Eco-restoration of a high-sulphur coal mine overburden dumping site in northeast India: A case study

J Dowarah[1], H P Deka Boruah[1,*], J Gogoi[1], N Pathak[1], N Saikia[1] and A K Handique[2]

[1]*Biotechnology Division, North-East Institute of Science & Technology, CSIR, Jorhat 785 006, Assam, India.*
[2]*Biotechnology Department, Gauhati University, Guwahati 781 014, Assam, India.*
[*]e-mail: dekaboruah@yahoo.com hpdekaboruah@yahoo.com

Eco-restoration of mine overburden (OB) or abandoned mine sites is a major environmental concern. In the present investigation, an integrated approach was used to rejuvenate a high-sulphur mine OB dumping site in the Tirap Collieries, Assam, India, which is situated in the Indo-Burma mega-biodiversity hotspot. A mine OB is devoid of true soil character with poor macro and micro-nutrient content and contains elevated concentrations of trace and heavy metals. Planting of herbs, shrubs, cover crops and tree species at close proximity leads to primary and secondary sere state succession within a period of 3 to 5 years. A variety of plant species were screened for potential use in restoration: herbs, including *Sccharum spontaneum*, *Cymbopogon winterianus* Jowitt (citronella), and *Cymbopogon flexuosus* (lemon grass) cover plants, including *Mimosa strigillosa*, *M. striata*, and *M. pigra*; shrubs, including *Sesbania rostrata* (dhaincha) and *Cassia streata* (cassia); and tree species, including *Gmelina arborea* (gomari) and *Dalbergia sissoo* (sissoo). Amendment with unmined soil and bio-organic matter was required for primary establishment of some plant species. Management of these plant species at the site will ensure long term sustainable eco-restoration of the coal mine-degraded land.

1. Introduction

The dumping of mine tailings and other reject materials (referred to as overburden, OB) generated from opencast coal or metal mines is considered as a major contributor to the ecological and environmental degradation (Cherfas 1992; Chaoji 2002; Ghose 2004; Deka Boruah *et al* 2008). OB materials are nutrient-poor, loosely adhered particles of shale, stones, boulders, cobbles, and so forth and are devoid of true soil character (Raju and Hassan 2003; Deka Boruah 2006; Gogoi *et al* 2007). Mine OB materials also contain elevated concentrations of trace metals. Consequently, ecological succession in a mine OB is a lengthy process. A minimum period of 50 years to a century is required to establish advanced specific plant species in denuded, mine OB-filled land; but this long time scales due to specific problems can be overcome by artificial interventions, that once identified, which are most successful if they use or mimic natural process (Dobson *et al* 1997).

Traditionally, mines are the sole mineral supply source, and exploration for coal is conducted without giving much regard to its serious impacts on the ecology and environment. Therefore, the coal mining industry is being placed under the red category, meaning it is in the top bracket of environmental degradation (Chaoji 2002), and coal mining is being considered for inclusion under the national superfund scheme. The chief environmental impacts due to mining are changes in soil stratification, reduced biotic diversity, and alteration of structure and functioning of ecosystems; these changes ultimately influence water and nutrient dynamics and trophic interactions (Matson et al 1997; Almas *et al* 2004; Ghose 2004).

Keywords. Mine overburden; environment degradation; ecology; eco-restoration; primary, secondary ecological succession.

The remediation of soil that is heavily contaminated due to coal or metal mining involves excavation, removal of soil to secured land fields, and filling of top soil, which is expensive and requires site restoration. Alternatively, the contaminated soil may be dealt with bioremediation or phytoremediation, which is the use of plants or other biological measures to remove, destroy or sequester hazardous substances from the soil and waste piles (Salt *et al* 1995; Cunningham and Ow 1996; Ernst 1996). An account of specific plant species that have been used to combat different types of soil pollution has been given by Prasasd (2004). However, restoration of mine waste piles depends on the substrate characteristics and ability of the plant species to proliferate in the substratum.

In India, the amount of mine OB wasteland generated due to opencast coal mining is enormous. Presently, the north eastern coalfields of Coal India Limited (NECF-CIL), Margherita, Assam, have produced more than 1000 ha of mine OB wasteland. Reports are also available on the prospects and environmental issues related to the north east (NE) collieries (Akala 1995; Chaoji 2002). Due to the presence of high sulphur content (2–12%), the mine OB of the NE collieries is highly acidic (pH 2.0–3.0) (Deka Boruah *et al* 2008). Consequently, ecological succession takes even longer.

Though there are many success stories of eco-restoration around the world (Cunningham and Berti 1993; Mendez and Maier 2008; Gonzalez and Gonzalez-Chavez 2006; Wong 2003), and in different parts of the country (Tiwary 2001; Pal 2003; Ghose 2004; Maiti 2007; Juwarkar and Jumbalkar 2008), to date no attempt is being made to remediate mine OB dumps in the NE region of India by utilising native plant species. This investigation sought to achieve eco-restoration of a high-sulphur containing coal mine OB dumping site through primary and secondary ecological succession of plants. Emphasis was given to the physico-chemical characteristics of the mine OB waste, planting methodology, amendment of organic matter and establishment of the plant species. The entire *in situ* experiment was conducted in the Tirap opencast coal mine overburden dumping site in Assam.

2. Materials and methods

2.1 *Description of the site and collection of soil samples*

Samples of tailings were collected from the site according to IS specifications (436–1953). A detailed description and visual characteristics of the site are described in figure 1, plate 1A and B.

