

## VI.7

### Use of selected waste materials and biofertilizers for industrial solid waste reclamation

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#### VI.7.1. Introduction

Industrial projects have profound influence on society and environment, resulting in benefits, risks and hazards. They bring in their wake the concomitant ills of environmental pollution, depletion of resources, overcrowding, effects on human health, desecration of forests and aesthetic nuisance.

During the last decade there has been increasing concern regarding the disposal of industrial solid wastes at landfill sites. Capital costs and uncertain markets have limited prospects for use of solid wastes for other purposes. Due to the high content of organic matter in some industrial solid wastes only composting and land application are attractive alternatives for their disposal. Organic constituents in these waste materials are potential soil conditioners. The use of these solid waste materials as organic amendments to reclaim mine dumps and other types of wastelands has shown numerous benefits in terms of increased plant growth and yield, improved soil moisture retention, increased cation exchange capacity and better soil nutrient retention.

Solid waste generated in India may be classified under several principal generic categories such as crop residues, farm wastes, industrial wastes, forest products, municipal solid wastes, municipal sewage sludge, animal wastes, marine products, silvicultural energy farm products and aquatic biomass. Industrial solid wastes include wastes from mining, sugar, fermentation, pulp and paper, pharmaceutical industries and most significantly the hazardous and radioactive solid wastes. A considerable amount of solid waste is generated in the various stages of pulp and papermaking. The total annual paper production for 1999 in India was reported to be 3.795 Mt (million tons) that accounts for 1.2% of global production (FAO, 2001a). An integrated large mill having a turnover of 100 t/day discharges wastes of 50–60 t of lime sludge, 5–6 t of bamboo/wood dust, 3–4 t of fiber fines, in addition to about 60 t of coal ash (Bellamy et al., 1995). Handling and disposing of such materials is a continuous problem for the industry. The management of such a huge quantity of paper sludge is essential and requires proper planning for its utilization and disposal. Being rich in cellulose content, if dumped it may cause severe hazard to the environment.

Another waste of growing concern is the sugar industry waste. There are nearly about 300–500 small- and large-scale sugar industries functioning in India. In 2000 they

produced 18.94 Mt of raw sugar that gave India the unquestionable leading position in the world with 14.9% of the global production (FAO, 2001b,c). In the last decade (since 1991), the raw sugar production in India increased to 67% (FAO, 1998, 2001b,c). This reflects a scale of the problem concerning sugar industry waste management. On an average, 200 t of pressmud is produced per day by the sugar industry. Molasses, a by-product of the sugar industry has already earned commercial value and is extensively used for resource recovery through the fermentation route. Pressmud is rich in nitrogen, phosphorus and potassium and also has significant sugar content. Disposal of pressmud at landfill sites without any treatment and planning may cause an environmental hazard.

The mine waste generated from the mining industry poses serious environmental problems to the ecosystem. In India, 707,000 ha of area was used for mining and 1.677 Mt of manganese, 58.3 Mt of iron and 264.4 Mt of coal were produced in 1995 (Indian Bureau of Mines, 1995). Coal production shows particularly high dynamics. In 2000, India produced 310 Mt of coal that was used for generating about 66% of the national power production (World Coal Institute, 2000), with planned further fast growth. Coal demand is expected to double to 890 Mt/yr by 2010 (Gale, 1999); estimated coal consumption will reach 725 Mt/yr in 2011–2012 (Prasad et al., 2000). There is also a progressive worldwide increase in metalliferous mining in recent years underpinned by social, economic and technological demand (United Nations, 1991, 1992, 1998, 1999, 2000).

The mining industry turns large areas of land into barren dumps. In the typical Indian barren mine waste dump that consists of overburden and run-off mine spoil, which is full of stone and boulders, the only carbon source for microbial utilization is the plant biomass that is expected to accumulate over several growing seasons on the site. The large-scale opencast mining affects the quality of natural soil. The removal of organic surface soil during the mining process substantially reduces the *fertility* and water, as well as nutrient retention properties of the soil.

Industrial solid waste reclamation measures are therefore considered to be an integral part of industrial solid waste disposal, planning and management. Among the industrial solid wastes, reclamation of the mine waste from the mining industry requires innovative techniques that reduce costs and increase the chances of plant establishment and survival. Essentially the mine waste reclamation objectives are directed towards the long-term stability of the land surface which ensures that there is no surface erosion by water or wind, reduction of leaching throughputs, lessening the amounts of potentially toxic elements released into local water courses and to groundwater, development of a vegetated landscape or ecosystem in harmony with the surrounding environment and with some positive value in an aesthetic productivity or nature conservation context.

### **VI.7.2. Constraints in mine waste reclamation**

The reasons that mine wastes present difficulties for plant growth is from a combination of their physical, chemical or biological properties. The absence of an organic fraction in surface layers adds to the prevention of plant growth. Organic matter, which crucially contributes to the soil structure, provides a reservoir of macronutrients and a resource for invertebrates and microorganisms.

The physical constraints of mine waste reclamation accounts for the unfavorable porosity, aeration, water infiltration and percolation properties, along with a high bulk density and absence of structural aggregates leading to water and wind erosion of unprotected disused land surfaces. The other growth limiting factors include mine land temperature and deteriorating groundwater level.

The chemical constraints involve the extremes of spoil pH, and a low concentration of essential plant macro and micronutrients, viz. nitrogen, phosphorus, potassium, calcium and magnesium. Nitrogen levels are invariably inadequate for plant growth, phosphorus levels are generally very low; and deficiencies of potassium, calcium and magnesium also may occur (Williamson et al., 1982). The high concentrations of heavy metals in some mine waste also have a deleterious effect on plant growth.

Biological constraints include the absence of beneficial microorganisms, which play an important role in restoring the physico-chemical and biological properties of spoil. The microorganisms contribute to the development of mine waste structure, synthesis of plant nutrients through the mediation of various biogeochemical cycles and amelioration of adverse chemical and physical limitations. The potential microsymbionts such as nitrogen fixers are associated with rhizosphere of plants. Moreover, mycorrhizal fungi are responsible for mobilization of nutrients, especially on nutritionally poor soils while phosphate solubilizers are responsible for the solubilization and mineralization of insoluble phosphates in soil. Therefore, to establish or to restore the biogeochemical cycles, it is essential to develop suitable strains of microflora as the mine waste is devoid of microorganisms. The mine waste cannot support the proliferation of microbes due to the poor nutritional and adverse physical conditions of spore such as extreme temperature and variable pH. Mine waste may be devoid of or have limited microbially mediated processes due to the abiotic properties of mine lands that include low moisture status, widely fluctuating temperature, soil physico-chemical factors such as extremes of pH and low levels of organic matter (Tate and Kerin, 1985).

The reclamation scheme that is adopted should be effective in ameliorating all the constraints with successful utilization of mine waste for developing a vegetative canopy on barren lands and thus restoring the mine waste productivity and fertility.

### **VI.7.3. Phytoreclamation: a holistic approach**

Reclamation with chemical fertilizers is expensive and requires intensive management and annual fertilizer additions for several years.

In undisturbed ecosystems primary production, decomposition and nutrient cycling are the main processes for the stability of the ecosystem. Therefore, the rapid re-establishment of the primary producers on disturbed land should be the main aim of a reclamation program. Once the vegetation is established, the rate at which essential nutrients are released from dead plant residues and returned to the plant system, and the rate of stable organic matter accumulation on these disturbed systems will largely be a function of biological characteristics of the mine waste. The soil microbial biomass and plant residues both are sources of carbon, nitrogen, sulfur and phosphorus. Further, due to high metabolic and reproductive rates, the soil microorganisms also have the capability to rapidly

immobilize nutrients that would otherwise be lost through leaching. Soil microbes also exhibit great metabolic versatility that allows them to adapt to the low nutrient levels and adverse chemical and physical characteristics of many mine wastes (Wali, 1979; Ellewood et al., 1980). Since mine waste often lacks such key nutrients as nitrogen and phosphorus, it is essential to utilize symbiotic microorganisms (i.e. nitrogen-fixing bacteria and mycorrhizal fungi) for improving the nutrient status of plants used to colonize mine wastes.

The technology of phytoreclamation envisages spreading of a specially blended organic material containing high percentage of organic matter, usually solid wastes from industries and inorganic fertilizers like N, P and K on the surface of dumped overburdens. Instead of chemical organic fertilizers, biofertilizers like *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate solubilizers and mycorrhiza can be used, which when added to the spoil have a special advantage. They fix atmospheric nitrogen and mobilize essential macronutrients making it easily accessible to plants. This approach helps to achieve the fertility of the post mining land (barren dumps) in a short time, thus improving the water holding capacity of the spoil and enables creation of topsoil to sustain high quality vegetation.

Phytoreclamation can be made successful by identification of constraints and resolving them by careful selection of plant species, appropriate amendment and selective microorganisms as biofertilizers. Therefore, phytoreclamation seems to be an attractive and cost-effective alternative for revegetating barren mine waste.

#### ***VI.7.3.1. Use of organic waste as amendment for improvement of the nutrient status of spoil***

Organic matter in the form of waste materials offers great advantage in redevelopment of drastically disturbed soils. Direct stimulation of plant growth on mine waste results from mineralization of plant nutrients contained in the organic matter. The level of organic matter in the soil is a result of the balance between biomass synthesis and mineralization. Stroo and Jencks (1982) found that recovery of microbial activity in mine spoil was directly related to organic matter and nitrogen accumulation. Immediately following amendment, the microbial respiration in the spoil increases and respiration rate declines to the low level as the readily degradable carbon sources are exhausted. This is followed by slow mineralization of the more biodegradation-resistant carbon substrates. An extended period of microbial activity and increased fertility and soil organic matter levels compared with unamended soil, results from the slow decomposition of the biodegradation-resistant plant components and the slow turnover of humified carbon compounds. The time of these reactions extend over several decades or longer. This explains the slow development of soil structure in reclaimed mine soils (Schaffer et al., 1980). Buffering capacity, chelation and cation exchange properties of a soil are of prime importance in determination of toxicant availability in mine land soils as well as in leachates from disposal sites. Organic amendments rules out these properties.

For over two decades, reclamation of various mine waste disposal sites and other disturbed lands has been investigated or successfully implemented using different waste materials as organic amendments, e.g. cal-sag – a sediment from navigable water ways and organic waste from the city (Vanluik and Harrison, 1982), reused industrial orange waste (Correia et al., 1995), paper mill sludge (Feagley et al., 1994; Bellamy et al., 1995),

sewage sludge (Parkinson et al., 1980; Matcalf, 1984; Kooper and Sabey, 1986; Pietz et al., 1989; Danker et al., 2003) or other organic waste such as composted dairy manure, poultry litter and biosolids (Sloan and Cawthon, 2003), also as a mixture with inorganic waste such as powerplant fly ash in order to utilize their water holding capacity and potential of both waste materials to supply all the essential nutrients for plant growth. The generally positive results of investigations of such mixtures with fly ash have been reported recently, e.g. composted mixtures of orange peels, municipal compost (Alva et al., 1999a,b), biosolids (Yuncong et al., 2001), dairy manure, poultry litter and biosolids (Sloan and Cawthon, 2003) and sewage sludge (Bhumbla et al., 2001); the latter two mixtures were applied to mine soils.

The organic matter was found also to have regulating effect on the soil temperature. It delays the fixation of mineral phosphoric acid and supplies organic decomposition products that aid the growth. Moreover, it is a source of slow and uniformly active nitrogen and consequently has a beneficial influence on the protein content of the plant. By virtue of these properties organic matter often creates the conditions necessary for the successful use of inorganic fertilizers.

Through cooperation of organic waste materials that improve the soil properties on the one hand, and biofertilizers, which supply plant nutrient on the other, adequate environmental conditions can be provided for the selected plant species on the mine land.

### **VI.7.3.2. Bioreclamation with use of biofertilizers**

The importance of using specialized biofertilizer cultures to improve the nitrogen fixation, mycorrhizal fungi for mobilization of plant nutrients, phosphate solubilizers and formation of aggregates of sand grains by fungi, bacteria, actinomycetes and algae highlights the need for an active microbial community in the mine waste in addition to the organic amendments.

#### **VI.7.3.2.1. Role of biofertilizers in reclamation**

Biofertilizers, a term which refers to microorganisms which either fix atmospheric  $N_2$  into plant-usable forms or enhance the solubility of soil nutrients, are becoming increasingly important as a key component of the integrated plant nutrient supply system.

