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ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI IN SUSTAINABLE DEVELOPMENT AND MINE WASTE LAND MANAGEMENT

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Mining and its impact on environment

Mining is one of the most common activities of ancient and modern world. Mining is regarded as the second largest industry after agriculture and has played a vital role in the development of civilization from ancient days. Most valuable materials for man such as metals, chemicals, fuels for energy, rocks and stones for building comes from mining (Trivedy, 1990). Land surfaces are inevitably disturbed in seeking to win ores from the earth. Mechanization and improved technology has brought increasingly large tracts of land into state of disturbance. With increasing demands, land has been constantly exploited for raw materials from the natural environment.

Land is not a resource, which automatically renews itself like rainfall or sunlight. It is a finite resource, being diminished by the spread of industry and urbanization (Colman, 1979). The excavation of iron ore exposes large chunks of earth's crust to the atmosphere that intrude upon the landscape. The mining operation is such that two classes of waste are produced *viz.*, piles of surface overburden waste rock and lean ore, which constitute the reject dumps and the fine grained waste resulting from the ore beneficiation process and deposited in large man made basins called tailing ponds.

The most common hazards of open cast mining of iron ore have been the defacing of landform by development of depression and elevation or sloppy terrain. It also leads to large-scale deforestation, destruction of wild life and natural resources resulting in a fragile ecosystem lacking in flora and fauna. In the process of mining the topsoil is removed, leaving bare rock, thereby making it hard for vegetation to become re-established. Normally, natural processes would gradually recolonise the mine sites and spoils heaps building up the soil and reclothing the landscape in vegetation. However this can take a long time. Meanwhile, the unprotected surface is subjected to erosion leading to the clogging rivers and lakes with silt.

Thus, mining activity is an unavoidable destructive process. Though, there are problems of mine wastes in terms of erosion, environmental pollution, damage to adjoining agricultural fields, forests *etc.*, which many a time they are exaggerated. These hazards are within measurable limits and can be easily be ameliorated to a significant extent by extensive research and proper planning. The common approach towards stabilization *i.e.* establishment of a permanent cover of vegetation involves not merely growing plants. But it necessitates bringing into a plant community that will maintain itself indefinitely without further attention or artificial aid such as irrigation. Such a performance could be achieved most advantageously, by selecting species adapted to growth, spread and reproduction under the severe conditions provided both by the nature of the dump materials and the exposed situation on the dump surface above the level of surrounding terrain. Hence, it is obvious that one must look for useful treatments and management strategy so that useful vegetation can be established quickly and economically leading to a self-sustaining ecosystem.

Characteristics of Mine Wastes

For reclamation of any degraded are, knowledge of physico-chemical parameters of degraded and un-degraded area in the locality is essential. However, the exact assessment of these parameters over the entire area is not easy, as the constitution of the soil varies even at the close proximity of the sampling sites due to the random dumping of the topsoil overburden, rock waste and due to interaction of various factors.

Some selected physical and chemical properties of iron ore mine rejects are depicted in **Table 1**. Soil texture is used extensively as a guide to evaluate soil water storage, water availability, surface erosion, land stability and chemical properties (Shetron and Trettin, 1984). Natural soil consists of an inorganic framework of sand, silt and clay particles, intimately mixed with organic material. It is seen that the rejects contain high clay content, which is known to give undesirable compactness. This results in reduction of moisture infiltration and poor plant growth. This undesirable assemblage of materials often renders the spoils liable to water and wind erosion. Cation exchange capacity (CEC) is important as it is a measure of total exchangeable cations (Ca, Mg, K & Na) in soil materials (Black, 1968). Low water holding capacity of the rejects and tailings can be attributed to the poor soil texture, structure and organic matter content which are known to be responsible for improving water-holding capacity.

Table 1: Some properties of iron ore mine rejects (Rodrigues, 1997).

Properties	Mean (S.D.)
Soil texture	
Sand %	44.3
Silt %	19.3
Clay %	33.9
pH	6.02 (0.18)
EC (mS /cm)	0.051 (0.012)
Total N	93.2* (N.A)
Available N	3.8* (N.A.)
P	1.5 (N.A.)
SO_4^{-2}	<0.1 (N.A.)
Ca	1.76 (0.80)
Mg	0.92 (0.55)
K	0.76 (0.26)
Na	2.60 (0.54)
Cu	<0.05 (N.A.)
Fe	<0.01 (N.A.)

