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RECLAMATION OF MINING WASTE THROUGH THE USE OF MYCORRHIZAL FUNGI SELECTING DIFFERENT TREE SPECIES – A REVIEW

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ABSTRACTS:

Mining is vital sector contributes in GDP of the country but causes the destruction of natural ecosystems through removal of soil and vegetation and burial beneath waste disposal sites. Besides many adverse effects of mining, it cannot be stopped but the restoration process of mined areas can be rapid and successful. In India, the restoration of mined land in practice largely considered as ecosystem reconstruction in the re-establishment of the tree species with the capability of the land to capture and retain fundamental resources. This paper reviews the development of conceptions and reclamation approaches in post-mining and the role of mycorrhizal fungi in successful restoration and vegetation development after open-cast mining selecting tree species. AMF is one of very important constituent of plant- soil-microbe system greatly reduced in mine spoil and hence the spoils become inhospitable for a forestation of forest species. Plantation of seedlings inoculated with AMF provides favorable soil conditions not only for selected tree species but also for pioneer ground vegetation occupying on mined overburdens. Four species namely Pongamia pinannata, Dalbergia sissoo, Albizia lebbeck and A. procera and Azadirachta indica emerged as suitable species for mining areas in relation to AMF interaction and trapping of spores. These species also modifies the physico-chemical properties of the soil and allow other species to grow by providing shade and sharing of nutrient and moisture. Despite well known benefits of AMF, in our country the practice of mycorrhizal use is not popular results nearly 40% of seedlings die after one year of planting. The recovery period of vegetation and structure of soil in mining area can be reduced upto many years depending upon the species and AMF improvement.

INTRODUCTION:

The mining and metallurgical sector is vital to the development and economic growth of developing country like India. The products of the sector are not only essential for developmental activities and many industrial processes, but are also often a valuable source of foreign exchange earnings. The geological and metallurgical history of India indicates rich mineral resources. India produces 87 minerals including four fuel minerals, 47 non-metallic minerals, 10 metallic minerals, 4 fuels, 3 atomic and 23 minor minerals. Mining is a major contributor (2'nd) to the national GDP (4%) occupying 36 lakh ha (0.11%) of total land area (329 m ha) and providing employment generation (4 %) for 1.1 million people of the country (GOI, 2011). India's ranked 2nd in chromite and baryte, 3rd in coal and lignite, 4th in Iron ore and 5th in bauxite production the in world (Table -1).

In almost every mineral bearing region, soil mining and land degradation have been inseparably connected. Unfortunately in most regions of earth, the underground geological resources are superimposed by above ground biological resources mainly forests. This is particularly more prominent in India. India recognizes that mining, unless properly regulated, can have adverse environmental and social consequences. Mining is essentially a destructive development activity where ecology suffers at the altar of economy. Hence mining operations necessarily involves deforestation, habitat destruction and biodiversity erosion. The extraction and processing of ores and minerals also lead to widespread environmental pollution. Scientific mining operations accompanied by ecological restoration and regeneration of mined wastelands and judicious use of geological resources, with search for eco-friendly substitutes and alternatives must provide sensational revelation to the impact of mining on human ecosystem (Chauhan, 2010).

Compared to normal soils, mining substrates derived from deep in the earth or wastes produced from the processing of the minerals can present extreme challenges to the colonization by plants and the formation of any kind of self-sustaining ecosystem. The physical and chemical nature of the substrates from mining operations is such that a fundamental basis for restoration, that of establishing vegetation, can be extremely difficult in the absence of top soil. Coarse texture and no organic matter may lead to high bulk densities, extreme compaction, low water infiltration rates and very low levels of macronutrients especially N, P and K with low pH. Physico- chemical parameters and concentration of heavy metals in mined soil exceeds the permissible limit and high pollution potential due to mining activities (Ashraf et al. 2010). These constraints on plant growth have been reviewed extensively (Tordoff et al. 2000). Mining substrates do vary considerably in their physical and chemical nature, but they are likely to inhibit natural colonization by most plant species for many years. In this context, ecological restoration of mined land represents the best approach to promote both sustainability and the maintenance of biodiversity.