Use of biofertilizers in mine waste reclamation has advantage over chemical fertilizer because of the poor physical structure of spoil. High porosity of spoil leads to leaching of chemical fertilizer to the groundwater while biofertilizer remains with the rhizosphere of the plant.

Biological nitrogen fixation (BNF) offers an economically attractive and ecologically sound route for augmenting N-supplies. Thus, *Rhizobium* for legumes, blue-green algae and *Azolla* for wetland rice, *Azotobacter* and *Azospirillum* for several crops can play significant roles in revegetation. Biofertilizers cannot meet the total nutrient needs and are in fact one of the inputs that can be used along with other fertilizers. The N-fixing

biofertilizers make a net addition to N supplies by fixing atmospheric N for the soil–plant system. The estimated contribution of different biofertilizers is as follows:

1 t *Rhizobium* = 100 t N (50 kg N-fixed/yr/crop at 500 g/ha dose)

1 t *Azotobacter* = 40 t N (20 kg N-fixed/yr/crop at 500 g/ha dose)

1 t *Azospirillum* = 40 t N (20 kg N-fixed/yr/crop at 500 g/ha dose)

1 t BGA = 2 ton N (20 kg N-fixed/yr/crop at 10 g/ha dose)

BNF with its ability to capture an inexhaustible source of N at low capital cost must play an increasingly important role in revegetation, spoil improvement and yield sustainability.

Phosphatic biofertilizers help in increasing the solubility/availability of phosphate that is already present in the soil in sparingly soluble forms. They in a way deplete the soil P reserves but considering the low utilization efficiency of phosphatic fertilizers, P-solubilizing biofertilizers can play an important role in improving the efficiency of P residues left in the soil.

#### VI.7.3.2.2. *Biodynamic influence and contribution of biofertilizers in mine land reclamation*

A profile of different biofertilizers are given in Table VI.7.1 (after Molsara et al., 1995). Biofertilizers are known to make a number of positive contributions:

- Supplement fertilizer supplies for meeting the nutrient needs of plants;
- Can add 20–200 kg N/ha (by fixation) under optimum conditions and solubilize/mobilize 30–50 kg P<sub>2</sub>O<sub>5</sub>/ha;
- Liberate growth promoting substances and vitamins and help to maintain soil fertility;
- Suppress the incidence of pathogens and control diseases;
- Increase yield by 10–50%, N-fixers reduce depletion of soil nutrients and provide sustainability to the ecosystem;
- Are cheaper than conventional nitrogenous and phosphatic fertilizers, pollution-free and are based on renewable energy sources;
- Improve soil physical properties, tilt and soil health in general, and act as biological conditioners of soil;
- Can easily be transported.

In addition to the above nitrogen fixers and phosphate solubilizers, mycorrhizal inoculation to plants can help in alleviating stress conditions on mine sites.

#### VI.7.3.2.3. *Effect of vesicular arbuscular mycorrhizae (VAM) on bioreclamation*

Principally VAM are broadly classified as ectomycorrhizae and endomycorrhizae. They are obligate symbionts and have not been isolated in pure cultures; the only method to maintain them is by inoculating the specific species of plants with spores of VAM. The classification of VAM is based on spore morphology and cellular structure. Most common VAM belong to the following genera (Verma, 1995):

Table VI.7.1. A profile of different biofertilizers (after Molsara et al., 1995).

A. Biofertilizers that fix nitrogen			
Biofertilizer	Function/contribution	Limitation	Used for crops
<i>Rhizobium</i> (symbiotic)	Fixation of 50–100 kg N/ha 10–35% increase in yield	Fixation only with legumes Visible effect not reflected in traditional area	Pulse legumes like chickpea, redgram, pea, lentil black gram, etc. Oil seed legumes like soybean and groundnut; forage legumes like clover and lucern Tree legumes like <i>Leucaena</i> , <i>D. sissoo</i> , Acacia, Cassia
	Leaves residual nitrogen	Needs optimum P and Mo	
<i>Azotobacter</i> (non-symbiotic) and <i>Azospirillum</i> (associative)	Fixation of 20–25 kg N/ha 10–15% increase in yield Production of growth promoting substances	Demands high organic matter	Wheat, maize, cotton, sorghum, sugarcane, pearl millet, rice, vegetables, several other crops and tree species such as teak, etc.
Blue-green algae or cyanobacteria (phototropic)	Fixation of 20–30 kg N/ha 10–15% increase in yield Production of growth promoting substances	Effective only in submerged rice Demands bright sunlight	Flooded rice
<i>Azolla</i> (symbiotic)	Fixation of 30–100 kg N/ha Yield increase 10–20%	Survival difficult at high temperature Great demand for phosphorus	Only for flooded rice

(continued)

Table VI.7.1. (Continued)

B. Biofertilizers that solubilize phosphorus		
Microorganisms	Important genus	Important species
Bacteria	<i>Bacillus</i>	<i>B. megaterium</i> var. <i>phosphaticum</i> <i>B. circulans</i> <i>B. subtilis</i> <i>B. polymyxa</i>
	<i>Pseudomonas</i>	<i>P. striata</i> <i>P. liquifaciens</i> <i>P. putida</i>
Fungi	<i>Aspergillus</i>	<i>A. awamori</i> <i>A. fumigatus</i> <i>A. flavus</i>
	<i>Penicillium</i>	<i>P. digitatum</i> <i>P. lilacinum</i>
Actinomycetes	<i>Streptomyces</i>	

Genus	Example of species
<i>Glomus</i>	<i>G. fassiculatum</i> , <i>G. mosseae</i>
<i>Gigaspora</i>	<i>Gigaspora nigra</i>
<i>Acaulospora</i>	<i>A. scrobiculata</i>
<i>Sclerocystis</i>	<i>S. clavispota</i>
<i>Endogone</i>	<i>E. increseta</i>

The potential use of mycorrhizal fungi as biofertilizers, bioprotectors and their role in sustainable agriculture and soil fertility is fascinating. Mycorrhizae are universal symbionts and colonize the roots of over 90% of all plant species to the benefit of both plant and fungus. The hyphae of VAM penetrate the roots of host plants, form specialized structures within arbuscles and sometimes vesicles. Arbuscles are considered to be where transfer of nutrients (to the host) and carbon (to the fungus) takes place and vesicles to be organs of storage. Outside the root, hyphae form an extensive mycelium often extending several centimeters from the roots (Li et al., 1991). This serves as the primary organ for nutrient uptake and can also bear spores, which is a means of survival for these obligate symbionts (Fig. VI.7.1). VAM is recommended for use for forest trees, forage grasses, maize, millets, sorghum, barley and leguminous crops.

Well-known benefits of plant colonization by VAM include:

- Enhanced phosphorus nutrition by reducing fertilizer inputs (Harley and Smith, 1983);
- Enhanced uptake of potassium, sulfate, copper and zinc (Barea et al., 1991);
- Enhanced uptake of nitrate and ammonium from the soil (Barea et al., 1987, 1989);

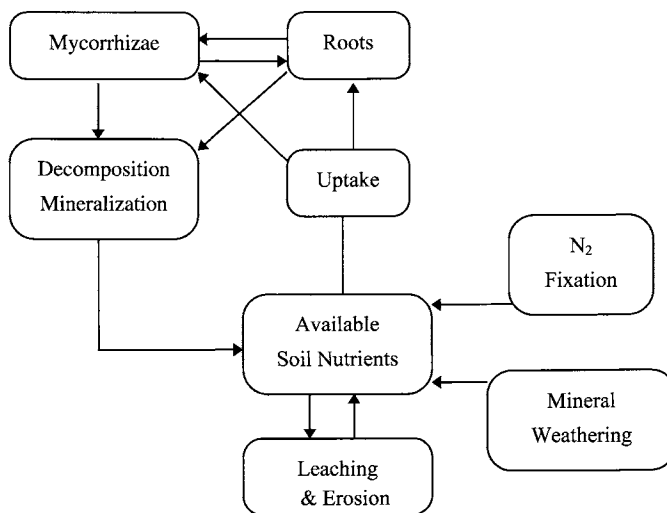


Figure VI.7.1. Role of VAM (after Li et al., 1991).

- Enhancing the nutrition of plants by developing profuse root system;
- Improving soil structure by binding soil particles and microaggregates by external mycelium (Miller and Jastrow, 1992);
- Biocontrol agent reducing the use of pesticides and enhancing resistance to root diseases;
- Reducing stunting on fumigated soil;
- Promoting more uniform crop, increases growth and yield;
- Helping for survival of plant in drought stressed conditions;
- Improving hardiness of transplanted stock.

The success of inoculation of biofertilizers in the field depends upon the production procedure used, product quality, application technique, presence of toxic agrochemicals and influence of soil environment.

### **VI.7.3.3. Bioreclamation of mine waste using biofertilizers**

Realizing the problems of using chemical fertilizers for mine waste reclamation, attention has been diverted to an alternative source, i.e. biofertilizers. The role of biofertilizers in agriculture is well established (Desmukh, 1998; Sharma, 2002). There is a need to transfer these established technologies and practices in establishing forest plantations and reclaiming degraded lands. Potential benefits of microsymbionts such as mycorrhizal fungi responsible for phosphorus absorption, specially on nutritionally poor soils, nitrogen fixers (*Frankia*) associated with non-leguminous trees, micro-aerophilic nitrogen fixers (*Azospirillum*) associated with tropical grasses, free living nitrogen fixers (*Azotobacter*, *Beijerinckia* and *Dexia*, etc.) associated with rhizosphere of plants and phosphomicrobials responsible for solubilization and mobilization of phosphate in soil have not yet been fully exploited for wasteland development and forest production. At present evidence is still insufficient to justify the use of inoculants other than *Rhizobium* for legumes to increase the quality of soil and plants associated with forest.

The essential nature of mycorrhizae for the successful colonization of certain mine wastes was established by the landmark work of J.R. Schramm in the early 1960s. Since that time, research has been expanded to include vesicular–arbuscular (VA) and ericoid mycorrhizae and the development of techniques for inoculating host plants with fungi specifically adapted to coal mine wastes in the harsh conditions of extremes of temperature and low nitrogen. Other limiting factors comprise available phosphorus, and other nutrients such as zinc, copper and ammonium, water scarcity and extremes of pH values.

Schramm (1966) found that nearly all the successful colonizers of coal wastes in Pennsylvania were mycorrhizal. These included species of *Pinus*, *Betula*, *Populus* and *Salix*, and all of them were ectomycorrhizal.

Marx et al. (1984) used the concept of forming ectomycorrhizae on tree seedlings in nurseries with specific fungi ecologically adapted to the planting site, which was originally developed by Moser and further used by other researchers. Cited successful applications of this technique include improving field performance of *Pinus caribaea* inoculated with pure culture of *Suillus polorans*, and *Pinus radiata* inoculated with isolates of *Rhizopogon luteolus*, *Suillus granulatus*, *S. luteus* and *Cenococcum geophilum* in Australia. Marx et al. (1984) further refined the Moser's technique and reported good results in inoculating

bare-root nursery beds with *Pisolithus tinctorius*. Mycorrhizal seedlings of *P. caribaea* inoculated with *R. luteolus* were more robust, healthy and superior in height and dry matter production than the uninoculated seedlings. Investigations have also shown that inoculation of container grown oak seedlings with specific ectomycorrhizal fungi further improved seedlings survival and early growth in green house and field. Container grown black Oak (*Quercus velutina* Lam.) and pines seedlings colonized with *P. tinctorius* and Sawforth Oak inoculated with *Thelephora terrestris* survived and grew better than bare rooted stock on a reforestation site.

The adhesion of soil particles to roots in dry soil has been suggested as a mechanism to increase water conductivity (Coutts, 1982) and it may also function to enhance the movement of mobile ions such as nitrate. Hyphae of VA fungi may extend up to 0.8 m from the root surface (Rhodes and Gerdemann, 1975), but rhizomorphs of *Pisolithus* may extend 4 m into the soil (Schramm, 1966), a result that suggests ectomycorrhizae are better adapted to long distance transport than VA mycorrhizae.

Ten-year-old untreated coal tips in Scotland were successfully colonized by both grasses and dicotyledonous plants that all but one species (which was non-mycorrhizal) were infected with VA fungi (Daft and Nicolson, 1974).

The harsh procedures used to remove bitumen from sand mined in northern Alberta resulted in mine tailings that are completely devoid of mycorrhizal inoculum (Parkinson, 1979). Zak and Parkinson (1982) found that less than 1% of slender wheat-grass roots grown in untreated sand were infected after one growing season, whereas tailings amended with peat from a forested site resulted in 23% infection.