Concentrations in $\mu g.g^{-1}$ oven dry spoil.
N.A. = Not applicable. S.D. = Standard deviation.
EC = Electrical conductivity. * = Mean of two replicates taken from bulked samples.

The physical analysis of iron ore wastes reveals that the tailings and rejects have high bulk and particle density, which is normally the characteristic feature of metalliferous mine waste (Rodrigues and Bukhari, 1996 & 1997). The bulk densities of natural soils fall within the range of 1.0 – 1.5g cm^{-3} (Williamson *et al.*, 1982) and particle density 2.63g cm^{-3} (Waddington, 1969). Bulk density is a useful measure of compaction to root penetration. Surface accumulation of fines in slim dams may give a bulk density as high as 7.5 g cm^{-3} with low infiltration (Ruschena *et al.*, 1974).

The pH values indicated that the rejects were neither highly acidic nor alkaline and would therefore pose no problems for plant growth. Maclean and Dekker (1976) studied the pH of different wastes and reported large variations in acidity among different sites ranging from pH 1.5 to above 10. Varying soil pH changes the concentration of many nutrients and toxic ions in soil solutions as well as the concentrations of hydrogen ions (Russell, 1973). In solutions of acid soils, there are often higher concentrations of aluminium and manganese, and lower concentrations of calcium, magnesium and molybdenum as compared to that in alkaline soils (Porter *et al.*, 1987). Shetron (1983) reported that in iron ore tailings the organic matter and nitrogen are essentially non-existent, P levels are low; Ca, Mg, K and metal range in availability, having alkaline pH and low cation exchange capacity. Thus the chemical composition of rejects material, which is highly variable even within a particular mining operation, not only depends upon the nature of the original ore but also on the metals extracted, the method of treatment and disposal, climatic conditions and weathering reactions that follow disposal.

Electrical conductivity (EC) was found to be very low indicating no likelihood of salinity problems. All the nutrients were present in very low levels, and lack of N. P. and K would severely limit plant growth. Nutrient deficiencies are widely reported as a major limitation, particularly in terms of a low or a complete lack of organic matter and nitrogen in mining wastes. Smith and Bradshaw (1970) stated that micronutrient deficiencies are frequently encountered in the mine wastes. Wong *et al.*, (1983) showed that the tailings were alkaline, lacking in organic matter and nitrogen, but were rich in metals such a Fe, Zn, Cu, Mn, Mg and Ca.

What are Arbuscular mycorrhizal fungi?

Endomycorrhizae produced by the nonseptate fungi are commonly called as "Arbuscular Mycorrhizal (AM) Fungi". Arbuscular mycorrhizal (AM) fungi, a major component of soil microbial community, forms symbiotic association with the roots of more than 90% of terrestrial plants. Arbuscular mycorrhizal colonization has also been reported in hepatics and hornworts. Fossil records indicate that the AM fungi may have played an important role in the success of early terrestrial plants. Arbuscular mycorrhizal fungi play a very important role in the improvement of plant growth. They are vital for the uptake and accumulation of ions from the soil and their translocation to the hosts because of their high metabolic rate and strategically diffuse distribution in the upper layers.

Presently, the AM fungi are placed in the phylum Glomeromycota, which currently comprises of approximately 150 described species distributed among 10 genera **(Table 2)**. With the exception of genus *Geosiphon*, remaining all are exclusively mycorrhizal.

Table 2: Most recent classification of AM fungi (with *Glomus* subgroups as defined by Schwarzott *et al.*, 2001).

Phylum: Glomeromycota
- **Class: Glomeromycetes**
  - **Order: Glomerales**
    - Family: Glomeraceae
      - Genus: *Glomus* (group A and B)
  - **Order: Diversisporales**
    - Family: Gigasporaceae
      - Genus: *Gigaspora*
        Scutellospora
    - Family: Acaulosporaceae
      - Genus: *Acaulospora*
        Entrophospora
    - Family: Pacisporaceae
      - Genus: *Pacispora*
    - Family: Diversisporaceae
      - Genus: *Diversispora*
        Glomus (group C)
  - **Order: Paraglomales**
    - Family: Paraglomaceae
      - Genus: *Paraglomus*
  - **Order: Archaeosporales**
    - Family: Geosiphonaceae
      - Genus: *Geosiphon*
    - Family: Archaeosporaceae
      - Genus: *Archaeospora*

Stages of development of AM fungi

Arbuscular mycorrhizal fungal spores occur in physiologically inactive stages in soil. The spore germinate grows and multiplies in the presence of actively growing roots of plants. The development of AM fungi in roots can be divided into four stages (Tommerup and Briggs, 1988):

- Spore germination and hyphal growth from infective propagules of AM fungi.

