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SOIL RECLAMATION OF ABANDONED MINE LAND BY REVEGETATION: A REVIEW

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ABSTRACT

Mining of mineral resources results in extensive soil damage, altering microbial communities and affecting vegetation leading to destruction of vast amounts of land. Reclamation is the process to restore the ecological integrity of these disturbed mine land areas. It includes the management of all types of physical, chemical and biological disturbances of soils such as soil pH, fertility, microbial community and various soil nutrient cycles that makes the degraded land soil productive. Productivity of soil can be increased by adding various natural amendments such as saw dust, wood residues, sewage sludge, animal manures, as these amendments stimulate the microbial activity which provides the nutrients (N, P) and organic carbon to the soil. The top soil gets seriously damaged during mineral extraction. The consequences of physical disturbance to the top soil during stripping, stockpiling, and reinstatement cause unusually large N transformations and movements with eventually substantial loss. Management of top soil is important for reclamation plan to reduce the N losses and to increase soil nutrients and microbes. Revegetation constitutes the most widely accepted and useful way to reduce erosion and protect soils against degradation during reclamation. Mine restoration efforts have focused on N-fixing species of legumes, grasses, herbs, and trees. Metal tolerant plants can be effective for acidic and heavy metals bearing soils. Reclamation of abandoned mine land is a very complex process. Once the reclamation plan is complete and vegetation has established, the assessment of the reclaimed site is necessary to evaluate the success of reclamation. Evaluation of reclamation success focuses on measuring the occurrence and distribution of soil microflora community which is regulated by interactions between C and nutrient availabilities. Reclamation success also measures the structure and functioning of mycorrhizal symbiosis and various enzymatic activities in soil. This paper includes physical, chemical and biological mine soil properties, their management to make soil productive, top soil management, vegetation of various species and assessment of effectiveness of reclamation.

Keywords: mining, soil, reclamation, revegetation

1. INTRODUCTION

Land is one of the most important resources on which human beings depend. The rate of consumption of mineral resources is continuously increasing with the advancement of science and technology, economic development, industrial expansion, acceleration of

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[§] Corresponding Author: A. S. Sheoran, Department of Mining Engineering, Faculty of Engineering, Jai Narain Vyas University, Jodhpur, India-342011, Email: as_sheoran@yahoo.com urbanization and growth of population. Growth of our society and civilization thus heavily rely upon the mining industry to operate and maintain comfort. The end result for mining activities on the surface is mining wastes and alteration of land forms which is a concern to the society and it is desired that the pristine conditions are restored. Mine wasteland generally comprises the bare stripped area, loose soil piles, waste rock and overburden surfaces, subsided land areas, other degraded land by mining facilities, among which the waste rocks often pose extreme stressful conditions for restoration. The mining disrupts the aesthetics of the landscape along with it disrupts soil components such as soil horizons and structure, soil microbe populations, and nutrient cycles those are crucial for sustaining a healthy ecosystem and hence results in the destruction of existing vegetation and soil profile (Kundu and Ghose, 1997). The overburden dumps include adverse factors such as elevated bioavailability of metals; elevated sand content; lack of moisture; increased compaction; and relatively low organic matter content. Acidic dumps may release salt or contain sulphidic material, which can generate acid-mine-drainage (Ghose, 2005). The effects of mine wastes can be multiple, such as soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Wong, 2003; Sheoran et al., 2008).

It is imperative from the above that the mineral extraction process must ensure return of productivity of the affected land. An increase in the concerns for environment has made concurrent post-mining reclamation of the degraded land as an integral feature of the whole mining spectrum (Ghose, 1989). Conservation and reclamation efforts to ensure continued beneficial use of land resources are essential. Reclamation is the process by which derelict or highly degraded lands are returned to productivity, and by which some measures of biotic function and productivity is restored. Long term mine spoil reclamation requires the establishment of stable nutrient cycles from plant growth and microbial processes (Singh et al., 2002, Lone et al., 2008; Kavamura and Esposito, 2010). Soil provides the foundation for this process, so its composition and density directly affect the future stability of the restored plant community. Restoration of vegetation cover on overburden dumps can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to human beings (Wong, 2003). Reclamation strategies must address soil structure, soil fertility, microbe populations, top soil management and nutrient cycling in order to return the land as closely as possible to its pristine condition and continue as a self-sustaining ecosystem.

