.61	23.81	129.79
Acacia leucophloea	62.76	63.99	7.67	134.42
Pithecellobium dulce	64.85	90.86	30.49	186.20
Albizia procera	64.85	96.69	53.38	214.92
Pongamia pinnata	51.04	35.51	8.88	95.43
Gmelina arborea	53.56	88.96	27.94	170.46
Dalbergia sissoo	82.84	95.29	56.63	234.76
Acacia mangium	100.00	100.00	100.00	300.00
Acacia catechu	55.64	51.69	16.09	123.42
Acacia holoserecia	81.17	85.23	74.23	240.63
Acacia auriculiformis	65.69	73.42	39.19	178.30

show equal growth performance at other coal mine regions with different environmental and edaphic conditions. The success of a particular species is related to climate and spoil characteristics and, as such, species selection is very important for each type of overburden.

Community structure

Total ground flora content and their IVI values are given in Table 5. Maximum (46) number of species was observed in the spoils after eight years of planting. There were nine early colonising species which invaded the spoil after one year. They continue to be present up to eight years, although their IVI values decreased gradually with increased age of planted species. *Cassia tora* had the highest IVI (140.4) in the spoils after one year. The invasion of *C. tora*, a leguminous and nitrogen fixer, is beneficial to the process of ecological succession of mined overburdens which are almost infertile in nature. *Cassia tora* remained as the dominant species in the plantation throughout the eight years and contributed considerably to community formation. On the basis of IVI values the following communities were identified.

Age after planting (year)	Community
1	*Cassia tora - Xanthium strumarium - Argemone mexicana*
2	*Cassia tora - Xanthium strumarium - Eulaliopsis binata*
4	*Cassia tora - Xanthium strumarium - Hyptis suaveolens*
6	*Cassia tora - Eulaliopsis binata - Xanthium strumarium*
8	*Cassia tora - Eulaliopsis binata - Hyptis suaveolens*

Xanthium strumarium contributed to the community formation for up to four years after planting as the second dominant species, after which it was taken over by *E. binata* and *H. suaveolens.* Jha and Singh (1991) reported that *X. strumarium* declined with age of the coal mine overburden spoils. Species like *C. tora,*

Table 5 IVI of natural colonisers in the plantation area at different years

Species	Age (year)				
	1	2	4	6	8
Alternanthera sessilis	-	-	-	-	1.34
Argemone mexicana	28.60	13.08	11.35	10.52	6.84
Aristida adscensionis	-	6.54	4.54	4.24	1.34
Aristida hystrix	-	-	-	-	1.34
Atylosia scarabaeoides	-	6.54	6.81	6.36	2.68
Azadirachta indica	-	-	-	-	3.42
Bidens biternata	-	-	-	3.68	1.09
Butea monosperma	-	-	-	4.24	6.84
Cassia auriculata	-	-	-	3.68	2.68
Cassia tora	140.40	130.08	99.88	78.26	52.54
Calotropis procera	7.80	6.54	6.81	4.24	5.36
Chloris virgata	-	-	4.54	-	1.34
Cynodon dactylon	16.64	19.62	18.16	16.96	12.68
Cyperus rotundus	-	-	-	-	1.09
Dactyloctenium aegyptinum	-	6.54	6.81	5.30	2.68
Desmodium triflorum	8.32	9.81	15.90	17.02	18.60
Dodonea viscosa	-	-	-	4.24	2.68
Echinops echinatus	-	-	-	8.48	6.84
Eleusine indica	-	-	-	-	1.34
Emilia sonchifolia	-	-	-	-	1.34
Eragrostis cilliaris	-	-	-	2.12	1.34
Eragrostis gangetica	-	-	-	-	2.68
Eragrostis tenella	-	-	-	-	2.68
Eulaliopsis binata	13.52	29.43	16.40	31.80	32.68
Evolvulus alsinoides	-	-	4.54	2.12	2.68
Evolvulus nummularia	-	-	6.81	-	1.09
Ficus bengalensis	-	-	-	-	2.68
Hyptis suaveolens	23.40	18.96	24.97	16.96	22.54
Lantana camara	-	-	-	-	2.68
Launaea procumbens	-	-	-	-	2.68
Mimosa pudica	-	-	-	-	1.34
Ocimum basiticum	-	-	-	-	1.34
Pennisetum hohenackeri	-	-	-	4.24	3.42
Pennisetum pedicilletum	-	-	-	-	2.34
Phyllanthus fraternus	-	-	4.54	2.12	3.42
Phyllanthus urinaria	-	-	4.54	1.06	2.68
Pogostemom pubescens	-	-	-	4.24	6.84
Saccharum spontaneum	-	-	6.81	12.72	16.84
Sida acuta	5.20	6.54	6.81	6.36	8.38
Solanum surettens	-	-	4.54	1.60	1.34
Syzygium cuminii	-	-	-	4.24	2.34
Tephrosia purpurea	-	-	9.08	10.60	4.68
Tridax procumbens	-	6.54	9.08	4.24	6.84
Woodfordia fruticosa	-	-	4.54	4.24	3.42
Xanthium strumarium	56.16	39.24	29.43	23.32	24.72
Ziziphus jujuba	-	-	-	2.12	2.34
Total number of species	9	13	21	29	46