- Growth of hyphae through soil to host roots. The mycelial systems surrounding the roots are dimorphic (Mosse, 1959; Nicolson, 1967).
- Penetration and successful initiation of infection in roots. Hypha penetrates mechanically and enzymatically into cortical cells (Kinden and Brown, 1975). At the point, penetrating hyphae may or may not form appresoria (Abbott, 1982).
- Spread of infection and development of internal hyphal system, arbuscules, which bifurcate inside a cell and bring about nutritional transfer between two symbionts and vesicles, which develop as terminal or intercalary swellings in inter- or intra-cellular hyphae. They are responsible for storage and vegetative reproduction.

Advantages of AM fungi

The main effect of mycorrhizal colonization on plant growth is increased efficiency of water and nutrient uptake mainly phosphorus, by extension of the penetration zone of the roots in the soil (Gray and Gerdemann, 1969; Rhodes and Gerdemann, 1975). The interconnected network of external hyphae acts as an additional catchment and absorbing surface in the soil beyond the depletion zone that would otherwise remain inaccessible.

Arbuscular Mycorrhizal fungi, by virtue of their symbiotic association with roots of virtually all vascular plants, are among the most significant microbes in terrestrial ecosystems. Mycorrhizae are not only more efficient in utilization of available nutrients from the soil but also involved in transfer of nutrients from components of soil minerals and organic residues to solution and in nutrient cycling in an ecosystem.

Besides, direct nutritional advantages, mycorrhizae have also been accredited with other benefits to the host plants such as ability of arbuscular mycorrhizal roots to overcome water stress by stomatal regulation in *Citrus* (Levy and Krukum, 1980). Mycorrhizal inoculation also stimulates rooting (Barrow *et al.*, 1977) growth and transplant survival (Bryan and Kormanik, 1977) of cutting and seedlings raised in sterilized nursery media. It also increases disease resistance by depressing root penetration and larval development of nematodes (Sikora, 1978). In addition to this, mycorrhizal plants have shown to have greater tolerance to toxic heavy metals, to drought, to high soil temperature, to saline soil, to adverse soil pH than the non-mycorrhizal plants (Schenck, 1984). Arbuscular Mycorrhizal fungi also bind soil into semi stable aggregates, thus improving the structure of the soil. Because of these attributes, mycorrhizae are now considered important in the establishment of plants in inhospitable sites like mine wastelands. It is known to increase the uptake of phosphorus, carbon sources and indirectly helps to increase biomass and productivity of the host plants.

Role of AM fungi in recovery of mine wastelands

Degraded mine wastelands can be stabilized by physical means such as, site preparation and overburden placement, soiling and mixing, amending with soil, mulch and fertilizers and selection of suitable plant materials, these techniques are very expensive and often short-lived (Smith and Bradshaw, 1979). The alternative is to cover the mine wastelands with vegetation (Street and Goodman, 1967). Revegetation of any site will occur naturally with time (Bradshaw, 1984) but, because mines are invariably poor in plant nutrients and tend to have physical shortcomings, natural colonization can be extremely slow. The use of expensive inputs is inappropriate for developing countries where there is general reduction to increase mining costs because of limited financial resources. The use of inorganic fertilizers is not advisable as they are derived from non-renewable resources and hence, are expensive and tend to be more expensive every year. Again, their constant use is known to degrade the soil. Hence, there is an urgent need of switching on to bio-fertilizers.

Arbuscular mycorrhizal fungi have been reported to increase the growth of plant by enhancing nutrient uptake through a reduction of the distance that nutrient must diffuse to plant roots (Rhodes and Gerdemann, 1975) by accelerating the rate of nutrient absorption and nutrient concentration at the absorbing surface (Cress *et al.*, 1979) and by chemically modifying the availability of nutrients for uptake by plants through hyphae.

Nicolson (1967) suggested that plant growth in industrial waste could be improved by incorporating AM fungi. Khan (1981) reported similar results for Australian coal spoils, noting that some members of Proteaceae were successful non-mycorrhizal invaders. However, species vary in their degree of dependency on mycorrhizal endophytes. Janos (1980) has explained that during succession, three main types characterize a range of ecological dependency: non-mycotrophs, facultative mycotrophs and obligate mycotrophs. In this case, obligate mycotrophs could fail to become established in sites of vary low inoculum density and may only become established after endophytes have colonized the area. If this is so, then these organisms are determinants of community composition during early succession and they may in part, control the progress of succession (Reeves *et al.*, 1979). Thus, much more investigations are needed to study the endophytic population, which can then be manipulated to enhance the revegetation of disturbed lands.