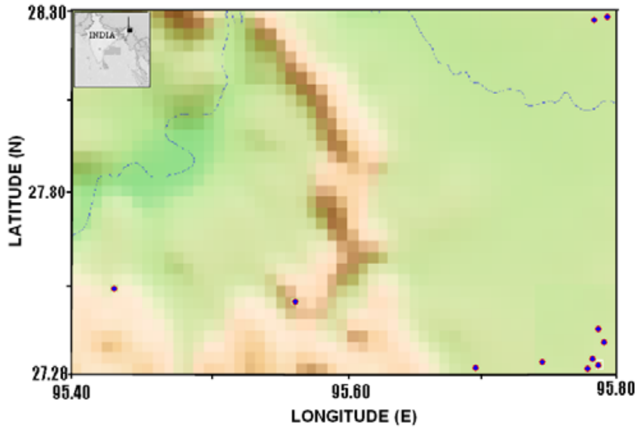

Figure 1. Location map of the eco-restoration site drawn with the help of generic mapping tools. Open stars indicate the sampling point of mine OB.

At each sampling location, 10 to 15 cores of the top 8 cm of substrate were collected at random. Composite samples were prepared by thoroughly mixing these samples as per IS specifications, and the prepared bulk samples were stored at 4°C. Biochemical analysis of the substrates was performed within seven days of sampling.

2.2 *Physico-chemical and biochemical characterisation*

The pH of 50% (w/v) soil and OB materials was determined using an automatic glass electrode pH meter, Systronics, Model 8330. Total carbon content was determined by potassium dichromate oxidation, and total nitrogen content by Kjeldahl digestion. The particle size of mine tailings and shale was determined in air dried samples by sieve analysis. Since 99% of the uncontaminated soil is contained in the < 0.355 mm fraction, unmined soils were not subjected for sieve analysis. The percentage of the total content of silt, sand and clays were analysed for < 0.355 mm fractions by laser diffraction particle size analyser, CILAS 100, Switzerland.

For sieve analyses, the mine OB was thoroughly mixed as per IS specifications, and representative samples of 1 kg each were passed through different sieve sizes ranging from > 25 mm to < 0.355 mm. The composition of silt, sand and clay was determined in the 0.355 mm size fractions by laser diffraction particle size analyser. To verify the maximum ability of the mine tailings to release finer particles, mine OB samples were also mixed with water (1:3 = material:water; 40 rpm, 3 h) in a 5 kg pot mill. The liberation of finer particles such as clay and silt will give an idea of the extent of degradation that could result due to long-term weathering of these materials in this highly rainy region.