Ecological restoration and mine reclamation have become important parts of the sustainable development strategy in many countries. Good planning and environmental management will minimize the impacts of mining on the environment and will help in preserving eco-diversity. This article assesses the deterioration of chemical, physical and biological soil properties due to surface mining and also their management with a purpose to get productive mine soil. The article also assesses effectiveness of soil from mining waste in reclamation of mined degraded land for its sustainable and beneficial use. Discussion on post mining land use forms and control of soil pollution through acid-mine-drainage is beyond the scope of this paper. Readers are encouraged to refer studies presented elsewhere on these subjects, e.g. Sharma et al., (1996) for post mining land use and, Saharan et al., (1995) and Sheoran and Sheoran, (2006) for acid-mine-drainage management issues.

2. SOIL PROPERTIES IMPORTANT FOR PLANT GROWTH

2.1 Chemical Property

2.1.1 Soil pH

Soil pH is a measure of active soil acidity and is the most commonly used indicator of mine soil quality. The pH of a given mine soil can change rapidly as the rock fragments weather and oxidize. Pyritic minerals (FeS_2), when present, oxidized to sulfuric acid and drastically lower the pH, while carbonate ($Ca/MgCO_3$) bearing minerals and rocks tend to increase the pH as they weather and dissolve. Unweathered (or unoxidized) mine soils those contain a significant amount of pyritic-S in excess of their neutralizers (carbonates) will rapidly drop the pH to a range of 2.2 - 3.5 after exposure to water and oxygen. Vegetation achieves optimal growth in soil at a neutral pH. When the soil pH drops below to 5.5, reduced legume and forage growth occur due to metal toxicities such as aluminum or manganese, phosphorus fixation, and reduced population of N-fixing bacteria. This growth hence inhibits plant root growth and many other metabolic processes. A mine soil pH range in the range of 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses (Gitt and Dollhopf, 1991; Gould et al., 1996). Maiti and Ghose, (2005) reported that the pH vary from 4.9 to 5.3 in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area in the Ranchi district of Jharkhand State of India and thus indicated the acidic nature of the dumps. This acidic nature arose due to the geology of the rock presented in the area. It has been reported earlier that at pH less than 5, along with Fe, the bioavailability of toxic metal such as nickel, lead and cadmium also increases (Maiti, 2003).

2.1.2 Soil Fertility

The three major macronutrients, namely nitrogen, phosphorus and potassium are generally found to be deficient in overburden dumps (Coppin and Bradshaw, 1982; Sheoran et al., 2008). All newly created mine soils, and many older ones, will require significant fertilizer element applications for the establishment and maintenance of any plant community. Organic matter is the major source of nutrients such as nitrogen, and available P and K in unfertilized soils (Donahue et al., 1990). A level of organic carbon greater than 0.75% indicates good fertility (Ghosh et al., 1983). The level of organic carbon in overburden was found to be 0.35% to 0.85%. Organic carbon is positively correlated with available N and K and negatively correlated with Fe, Mn, Cu, and Zn (Maiti and Ghose, 2005). Initial applications of fertilizers have shown to increase the specific numbers, plants co-density and growth rates of vegetation.

Some of the important metallic micronutrients that are essential for plant growth are Fe, Mn, Cu, and Zn. These micronutrients are available in the soil due to continuous weathering of minerals mixed with primary minerals. These metals are more soluble in acidic solution, and they dissolve to form toxic concentrations that may actually hinder plant growth (Donahue et al., 1990; Barcelo and Poshenrieder, 2003; Das and Maiti, 2006). Maiti and Ghose, (2005) while working on restoration of acidic coal overburden reported that it is essential to increase the pH and organic matter content for sustainable reclamation of mining overburdens. During investigation it was found that locally available drought resistant, fast-growing trees able to grow in acidic nutrient deficient soils increased the concentration of available Fe in all reclaimed dumps higher than 4.5 mg kg^{-1}, Mn with average value of 13 mg kg^{-1}, 9 to 42 mg kg^{-1} for Zn, 0.32 to 1.22 mg kg^{-1} for Cu. According to Lindsay and Norvell, (1978) if the concentration of micronutrients in the soil was higher than 4.5 mg $kg-^{1}$ for Fe, 1.0 mg kg^{-1} for Mn, 1.0 mg kg^{-1} for Zn and 0.4 mg kg^{-1} for Cu, the values are rated as highly sufficient for ecological sustainable reclamation.