Lambert and Cole (1979) found the significant effect of pH and a kind of mine waste on VA mycorrhizal yield, when they studied five different vegetated mine wastes and a forest soil as inoculum for white clover in the greenhouse with the spoil adjusted to either pH 4.5 or 6.5. Although VA mycorrhizal infection rates were similar among the inoculation treatments, yield response varied four times at pH 4.5 and fivefold at pH 6.5 with different inocula.

Some mine wastes may contain high levels of potentially toxic metals. On the basis of pot experiments with adding copper and zinc to pots containing a clay loam soil and seeding with clover inoculated with either an isolate of *Glomus mosseae* from metal contaminated soil or an isolate from an agricultural soil, Gildon and Tinker (1981) have shown that VA mycorrhizal symbionts can become adapted to metal contaminated soils. They concluded that endophyte tolerance was important, implying that the mycorrhizal symbionts must be considered as a component of whole plant tolerance to potentially toxic metals.

In field crops and horticultural plants, growth stimulatory influence of VAM-fungi inoculants is well known. Effectiveness of these inoculants has not been clearly demonstrated in forest species except in *Liriodendron tulipifera*, *Agathus australis* and *Araucaria* species. VAM fungi infected plants, when grown in nutrient deficient soils, often produce greater dry weight than not infected plants. Significant enhancement in growth and dry weight of seedlings (*Fraxinus americana*) inoculated with *Glomus epigaeum* has been found even at low levels of root colonization. VAM fungi inoculation of *Glomus etunicatum* can successfully be introduced for producing seedling of *Leucaena leucocephala* under low fertility levels. Growth and nutrient uptake by *Sesbania grandiflora* was improved when sterile soil was inoculated with *Glomus fassiculatum* and to lesser extent by *G. mosseae*. Due to VAM fungi inoculation, significant enhancement in

growth and survival of several other forest species, e.g. of cuttings of *Salix dasyalados* and *S. daphnoides* or flowering dog wood (*Cornus florida* L.) seedlings.

Growing information has been available concerning selection of *Rhizobium* strains and leguminous plants adopted for planting on mine wastes. The comparative efficiency of different legume species in building up nitrogen contents and increasing growth in a companion grass on mine wastes has been investigated. Introduction of free-living nitrogen fixing bacteria in the rhizosphere of revegetated perennial grass species on strip-mined land has been advocated. Many leguminous and non-leguminous plant species have been tried on coal and dolomite mine overburdens and bauxite mined out areas in Madhya Pradesh in India. The best performance was observed in the case of *Eucalyptus tereticornis* on coal mine overburdens. However, leguminous plants such as *Dalbergia sissoo*, *Albizia procera*, *A. lebbek*, *Acacia auriculiformis* and *Acacia melifera* are reported doing better than many non-leguminous plants (Dadhwal et al., 1995; Singh et al., 1995; Nikhil, 1999). At opencast mining sites, the nitrogen fixing trees (NFT) adapt to heavily disturbed soil system and at the same time grow faster to produce heavy foliage to cover the exposed sites.

Biofertilizers being a low cost technology may be advantageously used in wasteland development. Higher monetary return can be achieved with low expenditure as the inoculation cost comes to about Rs. 15–30/ha (Rs. 50  $\approx$  US \$1) by use of various inoculants marketed in India. In less productive soils where the plants are under stress in early growth period, application of 10–20 kg chemical nitrogen per hectare is required for initial growth and establishment of seedlings. *Rhizobia* can fix up to 80–100 kg nitrogen per hectare, equivalent to 90 kg of urea at just 40% of its cost. Findings from several field experiments revealed that less than a kilogram of high quality rhizobial inoculant, properly placed with legume seeds can replace more than 100 kg of nitrogenous fertilizers per hectare. Economically, the cost of application of *Rhizobium* culture comes out to be Rs. 0.30 per plant whereas equivalent dose of urea application is to cost about Rs. 2 per plant. *Azotobacter* culture inoculation can add 30–40 kg nitrogen per hectare per year. Several studies have demonstrated that the biofertilizer use (*Rhizobium*, *Azotobacter*, VA mycorrhizae) may provide a valuable and practical tool for achieving the desired end point of reclamation practices on mine wastes.

Here, an over decade's long experience with large-scale implementation in India of mine waste bioreclamation using the integrated biotechnological approach (IBA) has been discussed.

#### **VI.7.4. Case studies: bioreclamation of the manganese and coal mine wastelands**

National Environmental Engineering Research Institute (NEERI), Nagpur in collaboration with Manganese Ore India Limited (MOIL) and Coal India Limited (CIL) developed a reclamation strategy, which is environmentally compatible, economically viable and well suited to Indian conditions.

MOIL has six mines in Maharashtra state and four mines in Madhya Pradesh state and produces about 500,000 t of manganese ore per annum. Of the total ore production in the country, about 40% has been contributed by MOIL. The spoil generated in the mines is heaped at dumping ground that covers an area of 386 ha.

Western Coalfields Limited (WCL) is one of the eight subsidiary company of CIL contributing to about 11% of national coal production. WCL has mining operations spread over the states of Maharashtra and Madhya Pradesh. Of the 87 producing coal mines under WCL, 31 are opencast and 56 are underground with the total coal production of about 29.01 Mt and the overburden generation of about 59.39 Mm<sup>3</sup> (million cubic meters). The reclamation and revegetation project using IBA has been going on presently at five manganese ore mines, viz. Gumgaon, Chikia, Dongribuzurg, Tirodi and Mansar under MOIL and four coal mines Padmapur, Durgapur, Sasti and Umrer under WCL. Location of the reclamation sites under MOIL and WCL is depicted in Figure VI.7.2. Type of mining and areas under spoil dumps included into revegetation project are given in Table VI.7.2.

Below, the basic steps of the revegetation project, which started in early 1990s, have been briefly presented and discussed.

#### **VI.7.4.1. Experimental plan**

A detailed survey was carried out for spoil dump topography for landscaping at five mining areas under MOIL and four mining areas under WCL, which were under experiment. Spoil samples collected from the relevant sites were characterized with respect to the physico-chemical properties and microbiological characteristics. Barren manganese and coal mine waste dumps are shown in Figures VI.7.3 and VI.7.4, respectively. An approach plan was designed by NEERI for carrying out the reclamation work at different sites under MOIL and WCL (Fig. VI.7.5).

Physico-chemical properties of the dumped waste are presented in Tables VI.7.3 and VI.7.4. The manganese and coal mine wastes was a coarse material of pH values close to neutral or moderately alkaline; it contained low level of soluble salts indicated by conductivity of the water extract 1:10 in the range of 0.41–1.10 mS/cm. Organic matter content of spoil was very low, in the range of 0.08–0.13%. Similarly the nutrient status of both spoils in terms of NPK was poor. Both manganese mine waste and coal mine waste were deficient in nitrogen, which was in the range of 0.0004–0.0009%. The water holding capacity of the spoil was low and ranged from 7.6 to 8.0%.

The coal mine waste was characterized by the presence of heavy metals in the concentration sequence Mn > Zn > Pb > Cu > Cr. The manganese mine waste had high content of Mn (1275–2162 mg/kg) that was up to an order of magnitude higher than in coal mine waste whereas Cu > Ni > Pb were present in trace amounts. The higher bulk density and lower water holding capacity compared to soil, poor nutrient status, low organic carbon and texture of spoil were hostile for sustaining revegetation on the dumps. Hence, use of an organic amendment was essential to improve the physico-chemical and nutritive status of spoil. Ready availability, rich manurial value, non-toxic nature and low cost were the determinative factors for selection of an organic amendment. Keeping these factors in view, pressmud (a waste from sugar industry) and effluent treatment plant (ETP) sludge from pulp and paper industry were selected as ameliorants for manganese and coal mine waste dump reclamation, respectively (Tables VI.7.5 and VI.7.6). The pH of these ameliorants was moderately alkaline, around 8.0–8.2.



Figure VI.7.2. Location of mine sites selected for reclamation under MOIL and WCL.

### **VI.7.4.2. Laboratory studies**

#### **VI.7.4.2.1. Selection of the bedding material**

The first step in the study comprised screening of the most appropriate blend of spoil and amendments in terms of their effect on the plant growth. In pot experiments conducted in three replicates, five different mixtures (in the proportions of ingredients by weight) were screened:

Table VI.7.2. Type of mining and areas under waste dumps included into revegetation project.

State/location of mines	Type of mining/type of waste	Area under waste dump (ha)
<i>Manganese Ore India Limited</i>		
Maharashtra state		
Chikia	UG	38.73
Dongribuzurg	OC	50.15
Gumgaon	UG	6.38
Mansar	OC	17.80
Madhya Pradesh		
Tirodi	OC	131.91
Total under project		244.97
Total under MOIL		386.40
<i>Western Coalfields Limited</i>		
Maharashtra state		
Durgapur	OB	29
Padmapur	OB	Nd
Sasti	OB	Nd
Umrer	OB	Nd

Type of manganese mine: UG, Underground; OC, Opencast.

Type of coal mine waste: OB, Overburden.

Nd, not defined.



Figure VI.7.3. Barren manganese mine waste dump.



Figure VI.7.4. Barren coal mine waste dump.

- T1 – mine waste only;
- T2 – 4 parts of mine waste + 1 part of topsoil;
- T3 – 4 parts of mine waste + 1 part of topsoil + pressmud/ETP sludge  $\approx 25$  t/ha;
- T4 – 4 parts of mine waste + 1 part of topsoil + pressmud/ETP sludge  $\approx 50$  t/ha;
- T5 – 4 parts of mine waste + 1 part of topsoil + pressmud/ETP sludge  $\approx 100$  t/ha.

The pots were planted with *Tectona grandis* (teak), *D. sissoo* (shishum), *Gmelina arborea* (shiwan) and *A. auriculiformis* (acacia) saplings of approximately the same recorded height 0.2 m. At the end of 3 months, the height of the saplings was measured. T5 treatment appeared to be the most responsive mixture: the teak and shiwan plant height increased sevenfold; the heights of shishum and acacia plant were 10-fold higher than the initial height (Fig. VI.7.6). Hence, T5 treatment was selected for further field trials.

#### VI.7.4.2.2. Screening of suitable plant species for plantation on mine waste dump

The growth response of plants depends upon the productivity of rhizosphere, physiological nature of plant species and climate. The presence of specific pollutants in the rhizosphere also play important role in growth performance of plants on such unfriendly area. Therefore, laboratory studies were carried out to screen and ascertain the suitability of different plant species to be grown in manganese mine waste dump and mined out area using previously selected T5 combination of bedding material (by weight) that consisted of 4 parts of mine waste + 1 part of topsoil + pressmud/ETP sludge  $\approx 100$  t/ha. The plant species screened for plantation at MOIL included:

- Teak (*T. grandis*)
- Shishum (*D. sissoo*)
- Shiwan (*G. arborea*)
- Neem (*Azadirachta indica*)

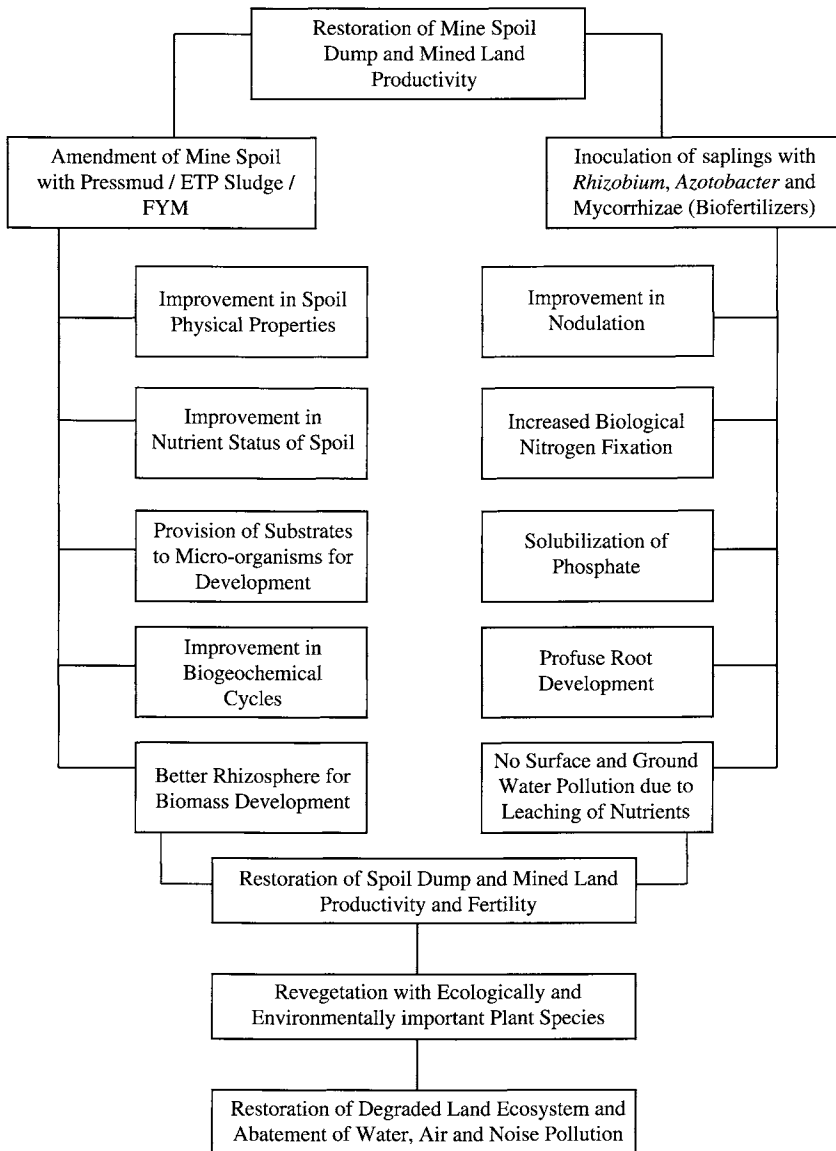


Figure VI.7.5. IBA developed for bioreclamation of mine waste dumps.