NATURAL RECOVERY:

Succession models are used to predict how restoration projects will achieve the defined goals. The most common goal of mining-land reclamation is an ecosystem that will achieve structures and functions similar to those of the native ecosystem (Parker, 1997). A common way to make such an evaluation is through the comparisons with appropriate native reference areas. The society for Ecological Restoration International provides a list of nine ecosystem attributes providing a guideline for measuring restoration success: (1) similar diversity and community structure in comparison with reference sites (2) presence of indigenous species (3) functional groups necessary for long-term stability (4) capacity of the physical environment to sustain viable populations (5) regular functioning (6) integration with the landscape (7) elimination of potential threats (8) resilience to natural disturbances and (9) self-sustainability. Ruiz-Jaen and Aide (2005) summarize that most studies have included one or more measures in each of three general categories of ecosystem attributes: diversity, vegetation structure, and ecological processes. Changes in species composition, participation of life forms and species diversity are usually expressed. At its simplest, ecological restoration may equate with primary succession for the recovery (Cairns 1991) of mined land when it is left to natural processes after disturbance. The presence of populations of plant species in a particular site will depend on the ability of propagules to be transported to the site and to germinate and of the young plants to survive and reproduce. The time scales involved are often long and the initial colonization phase, in particular, can show a considerable lag depending on the harshness of the site and substrate conditions (Ash et al. 1994). The complete recovery of the site may take 20 to 50 years depending on the soil factors influencing natural plant colonization include pH, nutrient levels, the amount of organic matter and the presence of mycorrhizal fungi (Hetrick et al. 1994, Chandra, 2014). Mine spoils present very rigorous conditions for both plant and microbial growth because of either coarse texture or compacted structure (Dutta and Agrawal 2000). Natural plant succession is very slow on coal mine spoil. The raising of plantations may accelerate this process leading to a self sustained ecosystem in a relatively short period of time. Plantations impart a favourable role in the biological reclamation of mine spoil due to modification of the soil characteristics.

ROLE OF TOP SOIL IN RESTORATION PRACTICE :

Extraction of subsurface materials to access mineral seams is a consequence of open cut mining. These subsurface materials called overburden require rehabilitation and restoration. Re-establishing native plants directly into subsurface materials is rarely successful due to lack of top soil (Roe 1997). Topsoil has a number of important attributes: organic matter and organic carbon contribute to good structure, enabling penetration by plant roots, minerals are available for plant growth, soil microbes and saprotrophic fungi contribute to nutrient cycling and arbuscular mycorrhizal fungi support diverse plant communities (Van der

Heiden 2002). Ideally when rehabilitating spoil, fresh or stored topsoil from the A horizon should be used to cap these subsurface materials. Aggregation in topsoil arises as a consequence of the combined effect of fine roots, hyphae of mycorrhizal fungi and microbial mucilages that interact with the physical and chemical properties of soil in a hierarchical manner (Tisdall 1994). Mine spoil clearly requires initial addition of organic matter if formation of a "capping topsoil" suitable to support native plant growth is the goal of restoration. Planting alone in mine spoil frequently fails to provide satisfactory vegetation (Carter and Ungar 2002). Addition of mycorrhizal plants alone did not improve as much to the establishment of a capping topsoil nor did the addition of compost without plants. The development of realistic microbially complex capping topsoil clearly requires addition of organic matter, plants and their attendant AM fungi.

BENEFITS OF MYCORRHIZAL FUNGI :

AMF plays an important role in the establishment of vegetation cover and initiation of nutrient cycling for the development of self-sustaining ecosystem in overburden (Mukhopadhyay and Maiti, 2008). Mycorrhizae benefit the vegetation by increasing a plant's ability to survive in a nutrient poor and water deficient environment. In undisturbed ecosystems, mycorrhizal relationships occur naturally. Mined sites, however, are chemically, physically, and biologically altered and often lack the necessary quantity of mycorrhizal fungi to sustain a tolerant plant community. There are five types of mycorrhizae are recognized – ectomycorrhizae (ECM), Arbuscular mycorrhizae (AM), and three others that are species restricted (Ericoid, Orchid, and ect-endomycorrhizae) (Norland 1993). ECM is common to woody plants and characterized by a sheath of hyphae that surround the plant root. AM penetrates the cell walls of the plant and forms arbuscules and vesicles within the roots. AM is host obligate, while ectomycorrhizae can exist without a plant host, but needs one to complete its life cycle. Both ECM and AM can be found on mined sites, but AM species have been found to colonize mine wastes more than ECM (Danielson 1985).