Type of fertilizer and its application rate will vary according to the site, soil type, and post mining land use (Kenny and Bremner, 1966). Care to be taken while preparing fertilizer prescription and applying on the rehabilitated areas. Roots of seedling can be damaged if the fertilizer is placed too close to the plant (Schmidt, 2003; Ghose, 2005).

2.2 Physical Properties

2.2.1 Rock Content

Soil particles those smaller than 2 mm are responsible for majority of water and nutrient holding capacity in the mine soils. Particles larger than 2 mm are referred to as "coarse fragments". Soils constituting high coarse fragments have larger pores that cannot hold enough plant available water against leaching to sustain vigorous growth over the summer months. The coarse fragment contents in a typical mine spoil vary (< 30- > 70%) due to differences in rock hardness, blasting techniques, and spoil handling. Particle size distribution of mine soils is directly inherited from their parent rocks or spoils. The rock content in the surface of a reclaimed bench or outslopes will decrease overtime due to weathering of rock fragments to soil sized particles. Top soil materials, when they can be salvaged, are typically much lower in rock content than spoils and therefore have better water retention characteristics (Nicolau, 2002; Moreno-de las Heras et al., 2008) Hu et al., (1992) are of the opinion that soil with stone content greater than 50% should be rated as poor quality. Stone content of coal mine overburden dumps has been reported to be as high as 80-85% (Maiti and Saxena, 1998). Maiti and Ghose, (2005) reported stone content in overburden dumps in range of 35%-65%, with an average value of 55%.

2.2.2 Soil Texture

Relative amount of sand (2.0 - 0.05 mm), silt (0.05 - 0.002 mm), and clay (< 0.002 mm) sized particles determine the texture of soil. Mine soils with sandy textures cannot hold as much water or nutrients as finer textured soils like loams and silts. The silts are finer textured soils and have a tendency to form surface crusts, often contain high level of soluble salts, and have a poor "tilth" or consistence. The particle size distribution of the soils with loamy textures is generally ideal. Silt loam textures are common where spoils are dominated by siltstones (Ghose, 2005). Ghose, (2005) reported the maximum sand content of 66% and clay only 8.6% in mined soil. Singh et al., (2004) and Singh and Singh, (2006) also reported maximum content of sand (80%) and least content of clay (11%) at the Singrauli Coal field India.

2.2.3 Soil Aggregation

Soil aggregation controls soil hydrology, affect soil diffusion and the degree of nutrient availability to the soil (Lindemann et al., 1984; Heras, 2009), and may reduce erosion potential (Elkins et al., 1984), and constitutes a pathway of organic carbon stabilization and long term sequestration(Six et al., 2004). Aggregate structure breaks down as successive layers of soil are removed and stockpiled elsewhere on the site when mining begins. The resulting compaction reduces water holding capacity and aeration. Macro aggregate stability is largely responsible for macro porosity, which determines soil drainage rate and aeration; it changes seasonally and is often affected by cultivation and cropping regime (Kay, 1990). Micro-aggregate stability is more resilient than macro-aggregate stability as the organic matters responsible for binding the soil particles together reside in pores too small for microorganisms to occupy (Gregorich et al., 1989). Micro-aggregates are less sensitive to cropping practices than macro-aggregates (Dexter, 1988) and are responsible for crumb porosity which controls the amount of available water for vegetation (Davies and Younger, 1994).