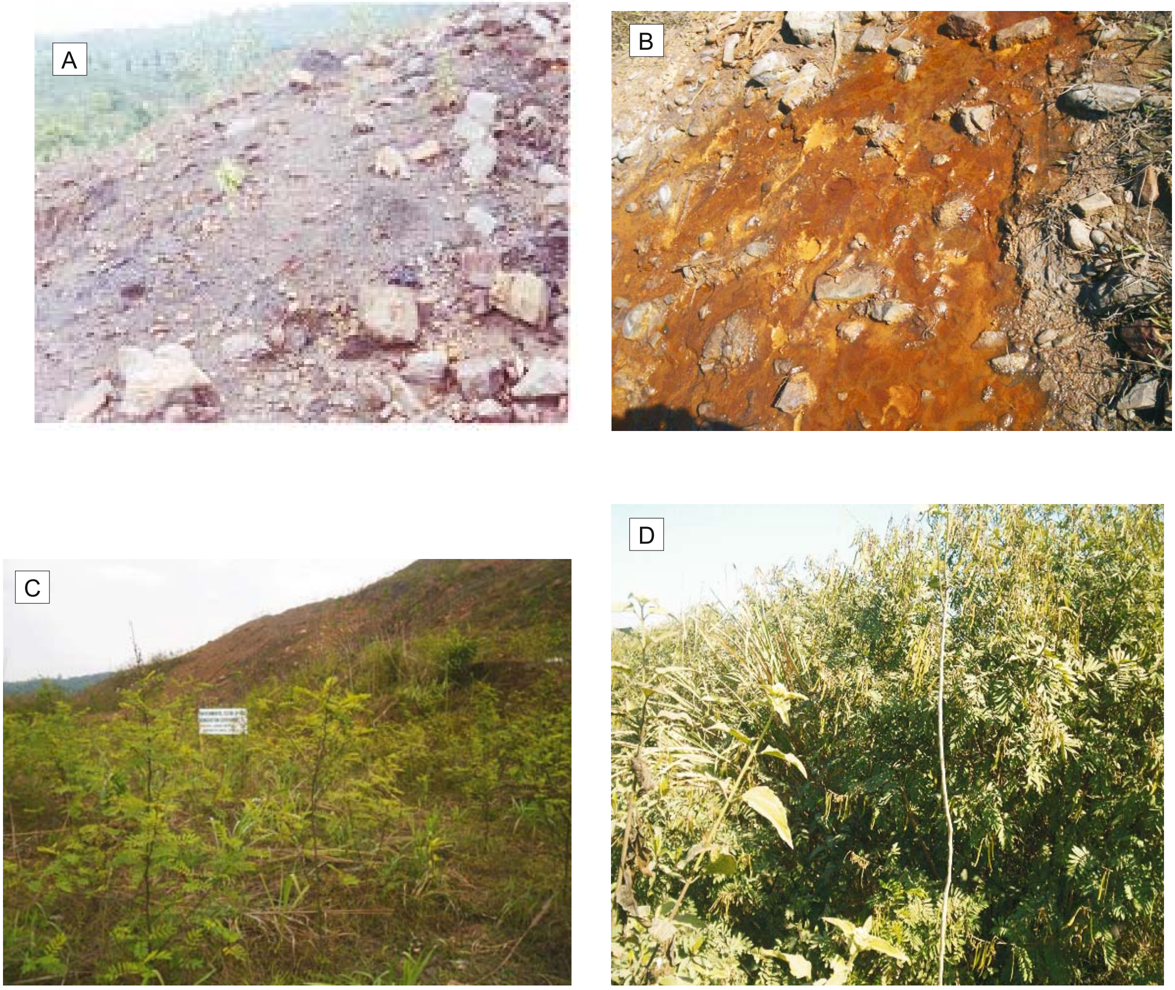

Plate 1. Mine OB dumping ground of Tirap opencast colliery, Assam, India. **A, B** = Before remediation of mine OB; **C, D** = After remediation of mine OB dumping site.

Microbial biomass carbon was determined by the chloroform-fumigation method, using 0.5 M K_2SO_4 for extraction (Vance 2000). The organic C content was estimated by oxidation with potassium dichromate. The difference in C content between the fumigated and non-fumigated soil was converted to microbial biomass C (expressed in mg kg^{-1} of oven dried soil) by applying a KC factor of 0.45 (Jenkinson 2004).

The serial dilution technique was used to determine the most probable number (MPN) of microorganisms as described by Alexander (1965). The presence of nitrogen fixing bacteria was determined using the medium developed by Bezbaruah *et al* (1995). Chemolithotrophic sulphur oxidisers present in coalmine tailings and unmined soil were grown using thiosulphate agar medium. For the enumeration of cellulose degraders, Skinner medium (1971) was used. Nutrient agar (Hi-media) was used to estimate the population density of heterotrophic bacteria. A colony counter was used to assess the total microbe count.

Phosphatase enzyme activity was determined by incubation at 37°C in phosphate buffer (pH 5.0) with *p*-nitrophenyl phosphate as the substrate. After 30 min $CaCl_2$ was added (to stop the reaction and to avoid coloration caused by organic and other matter), and the released *p*-nitrophenol was measured with a spectrophotometer at 570 nm (Tabatabai and Bremner 1969). β-glucosidase activity was determined as described for phosphatase activity except that the substrate was *p*-nitrophenyl-β-D-glucopyrenoside and the incubation time was 1 h. Both phosphatase and β-glucosidase activities were quantified using a standard curve prepared from *p*-nitrophenol, and are expressed in *p*-nitrophenol released in μmol $g^{-1}h^{-1}$. The dehydrogenase activity of the soil was determined according to Camina *et al* (1998) and quantified using an iodonitro tetrazolium formazon (INTF) calibration curve and expressed in μmol $g^{-1}h^{-1}$. The urease activity of the soil was determined according to Bezbaruah *et al* (1995), and the values

Table 1. *Vernacular plant species screened and their nature.*

Sl. no.	Name	Nature	Class	Family
1	*Bambosa*	Herbs, perennial	Monocot	Poaceae
2	*Elephant grass*	Herbs, perennial	Monocot	Poaceae
3	*Saccharum spontaneum*	Herbs, perennial	Monocot	Poaceae
4	*Auxonopus*	Herbs, perennial	Monocot	Poaceae
5	*Cymbopogon winterianus*	Herbs, perennial	Monocot	Poaceae
6	*C. flexosus*	Herbs, perennial	Monocot	Poaceae
7	*Commelina*	Herbs, perennial	Monocot	Commelinaceae
8	*Cyperus*	Herbs, perennial	Monocot	Cyperaceae
9	*Draecena*	Herbs, perennial	Monocot	Dracenaceae
10	*Musa paradisiaca*	Rhizomatous, monocarpic	Monocot	Musaceae
11	*Eclipta alba*	Herbs, annual	Dicot	Asteraceae
12	*Ageratum*	Semi woody herbs, annual	Dicot	Asteraceae
13	*Amaranthus*	Annual herb	Dicot	Amaranthaceae
14	*Solanum sp*	Herbs	Dicot	Solanaceae
15	*Ricinus communis*	Shrubs, annual to perennial	Dicot	Euphorbiaceae
16	*Croton*	Shrubs, perennial	Dicot	Euphorbiaceae
17	*Cassia streata*	Shrubs, perennial	Dicot	Caesalpiniaceae
18	*Cassia fistula*	Shrubs, perennial	Dicot	Caesalpiniaceae
19	*Caesalpania pulcherima*	Tree, perennial	Dicot	Caesalpiniaceae
20	*Cassia coronj*	Shrubs, perennial	Dicot	Caesalpiniaceae
21	*Sesbania rostrata*	Lianes, annual	Dicot	Leguminosae
22	*Mimosa pigra*	Lianes, annual	Dicot	Fabaceae
	M. pudica	Lianes, annual	Dicot	Fabaceae
	M. strigillosa	Lianes, annual	Dicot	Fabaceae
	M. streata	Tree, perennial	Dicot	Fabaceae
23	*Albizia lebbeck*	Tree, perennial	Dicot	Fabaceae
22	*Dalbergia sisso*	Lianes, annual	Dicot	Leguminosae
23	*Evolvulas*	Tree, perennial	Dicot	Convolvulaceae
24	*Dipterocarpus*	Tree, perennial	Dicot	Dipterocarpaceae
25	*Shorea robusta*	Tree, perennial	Dicot	Dipterocarpaceae
26	*Tectona grandis*	Tree, perennial	Dicot	Verbenaceae
27	*Gmelina arborea*	Tree, perennial	Dicot	Verbenaceae
28	*Termenellia arjuna*	Tree, perennial	Dicot	Combretaceae
29	*T. chebulla*	Tree, perennial	Dicot	Combretaceae
30	*Mellia azadiracta*	Tree, perennial	Dicot	Maliaceae
31	*Ficus bengalensis*	Tree, perennial	Dicot	Maliaceae
32	*Delonix regia*	Tree, perennial	Dicot	Fabaceae
33	*Eggle marmelos*	Tree, perennial	Dicot	Rutaceae
34	*Michelia champaca Etc*	Tree, perennial	Dicot	Magnoliaceae

All the plant species screened were vernacular plant and abundant in the neighbouring unmined site.

were expressed as μmol $g^{-1}h^{-1}$ of thiocyanate released.