- Karanj (*Pongamia pinnata*)
- Australian babul (*A. auriculiformis*)
- Cassia (*Cassia seamea*)
- Subabul (*L. leucophala*)
- Awala (*Emblca officinalis*)
- Bamboo (*Dendrocalamus stirectus*)

Table VI.7.3. Physico-chemical properties of manganese mine waste.

Parameters	Range in mine waste
<i>Textural classification (% wt)</i>	
Stones and gravels	40–60
Sand	24–32
Silt	10–16
Clay	4–7
<i>Chemical</i>	
pH	7.0–7.5
Electric conductivity, ECe (mS/cm)	0.113–0.140
<i>Heavy metals (mg/kg)</i>	
Total Pb	10.2–20.0
Available Pb	0.002–0.004
Total Cu	25.0–55.0
Available Cu	0.002–0.004
Total Ni	25.5–38.5
Available Ni	0.003–0.010
Total Mn	1275–2162
Available Mn	1.30–6.30
<i>Nutrients (% wt)</i>	
Nitrogen, N	0.004–0.009
Phosphorus, P	0.005–0.007
Potassium, K	0.011–0.018

The plant species for plantation at WCL included:

- Eucalyptus (Eucalyptus hybrid)*
- Neem (A. indica)*
- Teak (T. grandis)*
- Shiwan (G. arborea)*
- Shishum (D. sissoo)*
- Cassia (C. semea)*
- Gulmohar (Delonix regia)*
- Australian babul (A. auriculiformis)*
- Custard apple (Annona squamosa)*
- Peepal (Ficus religiosa)*
- Banyan (Ficus bangalances)*
- Awala (E. officinalis)*
- Tamarindus (Tamarindus indica)*

#### VI.7.4.2.3. Isolation and identification of nitrogen fixing bacteria and VAM fungi

Although organic carbon is a major constituent of the nutrient supply, the other macronutrients, viz. nitrogen, phosphorus and potassium are also equally required. As the

Table VI.7.4. Physico-chemical properties of coal mine waste.

Parameters	Range in mine waste
<i>Physical</i>	
Bulk density (g/cm <sup>3</sup> )	1.860–1.930
Maximum water holding capacity, WHC (%)	7.60–8.00
Porosity (%)	20.10–21.30
<i>Chemical</i>	
pH	7.80–8.10
Electric conductivity, ECe (mS/cm)	0.82–1.10
Organic carbon (%)	0.08–0.13
<i>Water extractable ions 1:10 (meq/l)</i>	
Na	1.30–1.70
K	0.08–0.09
Ca + Mg	6.80–7.50
HCO <sub>3</sub>	4.10–4.40
Cl	4.40–5.20
<i>Heavy metals (total), mg/kg</i>	
Chromium	12.8–13.3
Copper	42.0–46.4
Lead	72.0–76.0
Manganese	210.0–214.0
Zinc	80.0–86.0
<i>Nutrients (mg/100 g)</i>	
Nitrogen, N	
Total	6.50–7.60
Available	0.70–0.80
Phosphorus, P	
Total	9.60–10.5
Available	0.40–0.50
Potassium, K	
Total	0.28–0.34
Available	0.09–0.12

plants are unable to uptake atmospheric nitrogen, a biocompatible approach was adopted by the use of nitrogen fixing bacteria to trap atmospheric nitrogen and make it readily accessible to plants. The use of endomycorrhizal fungi also has many fold advantages. Hence, VAM species were isolated, identified and used for bioreclamation studies of manganese mine waste dumps in combination with nitrogen fixing bacterial strains of *Rhizobium* and *Azotobacter*.

Two site-specific biofertilizer strains were isolated and identified. *Bradyrhizobium japonicum* strain BRS1, a slow grower strain was isolated from a healthy nodule of *D. sissoo*. The inoculation effect of BRS1 resulted in profuse root development and nodule formation in *D. sissoo* which is depicted in Figure VI.7.7.

Table VI.7.5. Characteristics of pressmud from sugar industry.

Parameters	Range in pressmud
<i>Chemical</i>	
pH	7.40–7.60
Organic carbon (%)	39.8–44.7
<i>Heavy metals (mg/kg)</i>	
Total Mn	1480.20–1970.50
Total Zn	237.50–285.40
Total Cu	112.40–131.70
<i>Nutrients (% wt)</i>	
Nitrogen, N	1.12–1.85
Phosphorus, P	4.72–6.25
Potassium, K	1.75–2.45

The *Azotobacter chroococum* strain TA1 was isolated from rhizospheric soil samples in the vicinity of roots of *T. grandis* growing nearby the mine site. The effect of TA1 inoculation on roots of bamboo plant is shown in Figure VI.7.8.

Spores of VAM fungi were extracted from the rhizospheric soil samples collected from vegetated areas nearby the barren sites by using 20 g soil and Wet Sieving and Decanting technique (Gerdman and Nicolson, 1963). The spores were identified, which belonged to *G. fasciculatum* (Fig. VI.7.9) and *Gigaspora gigantea* (Fig. VI.7.10).

To assess the metal tolerance of the isolates, the minimum inhibitory concentrations (MIC) of site-specific biofertilizer strains of BRS1 and TA1 for common heavy metal contaminants Cu, Fe, Mn and Zn were determined. The MIC determination was done on HM minimal media of Cole and Elkan (1973). The MIC of Mn, Zn, Cu and Fe for BRS1 were 410, 400, 120 and 70  $\mu\text{g/g}$ . The MIC values for TA1 were somewhat lower and accounted for 360, 210, 65 and 55  $\mu\text{g/g}$ , respectively.

#### VI.7.4.2.4. Inoculation of saplings with biofertilizers BRS1 and TA1 and VAM spores of VAMB1 and VAMB2

Root inoculation method was adapted to inoculate the saplings of plants with biofertilizer strains. An adhesive solution was prepared by dissolving 50 g of gum acacia and 100 g of sucrose per liter of water. To this, 500 ml of broth cultures of BRS1 and TA1 (liter value =  $10^8$  CFU/ml) were added separately to make slurry. Roots of leguminous plant saplings were dipped in BRS1 slurry while roots of non-leguminous plant saplings were dipped in TA1 slurry for 20 min and transplanted immediately into the pits. 10 g of mixed inoculum of *Glomus* and *Gigaspora* species (30 spores/g) was suspended in water and pipetted onto ordinary filter paper. Filter paper was rapped around the roots of saplings at the time of plantation into the pits.

Table VI.7.6. Characteristics of ETP sludge from paper mill.

Parameters	ETP sludge
<i>Physical</i>	
Bulk density (g/cc)	0.28–0.31
Maximum WHC (%)	170.4–174.0
Porosity (%)	60.10–62.08
<i>Chemical</i>	
pH	8.00–8.20
Electric conductivity, ECe (mS/cm)	1.40–1.60
Organic carbon (%)	39.6–42.2
<i>Water extractable ions 1:10 (meq/l)</i>	
Na	8.60–9.80
K	0.40–0.60
Ca	3.60–4.40
Mg	1.40–1.80
HCO <sub>3</sub>	5.40–6.30
Cl	8.60–9.30
<i>Heavy metals (total), mg/kg</i>	
Chromium	12.6–34.2
Copper	44.8–47.6
Lead	65.0–79.2
Manganese	640.0–653.0
Zinc	253.0–302.0
<i>Nutrients (mg/100 g)</i>	
Nitrogen, N	
Total	106–110
Available	5.60–6.10
Phosphorus, P	
Total	390–410
Available	4.00–4.40
Potassium, K	
Total	1.67–1.72
Available	1.09–1.14

### VI.7.4.3. Field studies

Based on the laboratory studies the technology was transferred for field trial at manganese and coal mine dumps.

In total, 222 ha of mine dumps at Gumgaon, Chikia, Dongribuzurg, Tirodi and Mansar under MOIL (72 ha) and Padmapur, Durgapur, Sasti and Umrer under WCL (150 ha) have been planted since early 1990s. For planting at top surface and on slopes of mine dumps, pitting technique was adapted and 2500 pits were dug per hectare. Pits at mine sites on

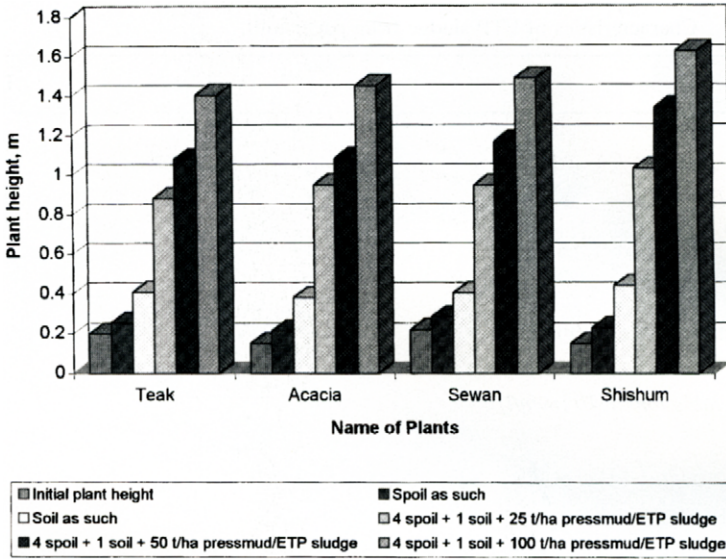


Figure VI.7.6. Effect of different combinations of bedding material on plant growth (after 3 months).



Figure VI.7.7. Profuse root development and nodule formation in the experimental shishum (*D. sissoo*) plant inoculated by *B. japonicum* strain BRS1 as compared to control.

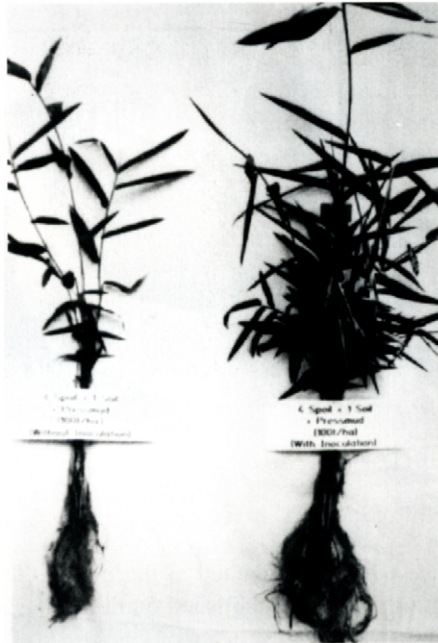


Figure VI.7.8. Profuse root development in the experimental bamboo (*D. strictus*) plant inoculated by *A. chroococum* strain TA1 as compared to control.

slope were of 0.6 m × 0.6 m × 0.6 m and at top level of 1 m × 1 m × 1 m in dimension, respectively. Each pit was filled with a previously selected T5 combination of bedding material (by weight) that consisted of 4 parts of mine waste + 1 part of topsoil + pressmud/ETP sludge ≈ 100 t/ha. Nearly 565,000 of various tree species of ecological

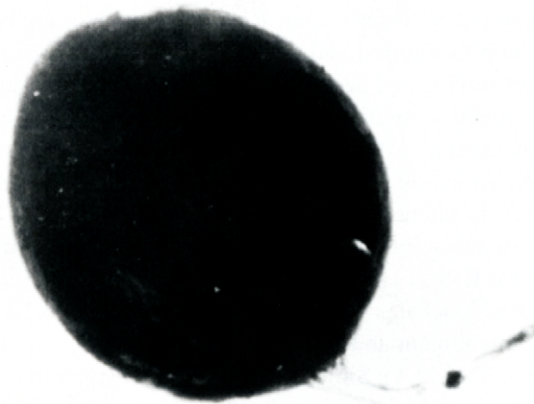


Figure VI.7.9. Single mature spore of *G. fasciculatum*.