2.2.4 Moisture, Bulk Density, Compaction and Available Rooting Depth

Moisture content in a dump is a fluctuating parameter which is influenced by the time of sampling, height of dump, stone content, amount of organic carbon, and the texture and thickness of litter layers on the dump surface (Donahue et al., 1990). During the winter, the average moisture content of 5% was found to be sufficient for the plant growth. During high summer (May-June), moisture content in overburden dumps was reported to be as low as 2-3% (Maiti et al., 2002). Maiti and Ghose, (2005) reported average field moisture content of all the dumps was 5%.

Bulk density of productive natural soils generally ranges from 1.1 to 1.5 g/cm^3. High bulk density limits rooting depth in mine soils. In seven year old overburden dumps, the bulk density was found to be as high as 1.91 Mgm^{-3} (Maiti and Ghose, 2005). Bulk density in the soil under a grass sward in the UK has been found to be as high as 1.8 Mgm-3 (Rimmer and Younger, 1997). Soil compaction directly limits plant growth, as most species are unable to extend roots effectively through high bulk-density mine soils. Severely compacted (bulk density > 1.7 g/cc) mine soils, particularly those with less than two feet of effective rooting depth, shallow intact bedrock and the presence of large boulders in the soil simply cannot hold enough plant-available water to sustain vigorous plant communities through protracted drought. Three to four feet of loose non-compacted soil material is required to hold enough water to sustain plants through prolonged droughts. Compacted zones may also perch water tables during wet weather conditions, causing saturation and anaerobic conditions within the rooting zone. Repeated traffic of wheeled mining machineries (loaders and haulers), and bulldozers to a lesser extent, form compacted zones in the mining dumps.

2.2.5 Slope, Topography and Stability

Mine soils with slopes greater than 15% are generally unsuitable for intensive land uses such as vegetable or crop production, but they may be suitable for grazing and reforestation. Broad flat benches and fills with slopes less that 2% often have seasonal wetness problems. Many benches with an overall gentle slope contain areas of extreme rockiness, pits, hummocks, and ditches. Average slope of most reclaimed modern mines is quite a bit steeper than the older benches, but the newer landforms are considerably smoother and more uniform in final grade. Bench areas directly above intact bedrock on older mined lands are usually fairly stable but may be subject to slumping, especially when near the edge of the out slope. Tension cracks running roughly parallel to the out slope indicate that the area is unstable and likely to slump. Decreased soil stability can lead to increase in bulk density because the matrix does not resist slaking, dispersion by water and the forces imparted by wheels, hooves and rainfall (Daniels, 1999).This, in turn, leads to decreased aeration and water infiltration rate and the development of anaerobic conditions. N losses by denitrification may follow under such environment (Davies and Younger, 1994).

2.2.6 Mine Spoil/Soil Color

Mining activities remove surface earth, piling it over unmined land and forming chains of external dumps i.e. mine spoil/ wasteland. Mine spoils possess very rigorous conditions for both plants and the microorganism culture. Biological functionality along with the nutrient cycle is disturbed leading to a non- functional soil system. This is mainly due to low organic matter contents and other unfavorable physico-chemical and microbiological characteristics (Singh and Singh, 1999; Jha and Singh, 1993; Singh and Singh, 2006). The color of a mine spoils or weathered mine soil can tell us much about its weathering history, chemical properties, and physical make up. Bright red and brown colors in spoils and soils generally indicate that the material has been oxidized and leached to some degree. These materials tend to be lower in pH and free salts, less fertile, low in pyrites, and more susceptible to physical weathering than darker colored materials. Gray colors in rocks, spoils and soils usually indicate a lack of oxidation and leaching and these materials tend to be higher in pH and fertility. Very dark gray and black rocks, spoils, and mine soils contain significant amounts of organic materials and are often quite acidic. Dark colored spoils are also difficult to re-vegetate during the summer months because they absorb a great deal of solar energy and become quite hot (Daniels, 1999). Natural succession process to recover this spoil may take hundreds of years.