In a survey conducted at Sanquelim iron ore mines, all the herbaceous plants growing on a 12 year old reject dump showed AM fungal colonization (**Table 3**). In all, a total of 30 species of AM fungi belonging to five Genera were recorded (**Table 4**).

Results on growth responses to various AM fungal treatments in *Artocarpus heterophyllus* Lam. and *Syzigium cumini* (L.) Skeels are summarized in **Table 5** and **Table 6**. Mycorrhizal plants showed distinct variations than the non-mycorrhizal plants for most of the growth parameters. Pre-inoculation with different AM fungal species had varied effects on the shoot and root growth, stem girth, leaf length, leaf area, leaf number, shoot and root fresh and dry weights and phosphorus content.

The increased growth of indigenous flora on mine reject dumps can be obtained by either increasing the population of the suitable AM fungal species and or/ transplanting plants pre-inoculated with suitable species instead of applying inorganic fertilizers and fertilizing the top soil cover. The evidences presented by Khan (1975) in his field studies indicates that introduced AM fungi can become established in competition with the indigenous AM fungi and can improve plant growth. The growth of Maple was increased when the plants, grown in anthracite waste containing bonemeal were colonized with AM endophyte (Daft and Hacskaylo, 1975). Similarly Bagyaraj and Manjunath, (1989) observed increased growth on inoculation with AM fungi in an unsterile Indian soil with low available phosphorus. Daft and Hacskaylo (1976) suggested that symbiotic association can be exploited in revegetation schemes and accelerate the development of a suitable plant community.

Table 3: Degree of root colonization (%) in some naturally occurring herbaceous plant species of iron ore mine wastelands of Goa. (Rodrigues & Bukhari, 1997).

Sr. no.	Plant species	Family	Degree of root colonization (%)	Type of colonization
1.	*Lygodium flexuosum* (L.) Swartz.	Schizaeaceae	72	H A
2.	*Polygala elongata* Klein ex Willd.	Polygalaceae	10	H A
3.	*Impatiens Kleinii* W.& A.	Balsaminaceae	81	H V
4.	*Atylosia scarabaeoides* Benth.	Fabaceae	19	H A V
5.	*Crotalaria pallida* Aiton	Fabaceae	19	H V
6.	*Smithia conferta* Sm.	Fabaceae	79	H V
7.	*Smithia sensitive* Ait.	Fabaceae	89	H V
8.	*Smithia salsuginea* Hance.	Fabaceae	69	H A V
9.	*Cassia tora* L.	Caesalpiniaceae	72	H A V
10.	*Hydrocotyle asiatica* L.	Apiaceae	42	H A V
11.	*Neanotis foetida* Benth. & Hook.	Rubiaceae	79	H V
12.	*Spermacoce hispida* L.	Rubiaceae	37	H V
13.	*Blumea mollis* (D. Don) Merr.	Asteraceae	87	H A
14.	*Parthenium hysterophorus* L.	Asteraceae	81	H V
15.	*Vernonia cinerea* (L.) Less.	Asteraceae	11	H V
16.	*Canscora diffusa* (Vahl.) R.Br.	Gentianaceae	40	H V
17.	*Merremia tridentata* (L.) Hallier f.	Convolvulaceae	96	H A
18.	*Lindernia crustacea* (L.) F.Muell	Scrophulariaceae	90	H A
19.	*Lindernia parviflora* (Roxb.) Haines	Scrophulariaceae	60	H A
20.	*Ramphicarpa longiflora* Benth.	Scrophulariaceae	36	H V
21.	*Striga asiatica* (L.) Kuntze	Scrophulariaceae	93	H V
22.	*Centranthera hispida* R.Br.	Scrophulariaceae	56	H V
23.	*Justicia procumbens* L.	Acanthaceae	23	H A V
24.	*Gomphrena celosioides* C.Martius	Amaranthaceae	62	H A
25.	*Amorphophallus commutatus* Engler	Araceae	74	H V
26.	*Eriocaulon cinereum* Br.	Eriocaulaceae	29	H V
27.	*Eragrostis amabilis* W & A.	Poaceae	29	H V
28.	*Heteropogon contortus* (L.) P. Beauv. ex Roeme & Schultes	Poaceae	30	H A
29.	*Ischaemum semisagittatum* Roxb.	Poaceae	67	H V

Legend: H = Hyphae; A = Arbuscules; V = Vesicles.