- : absent

H. suaveolens and *E. binata* are of higher successional order and prefer better soil conditions for their survival and growth. Although only a few species contributed to the community formation, other species identified in the spoils under different ages of plantation took part in various other ways to reconstruct and stabilise the disturbed ecosystem. Among the species which colonised the study sites, there were six leguminous herb and shrub species, namely, *Atylosia scarabaoides, Tephrosia purpurea, Cassia auriculata, Cassia tora, Dactyloctenium aegyptinum* and *Desmodium* *triflorum.* There were also 14 species, namely, *Aristida adscensionis, Aristida hystrix, Bidens biternata, Chloris virgata, Cynodon dactylon, Dactyloctenium aegyptinum, Echinops echinatus, Emilia sonchifolia, Leunea procumbens, Pennisetum hohenackeri, P. pedicilletum, Saccharum spontaneum, Tridax procumbens* and *Xanthium strumarium* belonging to Poaceae and Asteraceae, which act as soil binders and thus, stabilise the spoil and enhance the process of ecological succession. Tree species like *Azadirachta indica, Ficus bengalensis, Butea monosperma, Syzygium cuminii* and *Ziziphus jujuba* invaded the six- and eight-year-old plantation sites. Invasion of tree species is an indication of stabilisation of the ecosystem in the process of succession. These five tree species are very common in natural forest community of the tropical region and may be considered as the early colonising tree species in coal mine overburden of Bisrampur.

Nutritional characteristics

Since all species, except for *G. arborea,* were nitrogen fixers, there should be a considerable change in the nutritional characteristics of the spoils with the increased age of plantations. Initially the spoils were almost infertile. The nutrient status of the overburden spoil immediately after physical reclamation was as follows: organic carbon 0.11%, total N 0.009%, available N 23.2 ppm and available K 19.7 ppm. Available P was not detected. After eight years of planting, accumulation of organic carbon was highest in the spoil under *P. pinnata* (0.72%) followed by *A. procera* (0.70%) and *A. holoserecia* (0.68%) (Table 6). Increase of organic carbon was substantial under *A. mangium, D. sissoo* and *A. catechu* but under the rest of the species the increase varied as much as four to five times over the initial values. Nevertheless, there was a gradual increase of organic carbon in the spoil under each species with the increase in age. Results also revealed that organic carbon in the spoils varied significantly from species to species ($p < 0.01$). The variation may be attributed to the height, plant canopy and the amount of leaf litter produced. In spite of better growth of *A. mangium* compared with *P. pinnata,* organic matter under the latter was higher than that under the former. The variation may be attributed to rapid humification of *P. pinnata* leaves compared with *A. mangium.* Rimmer (1982) reported an organic matter accumulation of 0.8% per annum in 1- to 8-year-old spoils in North England. In a study at iron mine overburden spoils, Banerjee *et al.* (1999) reported an increase of about 1.5 times in organic matter for every five years from plantation age of 5 to 25 years old. Prakasham and Banerjee (2001) also found an increase in organic carbon of about four times in copper mine overburden spoil in Madhya Pradesh.