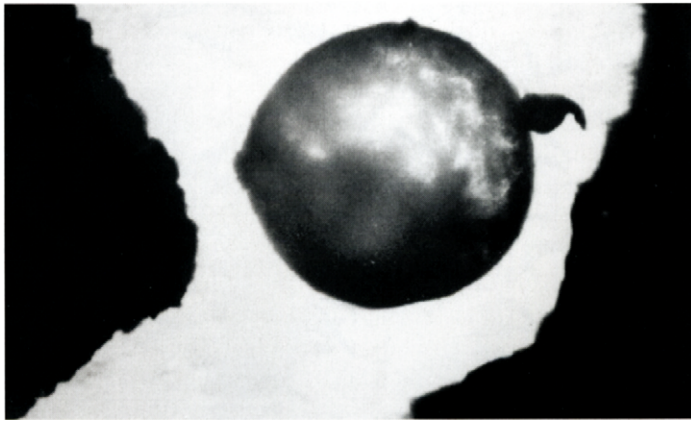


Figure VI.7.10. Single mature spore of *G. gigantia*.

and economical importance have been planted at these sites. The plants were irrigated regularly for 6 months until they were established on mine sites.

*VI.7.4.3.1. Impact of amendment, biofertilizer and VAM spore inoculation on rhizospheric microbial population and physico-chemical characteristics of spoil*

Five samples of bedding material per hectare were collected randomly from top 0.3 m from the pits planted with different tree species and analyzed in triplicate. The microbial population was enumerated in terms of colony forming units per gram of spoil (CFU/g) by using serial dilution and spread plate methods. Population of different microbes was studied following standard procedures for soil microbial estimations (Black et al., 1965; Page et al., 1982). Counts of aerobic heterotrophic bacteria, actinomycetes, fungi, nitrogen fixing strains of *Rhizobium* and *Azotobacter* were made by the spread plate method on nutrient agar, Kenknight and Munaier's agar, Rose Bengal Chloramphenicol agar, Yeast extract mannitol agar with Congo red and Jensen's agar, respectively. The VAM spores were enumerated by wet sieving and decanting technique (Gerdman and Nicolson, 1963). Changes in physico-chemical properties of coal mine waste were carried out according to standard methods of Black et al. (1965). The carbon mineralization studies were carried out according to Stotzky's method (1960). Nitrogen mineralization rate was monitored in leaching columns of 0.05 m diameter and 0.4 m length for 20 weeks. The columns were leached using 0.01 M calcium solution followed by addition of a nutrient solution (without N) containing 0.0025 M  $K_2SO_4$ , 0.002 M  $MgSO_4 \cdot 7H_2O$ , 0.002 M  $(CaK)_2(SO_4)_3$  and 0.005 M calcium phytate. Leachates were analyzed for  $NH_4-N$  and  $NO_3-N$ .

After 24 months of amendment and reclamation, the bacterial population reached to a count of  $10^8$  CFU/g (Fig. VI.7.11A). Similar trend was also observed in the case of fungal and actinomycete population, which stabilized and reached to  $10^6$  and  $10^5$  CFU/g of spoil sample, respectively (Fig. VI.7.11B,C). The manganese and coal mine waste initially were completely devoid of nitrogen fixers but on inoculation of saplings with biofertilizer

strains of BRS1 and TA1, the *Rhizobium* count remarkably reached to  $8.9 \times 10^7$  CFU/g (Fig. VI.7.11D) whereas *Azotobacter* count stabilized in the range of  $2.2 \times 10^7$ – $6.3 \times 10^7$  CFU/g (Fig. VI.7.11E).

The VAM spores, which were initially absent in the mine wastes, after 24 months reached the count up to 41 spores/g (Fig. VI.7.11F).

Amendment of mine waste with pressmud/ETP sludge  $\approx 100$  t/ha decreased the bulk density to  $1.33 \text{ g/cm}^3$  and increased the water holding capacity of the mine waste sevenfold and porosity threefold (Table VI.7.7). Changes in chemical characteristics of the coal mine waste due to amendment showed that the ECe (Electric conductivity) of amended spoil extract increased and was 1.4–2.5 times higher than the initial ECe of spoil. Sludge amendment resulted in the improvement of calcium, magnesium and potassium contents, which were useful for plant growth. The organic matter content of the amended spoil varied from 2.0 to 7.4% as against the 0.08–0.13% organic matter in unamended mine waste. The increased organic content complexes the heavy metals and decreases its availability in spoils. The available nitrogen increased for two orders of magnitude. Similar increase in available phosphate and potassium was observed. The increase in available NPK shows improved spoils productivity thus promoting luxuriant plant growth.

The  $\text{CO}_2$  evolution indicated the steady growth of the microbial population showing a linear trend. Microbial population brings about mineralization of carbon, nitrogenous compound present in the pressmud/ETP sludge. Results indicated that 19.6% carbon was mineralized after 20 weeks of incubation in T5 treatment whereas nitrogen mineralization was 18.3%, respectively (Figs. VI.7.12 and VI.7.13). The increase in nitrogen and carbon mineralization rate is an index of enhanced metabolic activity of rhizospheric microbial population.

#### *VI.7.4.3.2. Growth performance and survival rate of plants at manganese and coal mine waste dumps*

The IBA technology has resulted in successful reclamation of mine waste dumps and creation of lush green belt on the barren mine sites. Revegetated manganese and coal mine waste dumps are shown in Figs. VI.7.14 and VI.7.15. The IBA has resulted in over 85% survival of plant species and four- to fivefold increase in plant growth as opposed to around 20% survival of stunted plants without IBA (Figs. VI.7.16 and VI.7.17).

There was a six- to tenfold improvement in biomass after application of IBA (Fig. VI.7.18). Without IBA, the same process might have taken 100–300 years. Through NEERI's efforts, 150 ha of mine dumps in coal mines, and 72 ha of manganese spoil dumps have been successfully reclaimed.

#### *VI.7.4.4. Socio-economic impact of IBA*

A landmark in the reclamation program carried out by NEERI was the development of sericulture project at Gumgaon manganese mine site. On the foothill of the mine waste dump at Gumgaon about 0.3 m depth productive soil profile was prepared using mine waste, 15% topsoil and pressmud. Inoculum of mycorrhizal fungi was introduced to make the rhizosphere more productive. 40,000 mulberry shoots were planted on dump as a diversified activity inline with the ecodevelopment and environmental protection.

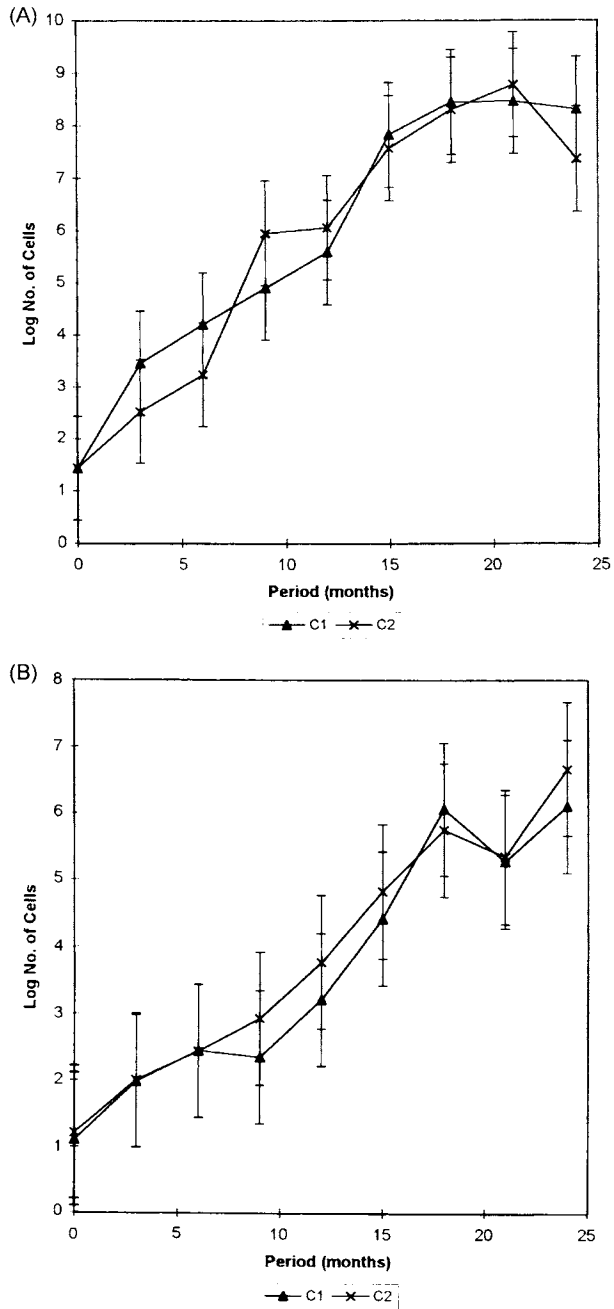


Figure VI.7.11. A–F. Variation in rhizospheric microbial population at different time intervals in 2 years' period. C1 – Pits filled with 75% spoil, 13% topsoil and 12% pressmud/ETP sludge and tree species inoculated with *B. japonicum* BRS1 and *G. fasciculatum* VAMB1; C2 – Pits filled with 75% spoil, 12% topsoil and 12% pressmud/ETP sludge and tree species inoculated with *A. chroococum* TA1 and *G. fasciculatum* VAMB1 and *G. gigantia* VAMB2. A – Variation in bacterial population; B – Variation in fungal population; C – Variation in actinomycetes population; D – Variation in rhizobial population; E – Variation in *Azotobacter* population; F – Variation in VAM population.

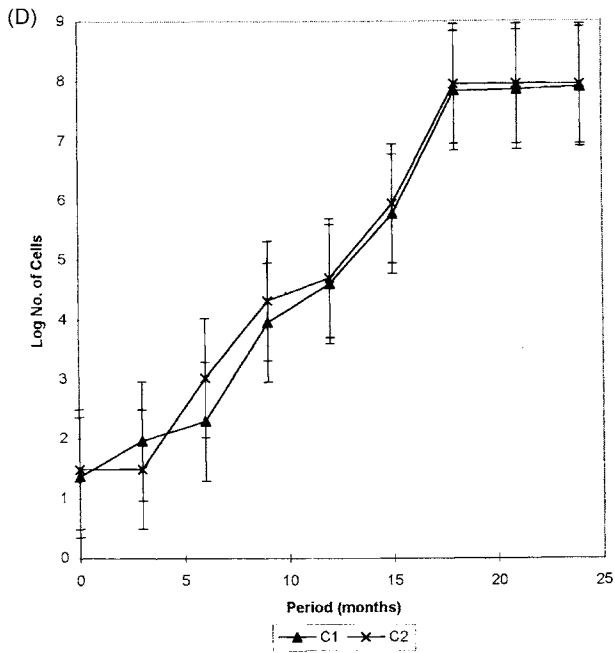
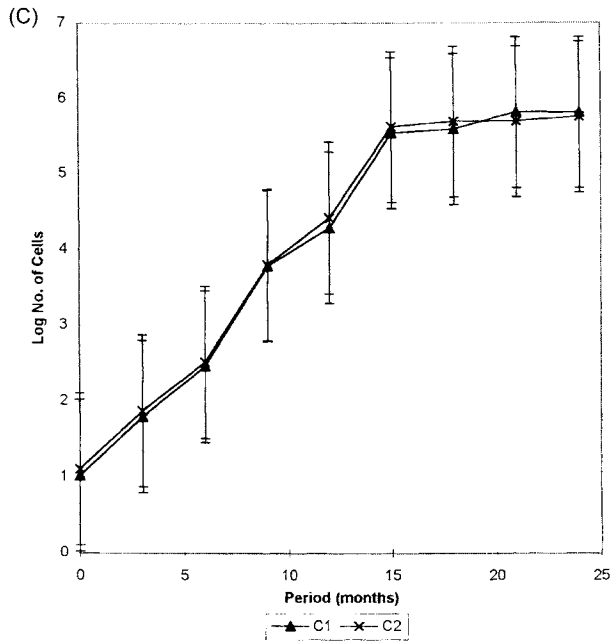