Table 4: Diversity of AM species found on iron ore mine reject dumps of Goa. (Unpublished data).

Sr. No.	AM species	Sr. No.	AM species
1.	*Glomus geosporum*	16.	*Glomus deserticola*
2.	*Glomus mosseae*	17.	*Glomus vesiculiferum*
3.	*Glomus fasciculatum*	18.	*Glomus rubiforme*
4.	*Glomus hoi*	19.	*Acaulospora bireticulata*
5.	*Glomus citricola*	20.	*Acaulospora foveata*
6.	*Glomus australe*	21.	*Acaulospora laevis*
7.	*Glomus reticulatum*	22.	*Acaulospora nicolsonii*
8.	*Glomus clarum*	23.	*Acaulospora spinosa*
9.	*Glomus constrictum*	24.	*Acaulospora elegans*
10.	*Glomus caledonium*	25.	*Acaulospora scrobiculata*
11.	*Glomus radiatum*	26.	*Acaulospora mellea*
12.	*Glomus etinucatum*	27.	*Acaulospora morrowiae*
13.	*Glomus albidum*	28.	*Scutellospora gregaria*
14.	*Glomus monosporum*	29.	*Scutellospora gilmorei*
15.	*Glomus microcarpum*	30.	*Gigaspora albida*

Conclusion

"Mine land is a fascinating challenge because the pre existing ecosystems are extinguished". It is challenge to the biologists and engineers to replace them as they were. It is also a challenge to the soil scientists, ecologists and to the agriculturists to reconstruct an ecosystem from nothing at minimal cost.

Mine rejects are not true soils but are derived mostly from crushed bedrock and /or glacial deposits hence they are low in nutrients. In this relation, the role of microorganism in rehabilitation has received little attention than correction of nutritional deficiencies and imbalances, toxicity, moisture deficits and wind erosion.

Research oriented towards revegetation should be given importance to methods of maintaining inoculum level in soil as well as technique for introducing the endophytes. Naturally colonizing plant species should be given preference while considering revegetation strategies. Seedlings of such plant species should be inoculated with AM fungi in nursery stages and than transplanted to the target site. This would enhance plant growth and survival in the inhospitable sites.

Table 5: **Response of various AM fungi on plant growth, biomass, and phosphorus uptake in *Artocarpus heterophyllus* Lam. (Bukhari, 2002).**

Parameter	Treatments				F Stats
	Control	GI	GM	GI+GM	
Stem girth plant^{-1} (cm)	1.48±0.19	1.68±0.18 (13.51)	2.12±0.12 (43.24)	2.03±0.0.27 (37.16)	13.62**
No.of leaves plant^{-1}	6.67±0.52	5.50±1.05 (-17.54)	6.83±1.17 (2.40)	7.17±1.17 (7.50)	3.08*
Leaf length (cm) (3rd leaf from top)	14.33±1.21	14.55±1.44 (1.53)	18.17±2.48 (26.80)	16.43±1.31 (14.65)	6.79**
Leaf area (cm^2) (3rd leaf from top)	86.83±10.85	81.83±15.10 (-5.76)	116.83±17.63 (34.55)	91.07±14.63 (4.88)	6.70**
Shoot length plant^{-1} (cm)	32.00±8.41	33.17±5.53 (3.66)	35.50±3.39 (10.94)	37.17±4.35 (16.16)	NS
Shoot fresh wt. g plant^{-1}	6.42±1.15	7.70±2.70 (19.94)	9.84±2.08 (53.27)	9.32±2.21 (45.17)	3.28*
Shoot dry wt. g plant^{-1}	2.13±0.70	2.72±0.66 (27.70)	3.49±0.67 (63.85)	3.14±0.88 (47.42)	4.39*
Shoot phosphorus μg100g^{-1}dry wt. plant^{-1}	12.12±1.09	14.74±0.26 (21.62)	18.07±1.31 (49.09)	17.30±3.01 (42.74)	14.45**
Root length plant^{-1} (cm)	18.83±3.61	19.17±3.97 (1.81)	21.33±3.50 (13.28)	16.67±3.67 (-11.47)	NS
Root fresh wt. g plant^{-1}	3.46±1.01	4.52±1.28 (30.64)	7.54±1.13 (117.92)	5.17±1.40 (49.42)	14.09**
Root dry wt. g plant^{-1}	0.83±0.302	1.08±0.300 (30.12)	1.61±0.37 (93.98)	1.34±0.42 (61.45)	6.23**
Root phosphorus μg 100mg^{-1} dry wt. plant^{-1}.	12.26±0.95	12.27±0.98 (0.08)	17.10±4.20 (39.48)	13.13±1.59 (7.10)	5.78**
Plant biomass dry wt. g plant^{-1}	2.96±0.320	3.80±0.95 (28.38)	5.10±0.83 (72.30)	4.48±1.27 (51.35)	6.08**