Total metal content associated in the composite material of mine OB and in the mine < 0.355 mm size fraction were analysed by atomic absorption spectrophotometer (AAS) and X-ray fluorescence spectrophotometry (XRF). For this the composite materials and < 0.355 mm grain size was ground to < 200 mm. It was then analysed by atomic absorption spectrophotometry (AAS) for the metals Cd, Co, Cu, Cr and Pb in acid extract (Perkin Elmer Analyst 100) with the detection limit of 0.05 mg L^{-1} to 0.10 mg l^{-1} while Hg was determined in mercury hydride systems model MHS10. Al, Fe, Ca, Mn and S were determined by X-ray fluorescence ED-XRF (P) photometer model, Xepos (Model: SPELLMANXRM 50P50-X3385; S/N: 054811-1-1065). The instrument was calibrated by solid and liquid standard provided by spectro. Detection limits of the individual elements

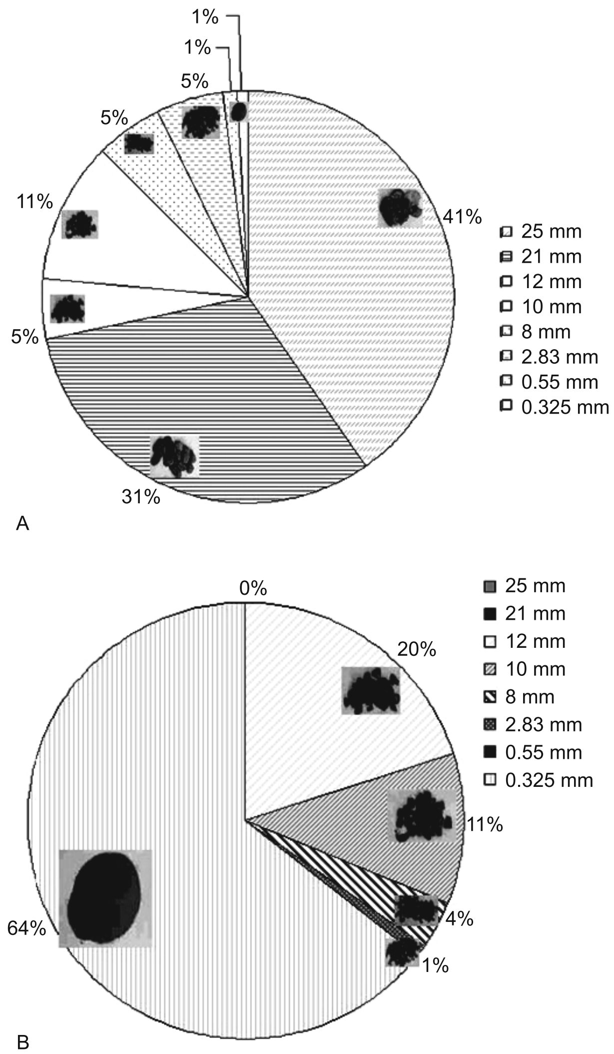

Figure 2. Grain size distribution of the overburden materials collected from Tirap collieries by sieve analysis.

ranged between 0.0003 and 0.15% for solid and between 1 and 100 ng cm^2 in liquid samples. Pellets were prepared by mixing 4 g of powder with 0.9 g of Hoechst wax in a homogenizer (Swing Mill MM301) and then pressed in a manual hydraulic press with 10 tones.

2.3 *In situ eco-restoration*

A series of preliminary experiments were performed to screen the plant species for restoration suitability. Earthen pots with dimensions $14 \times 17 \times 24$ cm were filled with mine OB. Lianes, shrubs and tree species were planted, and herbaceous species were included to create micro-climate conditions (table 1). The survival rate of plant species was recorded. Screened plant species were planted singly and alternately to achieve the primary and secondary sere state succession. Terracing was constructed in mine OB dumps for eco-restoration. In each terrace, a pit was prepared by amending with unmined soil and cowdung. Both line and fill methods were used to prepare the pits. Saplings grown without preparing the pit were considered controls. The ecological succession rate, i.e., population growth rate, diversity of plant species, vegetation structure, plant height, canopy size and ecological processes was recorded in the first and second year of restoration following standard ecological methods (Misrhra 1992).

2.4 *Growth rate over time*

The population growth rate for the study area was calculated according to the following formula (Mishra 1992): Population growth rate/new seedling/tiller generation $= \Delta N/\Delta t$ where Δ (delta) means change in $N = (N_2 - N_1)$ the number of organisms, and change in time $= t(t_2 - t_1)$. where ΔNn is production of new individuals in the population and specific mortality rate is expressed as % of initial population dying within a given time.

Measures of community structure, including density, frequency, abundance, relative dominance, and relative frequency of the restored sites were assessed by quadrate. The minimum size of the quadrate (60×60 cm) was determined by the species area curve method (Sharma 1995).