Figure VI.7.11. (Continued)

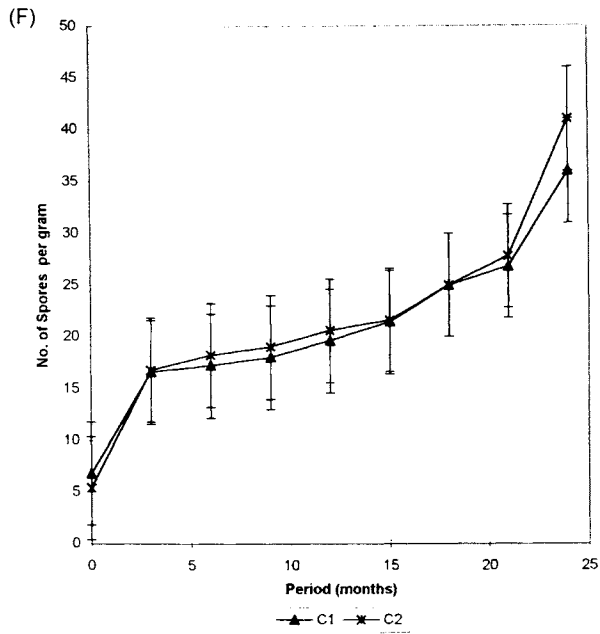
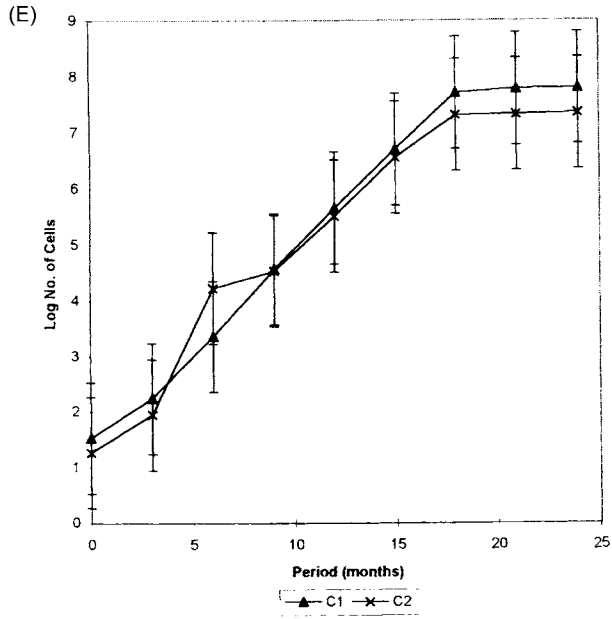


Figure VI.7.11. (Continued)

Table VI.7.7. Yearly changes in physico-chemical properties of coal mine waste due to blending with ETP sludge.

Parameters	1st year	2nd year	3rd year
<i>Physical</i>			
Bulk density (g/cm <sup>3</sup> )	1.61–1.76	1.42–1.68	1.26–1.35
Maximum WHC (%)	26.0–31.8	39.2–45.2	52.2–55.3
Porosity (%)	43.1–45.9	50.10–55.82	59.96–62.25
<i>Textural classification (% wt)</i>			
Coarse sand	45–60	42–58	40–50
Fine sand	20–32	22–29	18–28
Silt	14–20	13–19	11–18
Clay	8–12	10–15	20–26
<i>Chemical</i>			
pH	6.0–7.6	5.8–8.0	5.6–8.13
ECe (mS/cm)	1.14–2.74	0.654–1.73	0.285–1.09
Organic carbon (%)	2.0–4.10	2.14–5.20	2.27–7.40
<i>Water extractable ions 1:10 (meq/l)</i>			
Na	2.2–9.4	2.1–5.6	1.2–3.18
K	0.12–0.72	0.09–0.68	0.02–0.39
Ca	3.36–10.9	2.92–4.8	0.90–3.3
Mg	2.02–10.9	1.06–5.9	0.65–3.7
HCO <sub>3</sub>	2.0–8.0	1.8–6.4	0.78–4.1
Cl	6.2–13.6	4.3–9.3	1.27–5.7
<i>Heavy metals (total), mg/kg</i>			
Chromium	16.5–22.0	10.2–18.1	7.2–12.9
Copper	36.3–40.7	27.8–32.2	10.3–21.8
Lead	68.8–65.3	34.6–42.8	26.4–31.1
Manganese	41.0–436.3	161.3–319.8	162.9–305.5
Zinc	162.2–187.8	102.3–155.5	98.6–132.3
<i>Nutrients (mg/100 g)</i>			
Nitrogen, N			
Total	216.0–437.3	226.6–556.1	240.0–794.2
Available	23.2–45.8	27.1–62.5	31.6–81.9
Phosphorus, P			
Total	32.7–34.6	43.26–45.32	54.3–56.4
Available	4.8–5.22	5.9–6.1	6.8–7.0
Potassium, K			
Total	75.3–82.5	96.1–105.0	125.2–136.3
Available	7.6–9.0	9.8–11.8	12.9–14.7

Subsequently additional area was developed and 120,000 mulberry plants were planted covering an area of over 6 ha. Rearing of silkworm on mulberry leaves was done and cocoons were obtained which were later sold to Khadi Gram Udyog. This activity besides giving boost to the sericulture was promoted with socio-economic objective and to create

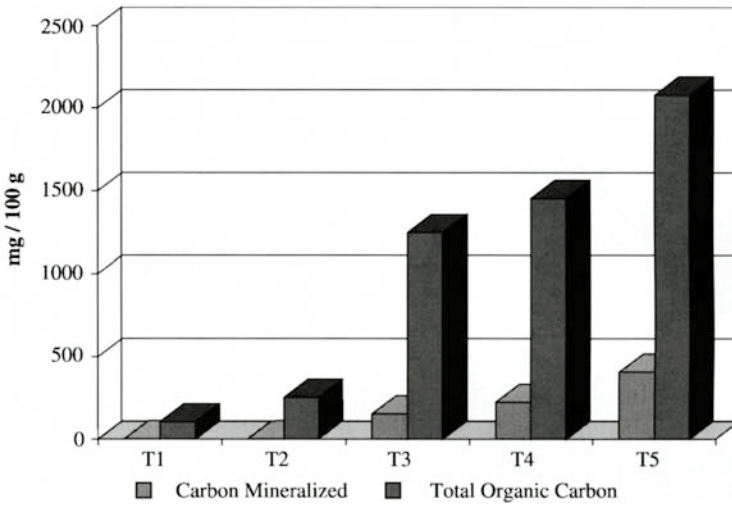


Figure VI.7.12. Carbon mineralization rates at different combinations of bedding material (T1–T5 treatment options).

positive awareness among a large section of people around the mining area. The commercialization of mulberry plantation and silkworm rearing has been started by MOIL since the early 1990s. During 1991–1995, annual yield of cocoons ranged from 37 to over 115 kg, and mulberry shoots up to 9 t.

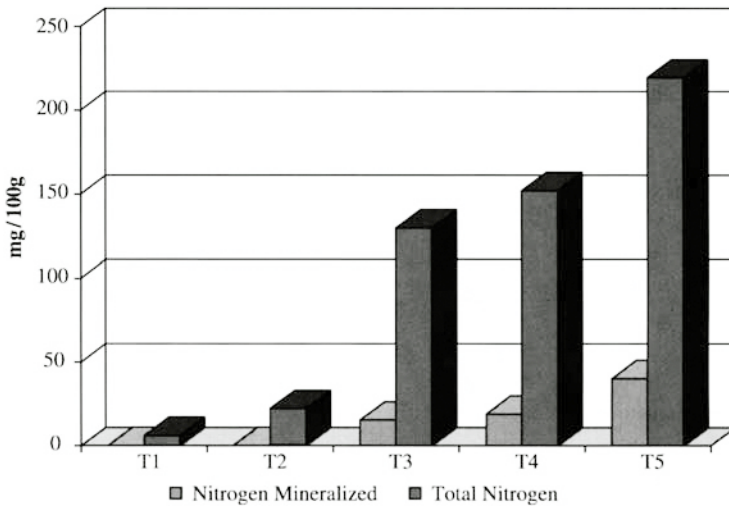


Figure VI.7.13. Nitrogen mineralization rates at different combinations of bedding material (T1–T5 treatment options).



Figure VI.7.14. Revegetated manganese mine waste dumps using IBA.

#### VI.7.4.5. Cost-benefit analysis of the integrated biotechnological approach

The economical feasibility of the application of IBA in the bioreclamation of mine waste dumping sites and land disturbed due to mining activity, is illustrated below in the cost-benefit analysis for bioremediation of 10 ha mining site in India:

Dump area for bioremediation	10 ha
Total cost <sup>a</sup> including pitting, planting and maintenance for 3 years	Rs. 600,000 (≈ US \$12,000)
Benefits (4–20 years)	Rs. 1,600,000–5,900,000 (≈ US \$32,000–118,000)
Payback period	2.5 years

<sup>a</sup>In Rupees; US \$1 ≈ 50 Rs.

#### VI.7.5. Concluding remarks

The final goal of a reclamation program is establishment of a self-sustaining vegetative cover that requires a minimum of maintenance. Successful establishment of vegetation is dependent on climatic and edaphic factors, and chemical, physical and biological characteristics of the mine wastes to be reclaimed.

There are problems of survival and growth of plants on the mine waste dumps due to poor physical properties, low nutrient status and absence of microflora.

The NEERI, Nagpur in collaboration with MOIL and CIL developed a reclamation strategy that is environmentally compatible, economically viable and well suited to



*Figure VI.7.15.* Revegetated coal mine waste dumps using IBA as compared with non-reclaimed foreground devoid of vegetation.

Indian conditions. Under a massive afforestation program carried out since early 1990s at selected manganese and coal mine waste dumps in Maharashtra and Madhya Pradesh states, over 220 ha of wasteland had been successfully reclaimed by using a systematic and scientific approach. An IBA was adopted for sustainable revegetation, and a biocompatible technology comprising biofertilizers + VAM and industrial waste materials as organic amendments to ameliorate mine waste was used.

The IBA helped in successful reclamation of the barren dumps, which resulted in 90–95% plant survival rate; 6–10-fold increase in biomass production; establishment of biogeochemical cycles and microflora resembling that observed in good productive soil in just 18 months. This was the most important achievement for re-establishment of a sustainable rhizosphere. The IBA helped in reclaiming the mine waste dumps and wastelands within 3–4 years without the use of chemicals and inorganic fertilizers. The IBA promoted resource conservation through waste utilization, helped in fast recovery and restoration of fertility and productivity of the degraded ecosystem and provided carbon dioxide sinks, built fertile topsoil; generated fuel, fiber, food, fodder and fruits and other economical benefits in terms of production of timber and industrial wood and raw material for cottage industry.

IBA also provided several ecological benefits in terms of oxygen production, soil erosion control, groundwater recharge and generation of carbon dioxide sinks. The IBA thus ensures clean and healthy environment by abating air, water and land pollution.

Using IBA, the joint venture of industry and the research institute has successfully turned barren landscape of MOIL and CIL's mines into lush forests of high economical and ecological value. Presented illustrative case studies summarize over decade's experience and contribution towards installation of the country's first model example of scientific reclamation program through IBA.