2.2.7 Top soil

Top soil is used to cover poor substrate and to provide improved growth conditions for plants. Stockpiling of top soil in mounds during mineral extraction has been shown to affect the biological, chemical and physical properties of soil (Hunter and Currie, 1956; Barkworth and Bateson, 1964; Harris et al., 1989; Johnson et al., 1991; Davies et al., 1995). Top soil is a scarce commodity, and it is never stored in the majority of potential sources. Also, in a tropical climate where 90% of rainfall is precipitated within three months of the rainy season, storing of the top soil and preservation of soil quality remains problematic. Top soil is never stored for reuse; instead it is borrowed from nearby areas for the reclamation of the degraded mined-out areas. At a depth about 1m in the stockpile, the number of anaerobic bacteria increases where as those of aerobic bacteria decreases (Harris et al., 1989). This inhibits nitrification due to poor aeration within the stockpile leading to an accumulation of ammonia in the anaerobic zones. Once the soil is removed from the stockpile and reinstated, aerobic microbial population rapidly re-establishes, usually higher than the normal level (Williamson and Johnson, 1991) and nitrification restarts at higher than the normal rates. If high level of ammonia is present in a reinstated soil, the amount of nitrate generated is likely to be much greater than the normal. Consequently there is high potential for N loss to the environment via leaching or/and denitrification (Johnson and Williamson, 1994). Nitrate leached to water courses is not only a threat to aquatic environment and drinking water supplies (Addiscott et al., 1991) but if nitrogen is lost from soil in the form of gaseous nitrogen or nitrous oxides; this will contribute the degradation of ozone layer (Isermann, 1994; Davies et al., 1995). The period between the initial removal of top soil and final laying of the same over the reclaimed area might have a long time lapse. Hence, properties of stockpiled soil continually deteriorate and ultimately become biologically non-productive if it is not preserved properly (Ghose, 2005).

2.3 Biological Properties

2.3.1 Soil Microbe

Soil microbe populations must be addressed deliberately as another soil component. It plays a major role in aggregate stabilization, which is important for maintaining suitable structural conditions for cultivation and porosity for crop growth (Ghose, 2005). Their activity declines when soil layers are disrupted and is slow to resume independently. Soil microbes include several bacterial species active in decomposition of plant material as well as fungal species whose symbiotic relationship with many plants facilitates uptake of nitrogen and phosphorus in exchange of carbon. They produce polysaccharides that improve soil aggregation and positively affect plant growth (Williamson and Johnson, 1991). Sites with an active soil microbe community exhibit stable soil aggregation, whereas sites with decreased microbial activity have compacted soil and poor aggregation (Edgerton et al., 1995). Microbial activity decreases with depth and time as topsoil continues to be stored during mining operations (Harris et al., 1989). Microbial activity, measured in ATP (adenosine tri phosphatase) concentrations, plummets to very low levels within a few months. Response to glucose is slower by microbes at all depths, suggesting that metabolic rates decrease with time (Visser et al., 1984).

2.3.2 Bacteria

Bacteria play an important role in decomposition of organic materials, especially in the early stages of decomposition when moisture levels are high. In the later stages of decomposition fungi tend to dominate. Rhizobia are single celled bacteria, belongs to family of bacteria Rhizobiacea, form a mutually beneficial association, or symbiosis with legume plants. These bacteria take nitrogen from air (which plant cannot use) and convert it into a form of nitrogen called ammonia (NH_4^+) used by plants (Gil-Sotres et al., 2005). Free living as well as symbiotic plant growth promoting rhizo-bacteria can enhance plant growth directly by providing bioavailable P for plant uptake, fixing N for plant use, sequestering trace elements like iron for plants by siderophores, producing plant hormone like auxins, cytokinins and gibberlins, and lowering of plant ethylene levels (Glick et al., 1999; Khan, 2005).

When soil layers are removed and stockpiled, the bacteria inhabiting the original upper layers end up on the bottom of the pile under compacted soil. A flush of activity occurs in the new upper layer during the first year as bacteria are exposed to atmospheric oxygen. After two years of storage there is little change in the bacterial numbers at the surface, but less than one half the initial populations persist at depths below 50 cm (Williamson and Johnson, 1991).