2.5 *Statistics*

All the data were subjected to one way ANOVA analysis, and significant differences were calculated at $p < 0.01$ and $p < 0.05$.

3. Results

3.1 *Physico-chemical and biochemical characteristics*

The study site is situated between latitude 27°28″ to 28°30″ and longitude 94°40″ to 95°80″ in Assam, India, which is one of the locations of Indo-Burma mega-biodiversity (figure 1). The heaviest rainfall was recorded from May to October, and the maximum temperatures occurred from June to October (data not shown). Spot stratification observations of the mine OB dumping site showed no clear-cut horizons. Sieve analysis confirmed that only 0.5% to 1.0% of the total mine OB was in the < 0.355 mm grain size fraction (figure 2A). Further, pot mill experiments confirmed that the mine OB metamorphoses immediately on coming in contact with water (figure 2B).

The pH of the mine OB was 2.5–3.0, and the C, N and P contents were below the threshold limit (table 2). The mine OB was also found

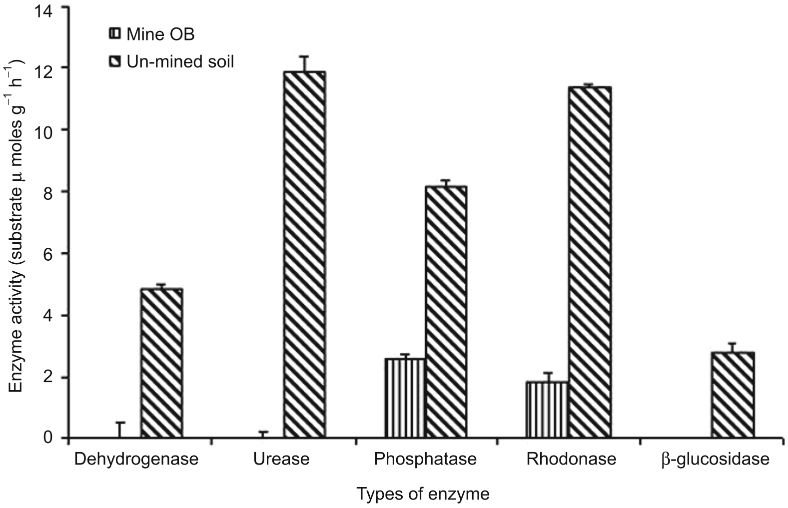

Figure 3. Comparison of microbial enzyme activity of the overburden materials in < 0.355 mm size grain collected from Tirap collieries and unmined soil.

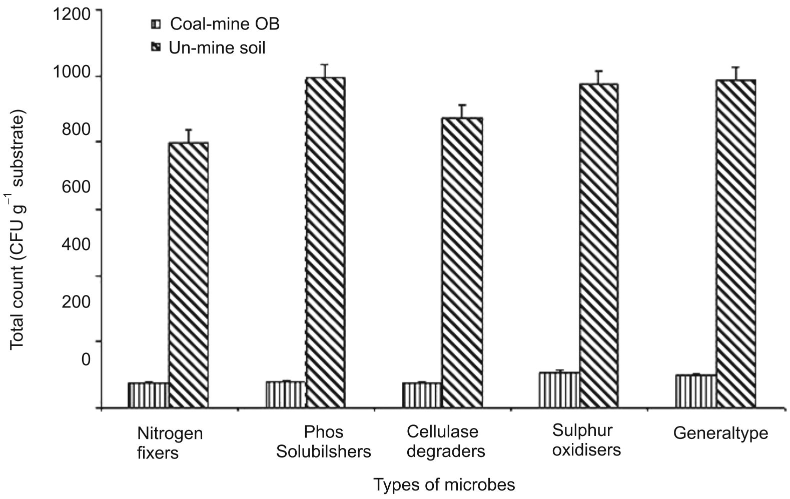

Figure 4. Comparison of total microbial count of the overburden materials in < 0.355 mm size grain collected from Tirap collieries and unmined soil.

to be of the sandy type, and the silt : sand : clay ratio was 39.9 : 39.9 : 21.9. In addition, significantly less microbial biomass was found in coal mine OB (64.33 mg kg^{-1}) compared to unmined soil (524 mg kg^{-1}). Similarly, significantly lower microbial MPN counts were found in mine OB (figure 5).

No β-glucosidase, dehydrogenase or urease activity was detected, and significantly less phosphatase and rhodanase activity was found in coal mine OB compared to unmined soil (figure 5). The enzyme activity of phosphatase and rhodanase was almost two times less than that of unmined soil.

A significantly higher amount of trace metals were detected in mine OB compared to unmined soil (table 3). In a composite sample of mine OB, Fe (81.0%) was the most abundant trace metal, followed by Al (19.79%), S (11.04%), and Mg (2.27%); trace amounts of Ca and Mn were also detected. In the < 0.355 mm size grain fraction, Al (20.14%) was most abundant, followed by Fe

Table 2. *Characteristics of mine OB collected from Tirap colliery.*

Constituents	Different constituents (%)
pH (50% suspension)	2.0–2.5
Clay	21.93(2.2)
Silt	38.13(2.2)
Sand	39.94(2.26)
Carbon	0.04
Phosphorus	0.005
Nitrogen	0.0001

Data in parenthesis are the standard deviation of observed values.