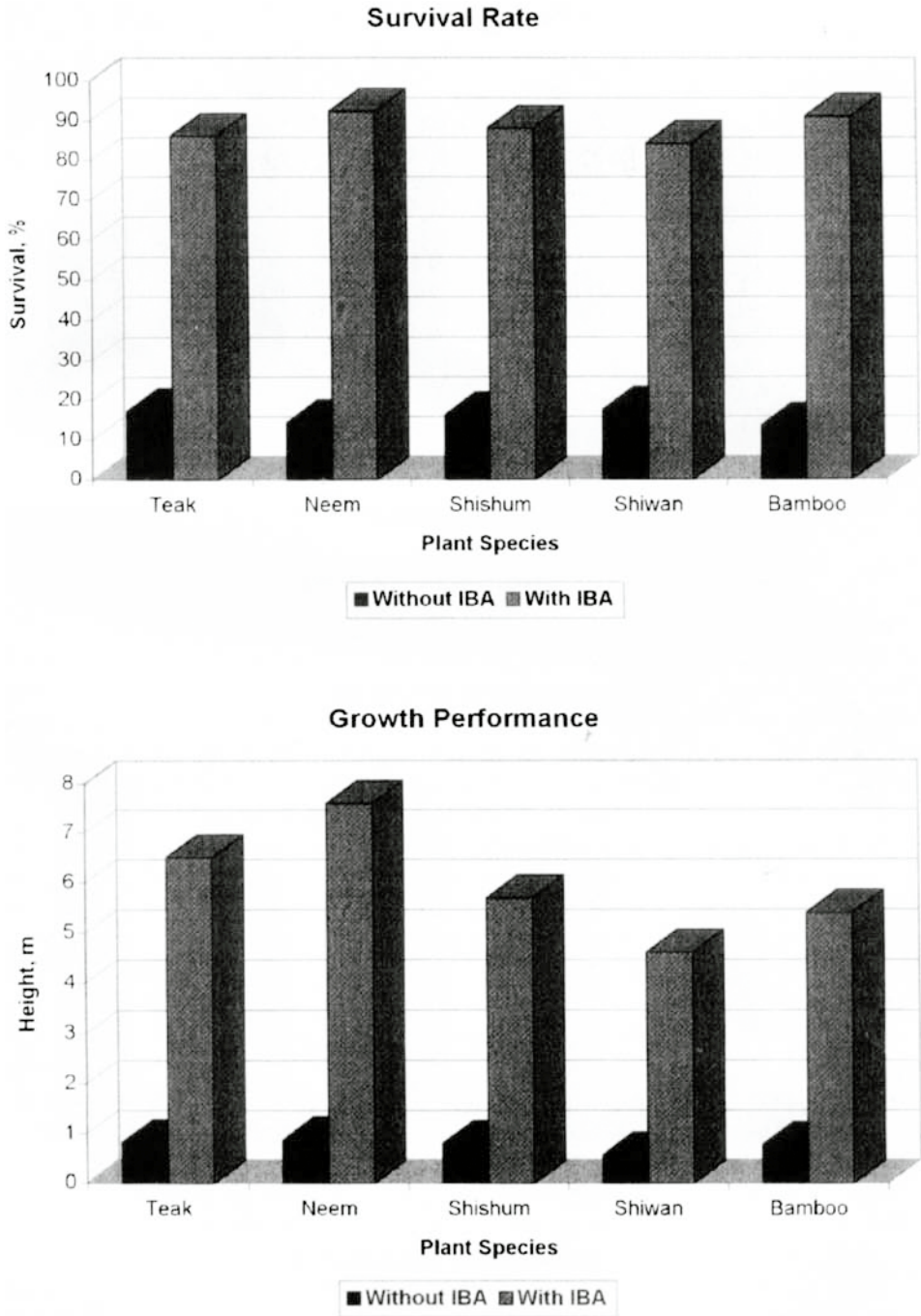


Figure VI.7.16. Survival rate and growth performance of different plant species on manganese waste dump.

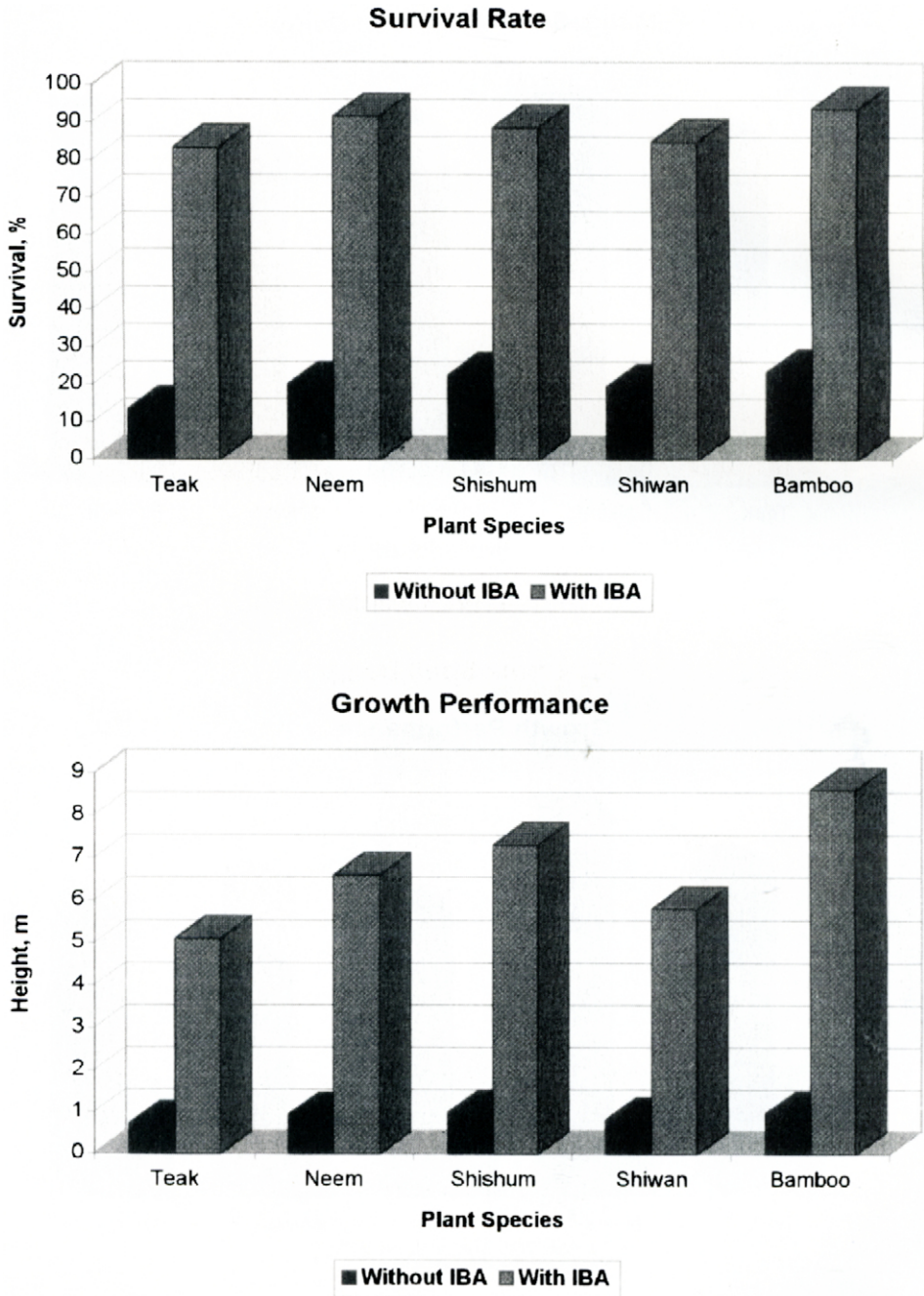


Figure VI.7.17. Survival rate and growth performance of different plant species on coal mine waste dump.

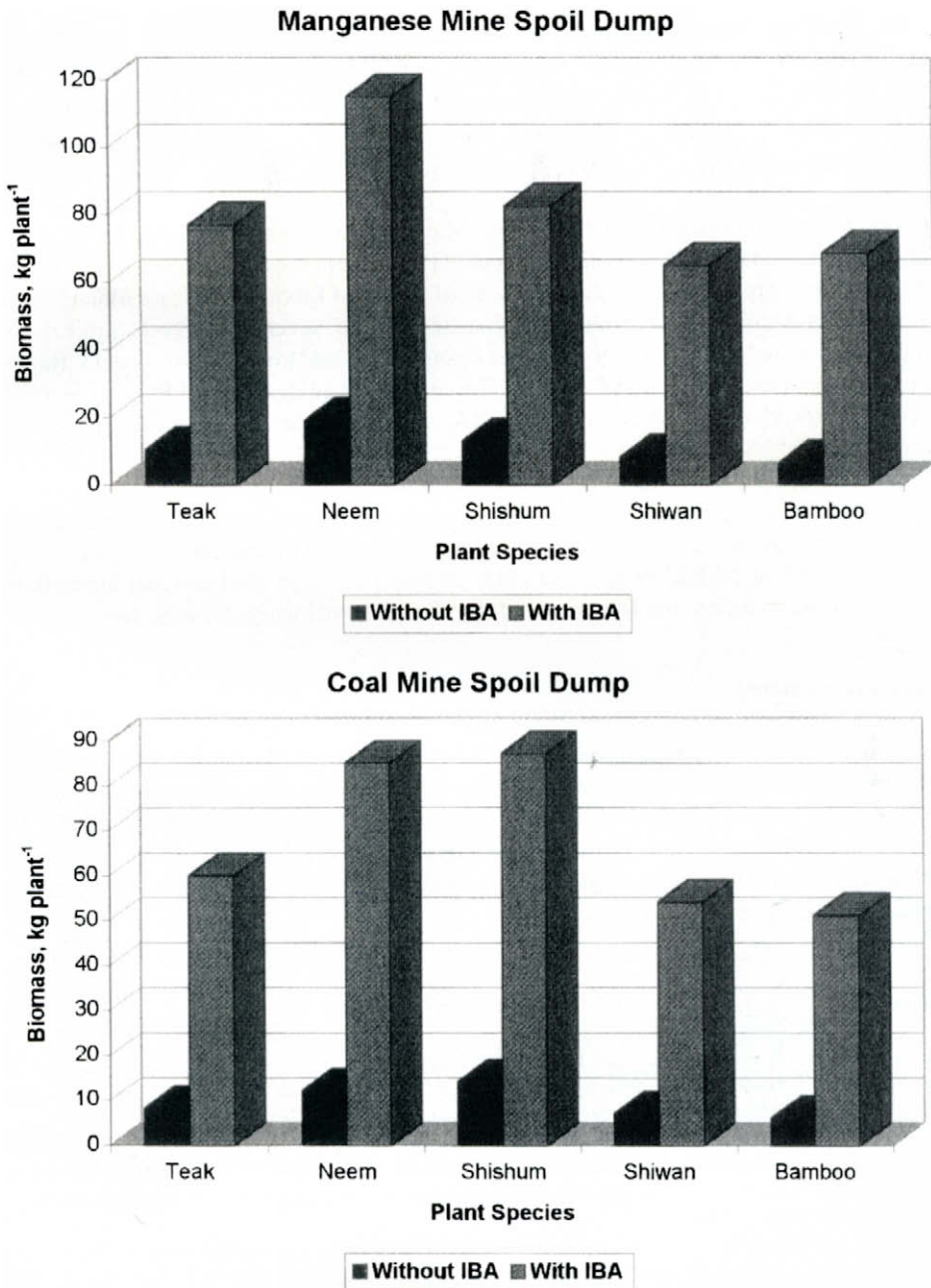


Figure VI.7.18. Biomass production of different plant species on manganese and coal mine waste dumps.

This study has shown that an IBA involving use of organic amendments, biofertilizers and VAM is the most appropriate solution for bioreclamation and development of mine waste dumps.

### Immemorial note

Dr A.S. Juwarkar, born on March 6, 1951, Maharashtra, India (July 11th, 1996) was a scientist of national and international repute. He had an outstanding academic record throughout his career. As a scientist and head of the Land Environment and Management (LEM) Division of NEERI, Nagpur, India, he pursued several important projects on bioreclamation and treatment of wastewater through high rate transpiration system. He had several national and international papers to his credit and guided several PhD students.

Dr A.S. Juwarkar significantly contributed in starting and developing a successful long-term program of bioreclamation of mine waste dumps using IBA that fetched him the Best Scientist Award from NEERI. Now, several years after his passing away, luxuriant vegetation in the first dumps that were reclaimed under his supervision, and in the wastelands that have been greened using his experience, makes us proud to continue his work.

We, the staff of NEERI bow to the chief architect of LEM Division and are making a sincere effort to follow the footprints left by the great visionary, Dr A.S. Juwarkar.