Values are mean of six replicates.
***, **, NS = Significant at P<0.05, P<0.01, not significant.**
± = Standard deviation Values in parenthesis indicates % increase over control.
C= Control; GI= *Glomus intraradices*; GM= *Glomus mosseae*; GI+GM= *Glomus intraradices + Glomus mosseae*.

Table 6: Response of various AM fungi on plant growth, biomass, and phosphorus uptake in *Syzygium cumini* (L.) Skeels (Bukhari, 2002).

Parameter	Treatments				F Stats
	Control	GI	GM	GI+GM	
Stem girth (cm)	0.41±0.04	0.80±0.09 (95.12)	0.87±0.186 (112.20)	0.90±0.06 (119.51)	24.77**
No.of leaves plant^{-1}	9.33±1.63	9.67±1.50 (3.64)	10.50±1.76 (12.54)	10.00±1.26 (7.18)	NS
Leaf length (cm) (3rd leaf from top)	3.50±0.44	4.93±0.69 (40.86)	5.50±1.00 (57.14)	6.00±0.89 (71.43)	11.34**
Leaf area (cm^2) (3rd leaf from top)	4.59±0.94	8.32±1.90 (81.26)	10.17±2.00 (121.57)	9.02±2.09 (96.51)	10.88**
Shoot Length (cm)	12.17±1.47	11.58±1.11 (-4.85)	13.33±1.63 (9.53)	11.17±2.64 (-8.22)	NS
Shoot fresh wt. g plant^{-1}	0.63±0.11	1.15±0.37 (82.54)	1.16±0.458 (84.13)	1.12±0.30 (77.78)	NS 1.000
Shoot dry wt g plant^{-1}	0.16±0.02	0.24±0.11 (50.00)	0.35±0.18 (118.75)	0.24±0.099 (50.00)	NS 2.581
Root length (cm)	8.83±1.33	17.00±2.37 (92.53)	15.17±3.49 (71.80)	19.00±3.033 (115.18)	16.16**
Root fresh wt. g plant^{-1}	0.24±0.09	0.84±0.34 (250.00)	0.75±0.05 (212.5)	0.71±0.240 (195.83)	7.029**
Root dry wt. g plant^{-1}	0.06±0.02	0.18±0.06 (200.00)	0.20±0.05 (233.33)	0.19±0.05 (216.67)	9.540**
Plant biomass dry wt. g plant^{-1}	0.22±0.04	0.42±0.162 (90.91)	0.55±0.23 (150.00)	0.43±0.136 (95.45)	4.462*
Phosphorus μg 100 mg^{-1} dry wt. plant^{-1}	10.71±0.87	13.44±1.65 (25.49)	16.08±1.714 (50.14)	14.55±0.69 (35.85)	17.815**

Values are mean of six replicates.
*, **, NS = Significant at P<0.05, P<0.01, not significant.
± = Standard deviation Values in parenthesis indicates % increase over control.
C= Control; GI= *Glomus intraradices*; GM= *Glomus mosseae*; GI+GM= *Glomus intraradices + Glomus mosseae*.

In addition to this alternative strategies such as reducing the angle of slope of reject dumps through terracing in order to improve water-holding capacity, addition of organic materials like sewage sludge, sea weeds, green manure *etc.*, would help to elevate the soil status and enhance mycorrhization in spoils. Also removal and storage of topsoil for reuse would make reestablishment of vegetation relatively easier as topsoil contains organic matter, plant nutrients, seed propagules and useful microbes. This would also lead to increase the inoculum potential of AM fungi thereby helping in plant growth and survival. Thus mining industry need not lead to degradation of environment if a combination of imagination, care and scientific skill is applied by those who are involved in such programmes.

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