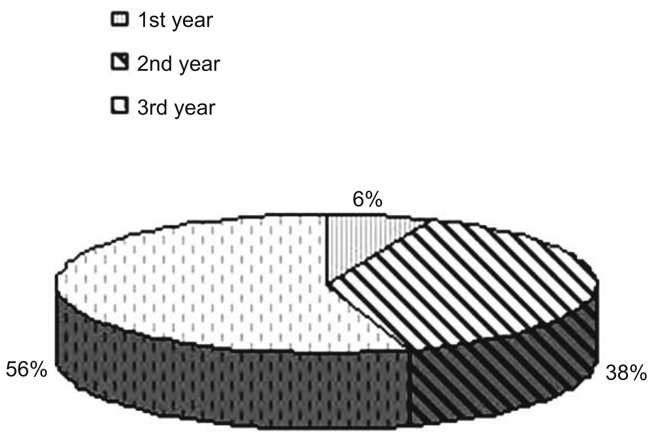

Figure 5. Population growth rate over the period of three years in the mine overburden eco-restoration site.

(13.21%), S (12.51%), and Mg (1.86%), with trace amounts of Ca and Mn.

Similarly, significantly higher concentrations of heavy metals were found in mine OB (table 4). The concentration of Cr (276.98 ppm) was highest, followed by Pd, Cu, Co and Cd, while Co was not detected in unmined soil. Similar trends were observed for mine OB samples in the < 0.355 mm grain size fraction.

3.2 *In situ eco-restoration*

Amongst the tree species screened, gomari (*Gmelina arborea*) and sissoo (*Dalbergia sissoo*) belongs to the family verbenaceae and leguminosae, respectively had a mortality rate of 75%, while the mortality of the other tree species belongs to the family caesalpiniaceae, dipterocarpaceae and also leguminosae were 90 to 100% (table 5). Two shrub species with the capability to fix atmospheric nitrogen, *Cassia streata*, a perennial, and *Sesbania rostrata*, an annual, shrubs belongs to the family caesalpiniaceae and leguminosae, respectively had a 75% mortality rate. In both cases, a pit was required for initial establishment. Amongst the cover crops screened, mimosa (*M. pigra*, *M. striata* and *M. strigillosa*) of the family fabaceae had a mortality rate of 80%, while the other cover crops had 100% mortality. However, good survival rates were recorded in the grass species citronella (*Cymbopogon winterianus* Jowitt), lemon grass (*Cymbopogon flexuosus*), and *Saccharum spontaneum*, as well as in wild bamboo species belongs to the family poaceae. The germination (new seedling emergence) rates observed for citronella and lemon grass were 0.58% and 0.625%, respectively, over the three-year study period. Germination rates of 45% and 21% were recorded for the shrub species *Sesbania rostrata* and *Cassia streata*, respectively. Over the period of observation, the cumulative population growth rate increased from 6% to 56% (figure 6). The plant species also reached an average height and canopy size of 40 cm to > 348 cm and 85 to 549 cm, respectively (table 6).

3.3 *Plant vegetation structure*

After restoration was completed, the frequency distribution of plant density was recorded in each year (figure 7). The densities of herb species in the restored site were 43% and 55% in 2005 and 2006, respectively. Similarly, an incremental increase in plant density was observed for lianes (3% to 10%) and shrubs (12% to 28%) over the period of observation. On the other hand, a decreasing trend of plant density was seen in tree species (38% to 8%).

The characteristics of plant diversity recorded over the period of observation are described in table 7, and ecological succession is shown in plate 1C and D. A sequential progression of cryptograms, including bryophytes and pteridophytes, was found in the restored site. The natural growth of bryophytes was observed in over 50% of the area of the restored site, while the natural growth of pteridophytes was noted in less than 30% of the area. In addition, the distribution of herbs, shrubs and trees after the completion of the experiment was more than 50%. After continuous monitoring for a period of three years, plant diversity indicative of secondary ecological succession was observed, including the progression from cryptograms to higher plants. This was achieved due to the introduction of coalmine OB resistant plant species in the restored sites in close proximity as well as successive refilling of the dead plants which makes the restored mine OB site suitable to grow lower plant and other invasive plant species.

Regarding vegetation structure in the restored sites, it was determined that 80 to 100% of the total area was covered with herbs, shrubs and tree species. In addition, for representative plant types (80%) in the restored site, biomass ranged from 85 to 700 cm^2, and the average height of the respective plant species ranged from 40 cm to 300 cm. The overall ecological processes were assessed for increased soil organic matter which was in incremental order from beyond the detectable limit of 0.5% to 1.5% over the period of three years.

4. Discussion

Tirap OB dumps comprised of boulders, rejected coal, stones, and loosely adhered boulders, with varied colours such as white, yellow, and black. Sieve analysis found that only 0.5% of the particles

Table 3. *Availability of metal content in mine overburden collected from Tirap colliery and unmined soil.*

	Metal content (%)					
Name of the soil	Al_2O	Fe_2O_3	MgO	CaO	Mn	S
Unmined soil	5.24 (2.1)	2.28 (0.6)	0.22 (0.02)	0.04	0.003	0.11 (0.01)
OB composite	18.79 (1.04)	81.99 (3.23)	2.27 (0.05)	0.29 (0.1)	0.014	11.04 (2.03)
OB < 0.355 mm	20.14 (1.23)	13.2 (1.51)	1.86 (0.91)	0.11 (0.07)	0.007	12.51 (6.03)

Data in parenthesis are the standard deviation of observed values.