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### References

- Alva, A.K., Bilski, J.J., Sajwan, K.S., van Clief, D., 1999a. Leaching of metals from soils amended with fly ash and organic byproducts, pp. 193–206. In: Sajwan, K.S., Alva, A.K., Keefer, R.F. (Eds), *Biogeochemistry of Trace Elements in Coal and Coal Combustion Byproducts*. Kluwer, New York, p. 359.
- Alva, A.K., Paramasivam, S., Prakash, O., Sajwan, K.S., Ornes, W.H., van Clief, D., 1999b. Effects of fly ash and sewage sludge amendments on transport of metals in different soils, pp. 207–222. In: Sajwan, K.S., Alva, A.K., Keefer, R.F. (Eds), *Biogeochemistry of Trace Elements in Coal and Coal Combustion Byproducts*. Kluwer, New York, p. 359.
- Barea, J.M., Azcon-Aguilar, C., Azcon, R., 1987. Vesicular mycorrhizae improve both symbiotic N<sub>2</sub> fixation and N uptake from soil as assessed with a 15 N technique under field condition. *New Phytol.*, 106, 717–725.
- Barea, J.M., Azcon-Aguilar, C., Azcon, R., 1989. Mycorrhizae and phosphate interactions as affecting plant development, N<sub>2</sub> fixation, N-transfer and N-uptake from soil in legume grass mixtures by using a 15 N dilution technique. *Soil Biol. Biochem.*, 21, 581–589.
- Barea, J.M., Azcon-Aguilar, C., Azcon, R., 1991. The role of vesicular–arbuscular mycorrhizae in improving plant N acquisition from soil as assessed with 15 N. In: Flitton, C. (Ed.), *The Use of Stable Isotopes in Plant Nutrition, Soil Fertility and Environmental Studies*. Joint IAEA FAO Division, Vienna, pp. 209–216.

- Bellamy, K.L., Chong, C., Cline, R.A., 1995. Paper sludge utilization in agriculture and container nursery culture. *J. Environ. Qual.*, 24, 1074–1082.
- Bhumbla, D.K., Sekhon, B.S., Sajwan, K.S., 2001. Trace elements bioavailability in mine soils treated with sewage sludge and fly ash mixtures, pp. 368–378. *Biogeochemistry of Trace Elements. ICOBTE 2001 Conference Proceedings, July 29–August 2, Guelph, Ontario, Canada, University of Guelph, Guelph*, p. 669.
- Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Dark, F.E. (Eds), 1965. *Methods of Soil Analysis. Chemical and Microbiological Properties. Agronomy 9, Part 2. ASA, Madison, WI*, pp. 1460–1466.
- Cole, M.A., Elkan, G.H., 1973. Transmissible resistance to Penicillin G, Neomycin and Chloramphenicol in *Rhizobium japonicum*. *Antimicrob. Agents Chemother.*, 4, 248–253.
- Correia, C., Guerrero, J., Carrascode Brito, 1995. Reuse of industrial orange waste as organic fertilizers. *Bioresour. Technol.*, 53, 43–51.
- Coutts, M.P., 1982. Growth of sitka spruce seedlings with roots divided between soils of unequal matrix potential. *New Phytol.*, 92, 49–901.
- Dadhwal, K.S., Singh, B., Narain, P., 1995. Effect of limestone mine spoil and soil mix on growth, biomass production and mineral composition of root, shoot and leaves of some tree species. *For. Improv.*, 147–160.
- Daft, M.J., Nicolson, T.H., 1974. Arbuscular mycorrhizas in plants colonising coal wastes in Scotland. *New Phytol.*, 73, 1129–1138.
- Danker, R.M., Adriano, D.C., Koo, B.-J., Barton, C.D., Punshon, T., 2003. Soil amendments promote vegetation establishment and control acidity in coal combustion waste, pp. 319–334. In: Sajwan, R.S., Alva, A.K., Keefer, R.F. (Eds), *Chemistry of Trace Elements in Fly Ash*, Kluwer, New York, p. 346.
- Desmukh, A.M. (Ed.), 1998. *Biofertilizers and Biopesticides. Vedams, New Delhi*, p. 228.
- Ellewood, D.C., Hedger, J.N., Luthan, M.J., Lyrich, T.M., Slater, J.H. (Eds), 1980. *Contemporary Microbial Ecology*, Academic Press, New York, pp. 215–237.
- FAO, 1998. *FAO Yearbook. Production 1997*, FAO, Rome.
- FAO, 2001a. *FAO Yearbook. Forest Products 1999*, FAO, Rome.
- FAO, 2001b. *FAO Yearbook. Production 1999*, FAO, Rome.
- FAO Statistical Databases, 2001c. Available at <http://www.fao.org>.
- Feagley, S.F., Valdez, M.S., Hundall, W.H., 1994. Paper mill sludge, phosphorus, potassium and lime effects on clover grown on a mining spoil. *J. Environ. Qual.*, 23, 759–765.
- Gale, J.J., 1999. Coal and energy for the XXI Century in India, pp. 307–315. In: Singh, T.N., Gupta, M.L. (Eds), *Clean Coal. Proceedings of the International Symposium on Clean Coal Initiatives, New Delhi, India, 1999*, Oxford & IBH Publishing Co., New Delhi, Calcutta, p. 790.
- Gerdman, J.W., Nicolson, T.H., 1963. Spores of *Mycorrhizal endogene* sp. extracted from soil by wet sieving and decanting. *Trans. Br. Mycol. Soc.*, 46, 235–244.
- Gildon, A., Tinker, P.B., 1981. A heavy metal tolerant strain of a mycorrhizae fungus. *Trans. Br. Mycol. Soc.*, 77, 648–649.
- Harley, J.L., Smith, S.E., 1983. *Mycorrhizal Symbiosis*. Academic Press, New York, p. 483.
- Indian Bureau of Mines, 1995. In: Controller-General, Indian Bureau of Mines, Nagpur (Ed.), *Indian Mineral Industry/1993–94/at a Glance*. IBM Press, Nagpur.
- Kooper, K.F., Sabey, B.R., 1986. Sewage sludge as a coal mining spoil amendment for revegetation in Colorado. *J. Environ. Qual.*, 15, 44–48.
- Lambert, D.H., Cole, H., Jr., 1979. Effects of mycorrhizae on establishment and performances of forage species in mining spoil. *Agron. J.*, 72, 257–260.
- Li, X.L., George, E., Marschner, H., 1991. Extension of the phosphorus depletion zone in VA mycorrhizal white clover in a calcareous soil. *Plant Soil*, 136, 41–48.
- Marx, D.H., Cordell, C.P., Kenney, D.S., Mexal, J.G., Artman, J.D., Riffle, J.W., Molina, R.J., 1984. Commercial vegetation inoculum of *Pisolithus tinctus* and inoculation techniques for development of ectomycorrhizal on bare-root tree seedlings. *Monograph 25. Forest Sci.*, 30 (3), 1–5.
- Matcalf, B., 1984. The use of consolidated sewage sludge as soil substitute in colliery spoil reclamation. *Water Pollut. Control*, 83, 288–297.
- Miller, R.M., Jastrow, J.D., 1992. The role of mycorrhizal fungi in soil conservation. *Am. Soc. Agron. Spec. Publ.*, 54, 29–44.
- Molsara, M.R., Bhattacharya, P., Srivastava, B., 1995. *Biofertilizer Technology. Marketing and Usage. Fertilizer Development and Consultation Organisation, New Delhi, India*.

- Nikhil, K., 1999. A field experience with bio-reclamation of coal overburden dumps, pp. 657–667. In: Singh, T.N., Gupta, M.L. (Eds), *Clean Coal. Proceedings of the International Symposium on Clean Coal Initiatives*, January 1999, New Delhi, India, Oxford & IBH Publishing Co., New Delhi, Calcutta, p. 790.
- Page, A.L., Miller, R.H., Keeney, D.R. (Eds), 1982. *Method of Soil Analysis, Part 2, Chemical and Microbiological Properties*. Agronomy 9, Part 2. ASA, SSSA, Madison, WI.
- Parkinson, D., 1979. Microbes, mycorrhizae and mines spoil. In: Wali, M.K. (Ed.), *Ecology and Coal Resource Development*, Pergamon Press, New York, pp. 634–642.
- Parkinson, D., Visser, S., Danielson, R.M., Zak, J., 1980. Restoration of fungal activity in tailing sand (oil sands). In: Dindal, D.L. (Ed.), *Soil Biology as Related to Land Use Practices. Proceedings of the VII International Colloquium of Soil Zoology*, Office of Pesticide and Toxic Substances EPA, Washington, DC, pp. 362–370.
- Pietz, R.I., Jr., Carlson, C.R., Peterson, I.R., Zenze, D.R., Lue-Hing, C., 1989. Application of sewage sludge and other amendments to coal refuse material. II. Effects on revegetation. *J. Environ. Qual.*, 18, 169–185.
- Prasad, B., Bose, J.M., Dube, A.K., 2000. Present situation of fly ash disposal and utilization in India: an appraisal. *Indo-Polish Workshop on Fly Ash Management*, Calcutta, February 2000, RRL-CSIR, Bhubaneswar, pp. 7.1–7.10.
- Rhodes, L.H., Gerdemann, J.W., 1975. Phosphate uptake zones of mycorrhizal and nonmycorrhizal onions. *New Phytol.*, 75, 555–561.
- Schaffer, W.M., Nielsen, G.A., Nettleton, W.D., 1980. Mine soil genesis and morphology in a spoil chronosequence in Montana. *Soil Sci. Soc. Am.*, 44, 802–807.
- Schramm, J.R., 1966. Plant colonization studies on black wastes from anthracite mining in Pennsylvania. *Trans. Am. Philos. Soc.*, 56, 1–194.
- Sharma, A.K., 2002. *Biofertilizers: For Sustainable Agriculture*, Agrobios, Jodhpur, p. 407.
- Singh, J.S., Singh, K.P., Jha, A.K., 1995. *An Integrated Ecological Study on Revegetation of Mine Spoil*, Banaras Hindu University, Dept. of Botany, Varanasi (unpublished).
- Sloan, J.J., Cawthon, D., 2003. Mine soil remediation using coal ash and compost mixtures, pp. 309–318. In: Sajwan, R.S., Alva, A.K., Keefer, R.F. (Eds), *Chemistry of Trace Elements in Fly Ash*. Kluwer, New York, p. 346.
- Stotzky, G., 1960. A simple method for the determination of the respiratory quotient of the soil. *Can. J. Microbiol.*, 6, 439–452.
- Stroo, H.F., Jencks, R.M., 1982. Enzyme activity and respiration of mining spoil. *Soil Sci. Soc. Am. J.*, 46, 548–553.
- Tate, R.L., III, Kerin, D.A. (Eds), 1985. *Soil Reclamation Processes: Microbiological Analysis and Applications*. Marcel Dekker, New York, p. 209.
- United Nations, 1991. *Environmental Aspects of Selected Non-ferrous Metals Ore Mining*. Technical Report. Series No. 5, United Nations Environment Programme/Industry 8 Environment Activity Centre, UNEP, Paris, p. 116.
- United Nations, 1992, 1998, 2000. *Monthly Bulletin of Statistics No. 8/92, 3/98, 10–11/2000*, UN, New York.
- United Nations, 2000. *Annual Bulletin of Steel Statistics for Europe, America and Asia*, UN, New York, Geneva, Vol. XXVI 1996–1999.
- Vanluik, A., Harrison, W., 1982. *Reclamation of Abandoned Mined Lands Along the Illinois Water Ways Using Dredged Material*. ANL/ES-12, Argonne Nat. Lab., Argonne, IL.
- Verma, A., 1995. Arbuscular mycorrhizal fungi: the state of art. *Crit. Rev. Biotechnol.*, 15 (3/4), 179–199.
- Wali, M.K. (Ed.), 1979. *Ecology and Coal Resource Development*. Pergamon Press, New York.
- Williamson, N.A., Johnson, M.S., Bradshaw, A.D., 1982. *Mining Waste Rehabilitation: The Establishment of Vegetation on Metal Mine Waste*. Mining Journal Books, London, p. 103.
- World Coal Institute, 2000. *Key coal statistics for 2000*. Ecoal, 40, 8–10.
- Yuncong, L., Zhang, M., Stoffella, P., Bryan, H., He, Z., 2001. Influence of fly ash compost application on distribution of metals in soil, water and plant, pp. 374–374. *Biogeochemistry of Trace Elements. ICOBTE 2001 Conference Proceedings*, July 29–August 2, Guelph, Ontario, Canada, University of Guelph, Guelph, p. 669–674.
- Zak, J.C., Parkinson, D., 1982. Initial VA mycorrhizal development of slender wheatgrass on two amended mining spoils. *Can. J. Bot.*, 60, 2241–2248.