Available N content of the spoil was maximum under *A. holoserecia* after eight years of planting followed by *P. pinnata* and *A. procera.* The increase over control was not much under *A. lebbek* and *G. arborea.* Available N increased by 2.6 to 9 times during the eight years of planting. Total N increased by 1.3 (*A. lebbek* and *G. arborea*) to 5.6 times (*P. pinnata*) after eight years of planting. Jha and Singh (1991) reported an increase of 26.5% of total N between 5 and 20 years under naturally colonised condition in coal mine spoil. Nandeswar *et al.* (1996) reported that at four to eight years the increase in total nitrogen accumulation in coal mine overburden at

Table 6 Organic carbon, total N and available N of the spoils under different species at different years

Species	Organic carbon (%)					Total N (%)					Available N (ppm)				
	1	2	4	6	8	1	2	4	6	8	1	2	4	6	8
Acacia nilotica	0.11	0.18	0.29	0.42	0.42	0.011	0.017	0.027	0.031	0.030	31	58	96	110	112
Albizia lebbek	0.16	0.20	0.36	0.40	0.42	0.010	0.014	0.023	0.030	0.021	27	54	90	98	96
Acacia leucophloea	0.18	0.23	0.38	0.48	0.50	0.013	0.019	0.029	0.033	0.033	32	61	118	130	130
Pithecellobium dulce	0.22	0.22	0.34	0.44	0.44	0.017	0.025	0.035	0.042	0.043	31	48	120	131	130
Albizia procera	0.20	0.31	0.63	0.67	0.70	0.019	0.029	0.048	0.058	0.059	48	77	186	196	190
Pongamia pinnata	0.19	0.36	0.63	0.72	0.72	0.023	0.031	0.058	0.060	0.060	42	86	186	206	200
Gmelina arborea	0.11	0.18	0.26	0.40	0.42	0.010	0.012	0.019	0.022	0.021	26	33	60	61	60
Dalbergia sissoo	0.24	0.38	0.57	0.57	0.61	0.020	0.031	0.047	0.054	0.055	40	68	170	183	183
Acacia mangium	0.21	0.34	0.56	0.62	0.60	0.024	0.029	0.047	0.052	0.052	44	74	170	190	188
Acacia catechu	0.19	0.28	0.57	0.60	0.61	0.022	0.031	0.048	0.052	0.051	49	66	172	186	184
Acacia holoserecia	0.15	0.25	0.63	0.68	0.68	0.020	0.028	0.047	0.056	0.058	54	83	202	206	207
Acacia auriculiformis	0.15	0.22	0.40	0.48	0.48	0.018	0.024	0.034	0.036	0.035	32	47	134	142	142
SEM (±)	0.013	0.015	0.023	0.014	0.016	0.003	0.004	0.006	0.005	0.004	2.825	2.345	6.018	4.740	1.477
CD (1%)	0.036	0.043	0.066	0.041	0.045	0.009	0.010	0.015	0.013	0.012	7.94	6.59	16.91	13.31	4.15

SEM = standard error mean, CD = critical difference

Singrauli was 40 kg ha^{-1}, at eight to 15 years, 90 kg ha^{-1} and at 15 to 25 years, 140 kg ha^{-1}. Banerjee *et al.* (1999) reported that the increase in nitrogen ranged from 200 to 600 kg ha^{-1} in old iron mine spoils aged two to 25 years old. In the present study, the accumulation of nitrogen was much higher because of the leguminous species used, which accelerated the process of nitrogen fixation in the spoil both in the form of available and total N.

From the present study, it appeared that the flora and also the planted species gradually modified the nutrient status of the inert overburden spoils through constant litter return and atmospheric nitrogen fixation. The spoil environment, which was extremely harsh just after mining gradually became hospitable through the planting of suitable species, which accelerated natural plant succession and allowed new establishment of invaders.

Microbial studies

The distribution of microorganisms (bacteria, actinomycetes and fungi) under each species at different years after planting is given in Table 7. Irrespective of species, the population of microorganisms increased many folds with the increase in age of plantations. Before planting, the bacteria, actinomycetes and fungi counts of the spoil were 7.9×10^3, 3.7×10^3 and 0.12×10^3 respectively. During the eight years, the microbes increased ranging from 380 to 2810 times for bacteria, 702 to 4135 times for actinomycetes and 833 to 1066 times for fungi respectively. The number of microorganisms varied significantly from species to species. After eight years of planting, the number of bacteria was highest under *D. sissoo* (222×10^5 g^{-1} spoil) and lowest under *G. arborea* (30×10^5 g^{-1} spoil). For actinomycetes, the number was highest under *P. pinnata* (153×10^5 g^{-1} spoil) and lowest under *G. arborea* (26×10^5 g^{-1} spoil) and for fungi the highest number was under *A. procera* (128×10^4 g^{-1} spoil) and the lowest under *G. arborea* (10×10^4 g^{-1} spoil). Different types of organisms maintained significant positive correlation with organic carbon, total and available N (Table 8). No significant correlation between microorganisms and organic carbon was found in one-year-old plantation. Banerjee *et al.* (2000a) reported a significant positive correlation between the number of organisms and organic carbon in the coal mine spoil of Gevra colliery (latitude 22° 18' to 22° 30' N, longitude 82° 02' to 82° 16' E, Figure 1).