Table 4. *Availability of metal content in mine overburden collected from Tirap colliery and unmined soil.*

		Metal content (ppm)					
Name of the soil	Hg (ppb)	Mo	Pb	Cd	Co	Cu	Cr
Unmined soil	0.03	0.04	21.8 (2.3)	3.17 (1.8)	BDL	25.77 (2.5)	150.67 (2.7)
OB composite	0.25 (0.19)	0.12 (0.05)	74.29 (4.9)	14.14 (2.5)	21.82 (5.7)	46.03 (2.6)	276.98 (20.58)
OB < 0.355 mm	0.03 (0.01)	0.12 (0.01)	50.53 (6.46)	6.28 (1.1)	35.33 (8.3)	72.6 (0.11)	312.1 (15.44)

Data in parenthesis are the standard deviation of observed values.

Table 5. *Mortality and new seedling/tiller emergence rate over the period of observation in mine overburden eco-restoration site of Tirap colliery.*

Plant species	Mortality rate (%)		New seedling/tiller emergence (%)	
	1st year	2nd year	1st year	2nd year
Cymbopogon winterianus	50	30	1.58 (0.22)	0.42 (0.22)
C. flexosus	50	0	0.41 (0.21)	0.45 (0.20)
Bambosa wild type	30	0	0.25 (0.12)	0.62 (0.21)
Bambosa jatibah	100	Nil		
Mimosa pigra	80	0	62.5 (3.7)	62.50 (3.3)
M. strigillosa	80	0	60.12 (3.8)	60.12 (3.8)
M. streata	80	0	62.38 (5.3)	62.38 (3.7)
Sesbania rostrata	75	0	45.80 (3.4)	45.8 (2.8)
Cassia streata	75	35	20.83 (3.3)	21.7 (2.1)
C. coronj	90	0		
Caesalpaenia	100	0		
Siris	99	0		
Gmelina arborea	75	0		
Shorea robusta	99	0		

Plant species which showed survival after first year of planting were recorded. Data in parenthesis are the standard deviation of observed values.

in the OB dumps of Tirap collieries are in the < 0.355 mm grain size fraction and bears no true soil characters. The OB is highly acidic in nature (pH 2.0 or less) due to high amounts of elemental as well as pyretic sulphur. In general, the Fe (81.0%) and S (2 to 12%) concentrations were high in the mine OB of the Tirap collieries. The high concentration of S and the acidic pH in north-eastern OB dumps are unique in character. In addition, very low C, P and N contents were recorded. The trace metal concentrations were significantly higher in the mine OB of the Tirap collieries compared to that of unmined soil. A high S and Fe content along with acidic mine OB of

Table 6. *Height and canopy size of some of the plant species of the mine overburden eco-restoration site of Tirap collieries after three years.*

Plant species	Height (inch)	Canopy size (cm^2)
C. flexosus	132 (1.15)	200 (2.0)
Bambosa wild type	85 (2.6)	85 (2.5)
Saccharum spontaneum	302 (21.1)	183.17 (30.3)
Mimosa		540.00 (2.4)
Cassia streata	259 (4.9)	283.04 (2.1)
C. coronj	40 (3.6)	85 (1.5)
Dalbergia sisso	348 (5.0)	245.91 (12.0)
Gmelina arborea	132 (2.1)	203.29 (12.0)

Data in parenthesis are the standard deviation of observed values.

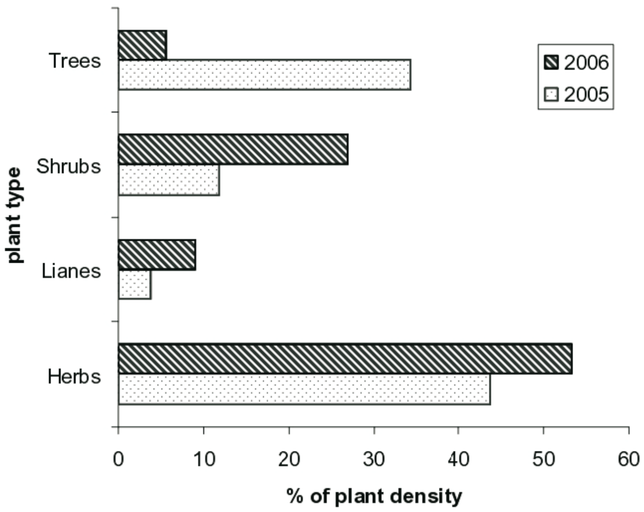

Figure 6. Frequency distribution of plant diversity in mine OB remediated site of Tirap collieries.

NE collieries were earlier reported by Akala (1995). Mine OB materials are devoid of true soil character, and contain boulders, cobbles, pebbles and other rejected mine materials were earlier reported by many workers (Cherfas 1992; Ford and Walker 2003; Juwarkar and Singh 2007; Kundu and Ghose 1994). Microbial population size and soil enzyme activity are considered to be good indicators of soil health (Anderson and Domsch 1990; Insam and Domsch 1988). Ghose (2004) described the effects of opencast mining on the fertility of soils. In the present investigation, very low microbial population size and enzyme activities were found in the mine OB dumping site of the Tirap collieries. No dehydrogenase, urease or β-glucosidase activities were detected in mine OB, while a ten-fold lower phosphatase activity was seen in the mine OB compared to the unmined soil.

High acidity and above threshold limits of trace metals such as Fe, Al, Cr with no true soil behaviour are the major hindranges in eco-restoration of OB dumps of Tirap collieries. High acidity and above-threshold limit of trace metals retard the germination, inhibit root growth and also highly phytotoxic. Reports are available on the cause of plant death in mine OB stress due to no organic matter or macronutrients, without normal soil structure with high levels of autotrophic iron and sulphur oxidisers associated with plant death in eco-restoration of highly acidic mine OB (Schippers *et al* 2000; Mendez and Maier 2008). Dobson *et al* (1997) stated that such mine OB wastelands require a period of 100 years to colonise specific plant species.