Mycorrhizal fungi act as providers and protectors for plants which increases nutrients intake in plant (Daft and Hacskaylo 1976). Higher concentrations of metals which can be harmful to plants on mined sites be filtered to tolerable amounts by the fungi for the plant (Norland 1993). Increasing plant hormones and acting as a barrier to plant pathogens are other benefits to the plant provided by mycorrhizae (Fuge 1986). Mycorrhizae can also alleviate the stress of higher surface temperatures and acidity that mined sites may have (Danielson 1985). Not only can mycorrhizae improve plant growth, but provide some resistance to drought and salinity as well (Duvert et al. 1990).

INOCULATION METHODS:

Several factors should be considered before applying any type of inoculums. First, effectiveness of inoculation form is usually dependent on fungal species, climate, and ecosystem. Second, a particular fungus may not necessarily do as well with a host in different environmental conditions or with the same host under varied environmental conditions. Inocula sources should be given strong considerations. Inocula from old mine spoils with established vegetation and from neighboring undisturbed sites are valuable sources (Helm and Carling 1990). There are practical difficulties of storage, reactivation and applications on a large scale inocula (Mosse 1981). The most successful inoculation is when applied in the root zone of actively growing plants without heavy fertilization (Norland 1993).

Mycorrhizal inoculum comes in four forms for application – infested soil, infected plant roots, pure cultures of fungi, and spores. Soil inoculum is the most widely used natural inoculum (Marx and Kenny 1982). An advantage of using soil inoculum is that it could contain nitrogen fixing bacteria and also consists of spores, roots and hyphae that all may be able to colonize seedlings (Helm and Carling 1990). Disadvantages are that the species within the soil cannot be controlled, there is no guarantee the desired fungi are contained in the soil, and the actual transportation of large loads of soil is difficult and costly (Marx and Kenny 1982).

The first successful use of root pieces to inoculate seedlings was in 1958 by Peuss. Root pieces tend to be lighter than blended pot culture material, colonize more rapidly than spores, and contain intraradical vesicles that have been found to be viable after two years of cold storage in pot cultures (Biermann 1983).

Spores as inoculums date back to the eighteenth century (Marx and Kenny 1982). Spores do not require an extended growth phase and are lightweight and can be collected and stored for years. Disadvantage is that it may also take 3 to 4 weeks longer than vegetative inoculum to germinate and infect a root. Other disadvantages include a possible insufficient availability of sporophores every year and lack of genetic definition of the spores (Norland 1993).

The use of mycorrhizal propagules has been proposed as a cost efficient long term technique to establish vegetation on mined land. Repeated application of fertilizer is expensive and may not reestablish plant communities that are self-sustaining (Helm and Carling 1990). Mycorrhizal inoculum used in conjunction with other techniques could improve reclamation success. Duel infections of bacterium and a mycorrhizal fungus resulted in increased vegetative success in coal wastes sites in Pennsylvania (Daft and Hacskaylo 1976). Mycorrhizae are an essential piece to reclamation success on mined lands.

VEGETATION ANALYSIS:

The species composition of the communities within reclaimed mine overburden is strongly influenced by age. It varies according to the wood species chosen for reclamation. Currently, an understanding of the self regulating abilities of ecosystems and of the limiting ecological parameters of the planting woods are basic requirements for successful forest reclamation campaigns on all types of anthropogenic soils (Vanek et al., 1998). The range of species used today corresponds closely with the pedological conditions and with climatic zoning and also with the particular phytogeographic region. In India Dalbergia sissoo, Dendrocalamus strictus, Albizia procera, A. lebbeck, Pongamia pinnata, Azadirachta indica, Pinus spp, Acacia auriculiformis, Eucalyptus spp, Prosopis juliflora, Cassia seamea are frequently planted out mostly on extreme sites. Seedlings of individual species or groups of species are planted out densely into small separated depressions and regular rows. Mycorrhizal fungi support the development of root systems and intake of water and nutrients which increase the viability of plants and their resistance to diseases (Kernaghan et al., 2002). Mycorrhizal colonization varies widely among the different tree species growing in reclaimed mine soils which indicates that during the selection of tree species importance of mycorrhizal colonization should be considered. The host plants having higher-root infections are suitable for the biological reclamation of mining wastes (Mukhopadhyay and Maiti, 2010). Out of 10 tree species, three species, namely Cassia seamea, Gmelina arborea and Acacia auriculiformis constituted approximately 70% of the tree population (**Table 3**). Some accidental tree species like F. retusa and F. relegiosa are also noticed in few areas. Plant possessing high level of AMF infection (75-95%) includes D. sissoo, C. seamea and A. auriculiformis. L. leucocephala, T. arjuna and D. strictus possessed moderate level of AMF colonization (50-75%). With this rationale, four species (Pongamia, Dalbergia, Albizia and Azadirachta) have emerged as having the highest frequency of reporting in relevant agro- and socio-economical properties along with notably similar environmental outcomes regarding their impact toward above- and belowground ecological factors. These characteristics include that the members of the Fabaceae are promoters of nitrogen fixing interactions, while other are relatively fast growers, well adapted to environmental conditions within more adverse condition viz. intense heat, sunlight and have root architectural adaptations for drought tolerance (Lowry et al. 1994; Scott et al. 2008). In another study, physical characteristics of soil are maximally improved by E. hybrid,A. auriculiformis and C. equisetifolia (Dutta and Agrawal, 2002). This clearly indicates that the plantations on mine spoil modify the soil physicochemical characteristics up to several folds, but the plant species differed in their ability to modify the same. The plantations of different species have maintained the nutrient regeneration due to addition of organic matter and its further decomposition. Increasing availability of organic matter also enhanced N – mineralization, and hence the supply of plant available nutrients. The enhancement in plant available nitrogen due to plantations will be further helpful in soil-nutrient cycling. The study further suggests that E. hybrid, A. auriculiformis and C. equisetifolia have maximum favourable impact on modifying physical, chemical and biological properties of mine spoil (Table – 2). Thus identifying efficient mycorrhizal tree species for the dump reclamation should given more emphasis, where available nutrients and moisture contents are always limiting.

GROUND VEGETATION ANALYSIS:

In general Mean vegetation cover increases continuously with age of the overburden; however the succession process takes long time for complete recovery to its pre-mining level. In a study conducted by Jamaluddin and Chandra (2009) reported 29 ground flora within five year of biological restoration included 20 herb and 9 shrub species dominated by Ziziphus jujube and Lantana camera whereas 25 species were recorded from the forest area dominated by Cynodon dactylon, Calotropis procera, Ulna lobata and Parthenium species. This indicates rich biodiversity of mined soil than adjacent forest soil. But actually there was a difference in species composition and species dominance. The structure of the above-ground vegetation changes progressively from annual weeds, through temporal herbs to perennial plants, including bush and "climax" tree species (Zeleny and Ondracek, 2000) and soil microbial life also changes. Kumar et al. (2010) and also confirmed the presence of leguminous species in reclaimed sites advocated as a good sign to favor N_2 fixation and help in faster recovery of plant community with increased survival rate. Preponderance of Poaceae species also reported by several workers in mine dumps (Titus and Moral, 1998, Hanief et al. 2007). Jamaluddin and Chandra (2009) has reported almost equivalent diversity and richness of mined vegetation to the area without disturbance but observed variation in the dominance and species occurrence in different overburden and natural site. Similarly Korb et al. (2003), Mukhopadhyay and Maiti (2010) also reported the recovery period of vegetation in mining area between 4 to 20 years depending upon the species interaction to AM and improvement in nutrient status of soil. The variability of the succession processes on anthropogenic sites is very high and it is necessary to specify restoration programs that are consistent with the ecological characteristics of particular habitats. The afforestated tree species plays an important role in the catching and trapping of infective propagules of AMF fungi (Singh and Jamaluddin, 2006) which are further used by ground flora in the process of succession. The recovery of vegetational diversity and microbial population can be restored successfully by choosing suitable tree species.

TABLE 1:- INDIA'S CONTRIBUTION IN MINERAL PRODUCTION 2011-12.