Banerjee *et al.* (2000b) showed that coal mine overburdens at Gevra required about 54 years to attain total recovery, i.e. reaching nutrient status similar to an adjoining natural forest. Our study, however, showed that with plantation of nitrogen-fixing tree species, recovery was achieved in eight years. Annual litter returns, its decomposition, symbiotic nitrogen fixation, increased productivity in ground flora biomass and allied complex biological activities are responsible for the faster ecosystem development in planted area.

Table 7 Distribution of microorganisms in the spoils under different species at different years

Species	Bacteria (× 10^5 g^{-1} spoil)					Actinomycetes (× 10^5 g^{-1} spoil)					Fungi (× 10^4 g^{-1} spoil)				
	Age (year)					Age (year)					Age (year)				
	1	2	4	6	8	1	2	4	6	8	1	2	4	6	8
Acacia nilotica	0.86	12	78	96	96	0.43	8	34	54	63	0.11	0.82	6	11	12
Albizia lebbek	0.36	9	68	78	80	0.41	9	30	53	53	0.42	1.22	14	23	21
Acacia leucophloea	7.32	71	132	147	145	0.52	21	60	94	101	0.45	2.19	33	47	44
Pithecellobium dulce	3.22	57	129	142	143	0.54	19	71	101	106	0.43	2.76	46	61	67
Albizia procera	11.20	97	188	204	204	1.32	71	121	137	133	0.84	13.00	111	131	128
Pongamia pinnata	11.00	83	178	186	192	1.32	69	137	151	153	0.58	11.73	94	122	126
Gmelina arborea	0.20	5	29	31	30	0.14	4	18	23	26	0.04	0.16	2	10	10
Dalbergia sissoo	9.87	102	210	231	222	0.77	53	119	149	147	0.18	4.46	69	88	94
Acacia mangium	10.50	94	178	186	196	0.76	41	106	131	133	0.91	6.62	84	101	103
Acacia catechu	9.92	95	172	170	162	0.39	32	91	119	115	0.81	6.61	90	113	109
Acacia holoserecia	14.22	106	206	221	218	0.48	43	108	141	146	0.94	7.32	95	111	103
Acacia auriculiformis	2.28	61	134	126	132	0.47	17	46	59	64	0.58	3.22	42	57	61
SEM (±)	0.48	6.58	13.26	17.91	10.34	0.072	5.94	9.45	10.14	10.12	0.026	0.468	6.390	8.380	7.480
CD (1%)	1.36	18.49	37.26	50.32	29.05	0.202	16.69	26.55	28.49	28.45	0.075	1.316	17.95	23.56	21.03

SEM = standard error mean, CD = critical difference

Table 8 Correlation coefficient values (r) between microorganisms and nutritional characteristics

Plantation age (year)	Microorganism	Organic C	Total N	Available N
1	Bacteria	0.542	0.811**	0.929**
	Actinomycetes	0.545	0.577*	0.826**
	Fungi	0.341	0.709**	0.794**
2	Bacteria	0.787**	0.923**	0.723**
	Actinomycetes	0.878**	0.825**	0.826**
	Fungi	0.726**	0.780**	0.801**
4	Bacteria	0.912**	0.910**	0.965**
	Actinomycetes	0.938**	0.966**	0.934**
	Fungi	0.962**	0.943**	0.965**
6	Bacteria	0.841**	0.924**	0.943**
	Actinomycetes	0.889**	0.962**	0.944**
	Fungi	0.951**	0.967**	0.957**
8	Bacteria	0.857**	0.939**	0.958**
	Actinomycetes	0.880**	0.953**	0.938**
	Fungi	0.935**	0.964**	0.943**

* Significant at 5% level, ** significant at 1% level

Conclusions

Results of this study indicated that organic matter and nitrogen are good indices for microbial activity. Planting of suitable species in impoverished sites such as coal mine overburden can improve fertility of the spoil leading to higher microbial activity and better ecosystem development. Leguminous species enhance the microbial activity by fixing atmospheric nitrogen.

Afforestation with leguminous species in coal mine overburden spoils promote plant succession leading to earlier development of the spoil in respect to nutrient status and microbial activity. With increased age of planted species, higher nutrient recycling through litterfall will enhance the rate of soil formation and biological activity.

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