To overcome the plant death in eco-restoration of mine OB of Tirap colliery, screening of plant species to thrive under mine OB stress conditions was performed *in situ*. The principle behind the use of native plant species is that these species should be tolerant to high-stress conditions (Cunningham and Ow 1996). Thirty-six different plant species were screened representing twenty different families belonging to the herbaceous, liane, shrub and tree groups. Amongst the herbaceous plant species, *Axonopus*, *Saccharum spontaneum*, and the economically important essential-oil bearing plants *Cymbopogon winterianus* Jowitt and *C. flexuosus* were found to be the most stress-tolerant. These plants were able to resist the stress conditions of mine OB due to the nature of their fibrous root systems. The liane species *Mimosa pigra*, *M. streata*, and *M. strigillosa* were also able to resist OB stress. However, in order to cultivate these species in mine OB, acclimatisation of the plants in the *in situ* environment through preparation of an artificial pit was required. In addition, the shrub species *Cassia streata* and *Sesbania rostrata* and the tree species gomari (*Gmelina arborea*) and sissoo (*Dalbergia sissoo*) were determined to be resistant to mine OB stress in the Tirap colliery. The resistance of *Gmelina arborea* and *Dalbergia sissoo* to mine OB stress was also shown by the work of Juwarkar and Singh (2007) and Singh *et al* (1996).

Table 7. *Characteristics plant diversity, vegetation structure and ecological processes restored mine overburden dumping sites of Tirap collieries.*

Time	Plant diversity						Vegetation structure				Ecological processes
	Bryophytes	Pteridophytes	Herbs	Shrubs	Trees	Guild	Cover (% area covered)	Density	Bio-mass (cm^2)	Height (cm)	SOM (%)
2004	–	–	–	–	–	–	–	–	–	–	< 0.005
2005	**	*	**	**	**	PSS	> 50	> 1–56	85–540	40–100	0.5–1.3
2006	***	*	***	**	***	SSS	> 80–100	> 80	85–700	40–300	0.5–1.3

– = Number records of plant diversity and vegetation structure; * = number of plant species present in 10 to 30 quadrates; ** = number of plant species present in 30 to 50 quadrates; *** = number of plant species present in > 50 than quadrates; PSS = primary sere ecological succession (presence of > 50 different lower and medium type plant species); SSC = secondary sere ecological succession (presence of > 80% different lower and medium and tree type plant succession); Bio-mass = biomass express as total canopy size (cm^2) of survived plant species.

The goal behind the screening of herbs, lianes, shrubs and tree species was to achieve primary, secondary and tertiary ecological succession within a short period of time in an integrated approach. The herbs support creation of microclimatic conditions in the mine OB environment, and are able to proliferate by generating new tillers after establishment. Thereby, they can cover the exposed area rapidly. On the other hand, lianes (*Mimosa pigra*, *M. streata*, *M. strigillosa*) and shrubs (*Sesbania rostrata* and *Cassia streata)* are able to produce fruit within a year and thus increase their population size. This allows the plants to maintain their continuity across generations. In the present investigation, we found that the seedling growth rate was low, but sufficient to maintain the subsequent plant generations.

The outcome of eco-restoration depends on the nature of the plant distribution after restoration of the sites. Therefore, the record of ecological succession and processes is important to prove the success of eco-restoration (Eamus *et al* 2005). In addition, the general challenge of eco-restoration is in developing a site-specific strategy, as all sites around the world not alike (Hariis *et al* 2006). In the present investigation, an overall 8% to 50% frequency density of plant populations was found. The ecological succession measures studied were plant diversity, vegetation structure and ecological processes. The plant diversity results indicated the presence of cryptograms, bryophytes (*Riccia, Marchantia, Anthoceros*, and moss species), pteridophytes (*Lycopodium, Selaginella, Pteris*), herbs, shrubs and trees in the restored mine OB. Overall, a secondary sere ecological succession was observed in the restored mine OB site.

Regarding vegetation structure, 80 to 100% coverage was observed, the plant species density was more than 80%, and biomass production was 700 cm^2. The vegetation height in the restored site was determined by both understory and tree species. Soil organic matter is considered to be an indicator of total biomass production in restored sites; in the present investigation, ecological processes produced an appreciably enhanced soil organic matter accumulation, with concentrations increasing from 0.001–0.005% to 0.5–1.3%. A strategic change was adopted to achieve a quick succession of plant cover in exposed land within a period of one to three years. Therefore, simultaneous planting of different plant species using a filled pit preparation method to enhance plant survival and density was performed to achieve an ecological pyramid of primary, secondary and tertiary sere states of ecological succession. Dobson *et al* (1997) reported a similar strategic approach to achieve a climax state of succession within a short span of time. In the present investigation, a 100% succession of primary and secondary ecological states was achieved by cultivating various plant species.

5. Conclusion

Lack of true soil characteristics, low biological activity, and acidic pH (2.0) were unique phenomena in a mine OB dumping site in NECF-CIL, Margherita. Trace metal concentrations were also significantly higher in the mine OB environment compared to unmined soil. Under these adverse conditions, establishment of plant species takes a long period of time and ecological degradation is enormous. Planting of herbaceous monocots with fibrous root systems such as citronella, lemon grass, *Saccharum spontaneum*, lianes and shrub species accelerates the ecological processes in an adverse mine OB environment of Tirap colliery. The present investigation will be helpful in screening and simultaneous planting of various plant species to re-cover high sulphur containing mine OB-denuded land, leading to long term sustainable eco-restoration.

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