Mineral	Unit	Production		Contribution (%)	India's rank in World
		World	India		
Chromite	000T	18,700	3413	18.20	2nd
Baryte	000T	7,100	2,138	30.10	2nd
Coal & Lignite	MT	6,938	566	8.20	3rd
Iron Ore	MT	2,248	219	9.70	4th
Manganese Ore	MT	33.40	2.44	7.30	5th
Bauxite	MT	199	139.52	7.0	6th

Source- Annual report 2011-12, Ministry of Mines, GOI

TABLE 2:- PHYSICAL PROPERTIES OF SOIL AROUND DIFFERENT PLANT SPECIES PLANTED ON COAL MINE SPOIL AND ON THE FRESH MINE SPOIL (MEAN ± 1 SE).

Parameters	Fresh mine spoil	A. auriculiformis	C. Equisetifolia	C. siamia	E. hybrid	G. pteridifolia
Sand (%)	89.30 ± 2.27	83.95 ± 2.86	84.95 ± 2.00	83.31 ± 4.40	81.41 ± 3.20	82.58 ± 4.28
Silt	8.20 ± 0.22	12.60 ± 0.26	12.35 ± 0.17	13.40 ± 0.20	13.60 ± 0.21	13.00 ± 0.05
Clay	2.50 ± 0.01	3.45 ± 0.01	2.70 ± 0.02	3.29 ± 0.04	5.02 ± 0.07	4.42 ± 0.02
Bulk density g/cm^2	1.45 ± 0.03	1.62 ± 0.04	1.63 ± 0.02	1.61 ± 0.02	1.61 ± 0.04	1.58 ± 0.04
Moisture %	6.83 ± 0.10	7.42 ± 0.14	8.26 ± 0.09	7.52 ± 0.02	8.95 ± 0.04	7.95 ± 0.08
Porosity	45.20 ± 1.20	38.86 ± 2.00	38.49 ± 2.10	39.24 ± 2.00	39.26 ± 1.90	40.34 ± 1.70
WHC %	25.00 ± 1.24	27.98 ± 1.25	30.68 ± 2.10	28.66 ± 2.11	35.01 ± 1.75	30.73 ± 1.33
Ph	6.40 ± 0.04	6.86 ± 0.07	6.61 ± 0.04	6.86 ± 0.07	6.71 ± 0.06	6.85 ± 0.08
Organic C (%)	0.46 ± 0.02	0.60 ± 0.03	0.58 ± 0.02	0.47 ± 0.03	0.51 ± 0.01	0.55 ± 0.02
Total N (%)	0.028 ± 0.0002	0.062 ± 0.0003	0.057 ± 0.0012	0.047 ± 0.0005	0.051 ± 0.0008	0.058 ± 0.0014
Total P (%)	0.010 ± 0.0001	0.015 ± 0.0004	0.017 ± 0.0004	0.0098 ± 0.0001	0.011 ± 0.0003	0.014 ± 0.0008
Available P	3.15 ± 0.04	3.60 ± 0.06	4.20 ± 0.06	3.40 ± 0.06	4.00 ± 0.06	4.0 ± 0.06

Source : Dutta and Agrawal (2002)

TABLE 3:- DEVELOPMENT OF AMF FUNGI IN RHIZOSPHERE OF DIFFERENT TREE SPECIES USED FOR RESTORATION OF COAL MINE OVERBURDENS.

Plant Species	Year of Plantations on dumps					
	2 year		3 years		5 Years	
	Root infection (%)	Spore Density (100g soil)	Root infection (%)	Spore Density (100g soil)	Root infection (%)	Spore Density (100g soil)
Acacia auriculiformis	12.53	59	38.83	95	42.35	192
Acacia nilotica	26.18	68	19.00	119	18.47	145
Albizzia procera	16.10	46	18.25	85	18.26	109
Dalbergia sissoo	28.18	85	44.60	149	63.04	272
Dendrocalamus strictus	20.70	80	39.91	115	43.50	201
Eucalyptus hybrid	11.45	39	30.80	180	39.88	238
Gmelina arborea	17.79	60	22.25	107	22.31	103
Peltophorum ferrugineum	14.00	63	24.30	133	61.03	105
CD $P < 0.05$	2.021	6.55	2.902	13.165	3.224	11.190

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