2.3.3 Mycorrhizal Fungi

Arbuscular mycorrhiza fungi are ubiquitous soil microbe occurring in almost all habitats and climates. The hypha network established by mycorrhizal fungi breaks when soils are initially moved and stockpiled (Gould et al., 1996). It is well documented that mycorrhizal associations are essential for survival and growth of plants and plant uptake of nutrient such as phosphorus and nitrogen, especially P deficient derelict soils (Khan, 2005). An important arbuscular mycorrhiza genus is Glomus, which colonize a variety of host species, including sunflower (Marschner, 1995). Dual inoculation with *Trichoderma koningii* and AM fungi increased plant growth of *Eucalyptus globulus* under heavy metal contamination conditions (Arriagada et al., 2004, 2005).

There is a little decrease in viable mycorrhizal inoculum potential during the first two years of storage (Miller et al., 1985). Viability of mycorrhizas in stored soils decreases considerably and possibly to the levels 1/10 those of the undisturbed soil (Rives et al., 1980). Miller et al., (1985) indicate that soil water potential is a significant factor affecting mycorrhizal viability. When soil water potential is less than -2 MPa (drier soil), mycorrhizal propagules can survive for greater lengths of storage time; when soil water potential is greater than -2 MPa, length of storage time becomes more important. In drier climates, deep stockpiles may not threaten mycorrhizal propagule survival. In wetter climates, shallow stockpiles are more important to maximize surface-to-volume ratios with regard to moisture evaporation.

3. MANAGEMENT OF THE PRODUCTIVE MINE SPOIL

3.1 Rebuilding Soil Structure

The first soil component addressed during reclamation is the structure of the soil itself as it is replaced onto the reclamation site. Soil structure includes soil aggregation, or the way in which soil particles are held together, and the size of the particles comprising the layers at different depths. The degree to which soil is loosely constructed versus compacted can be altered during reclamation by the method of replacement adopted (Visser et al., 1984). Using a tyre mounted mining machine (scrapers) than crawler mounted (dozers) to dig stored soil can minimize compaction. Transporting soil from the stockpile to the reclamation site on a conveyor belt with trundling action improves soil structure by breaking up massive aggregates. As smaller aggregates continue to tumble, they tend to acquire an agglomerative skin of fine particles, which promotes loose soil structure. Loosely constructed, or "fritted", subsoil is very important to plant root systems. The extent of the root system determines a plant's ability to maximize its surface area and access a greater volume of water and soil nutrients. Plants grown in fritted subsoil have root patterns with extensive vertical and lateral penetration. Rock contents in the surface of a reclaimed bench or out-slope will decrease over time due to weathering of rock fragments to soil sized particles and therefore have better water retention characteristics. Gypsum ($CaSO_4.H_2O$) has traditionally been used to improve sodic media for plant growth (Richards, 1954). It can be used to improve the structure of poorly structured sodic soils. Gypsum is normally incorporated into soil at about 5-10 tonnes/ha. Application of gypsum results in replacement of sodium with calcium on the soil exchange surfaces, which can improve the soil structure, reduce surface crusting and increase water infiltration. It may also reduce the pH of sodic soils (soil with pH>8.5) (Ghose, 2005). An exchangeable sodium proportion of greater than 6% can indicate an unstable soil structure.

3.2 Management of Soil pH

Acidic mine soils can be effectively neutralized once they have been again spread at the reclamation site by applying either cement kiln dust (CaO) or limestone ($CaCO_3$). Lime application rates must account for both past and future pyrite oxidation in order to maintain neutral soil pH levels over time. Lime addition is a common method to decrease the heavy metal mobility in soils and their accumulation in the plant as it increases the pH of soil. Plants like *Gravellia robusta*, can be planted at acidic dumps (pH 3.6-3.9), which increases the soil pH (Gitt and Dollhopf, 1991). Organic amendments such as woodchips, composted green waste or manure, biosolids etc also increases the soil pH, in addition improves soil structure, water holding capacity, cation exchange capacity, provide a slow-release fertilizer and serve as a microbial inoculum (Tordoff et al., 2000; Jordan et al., 2002).

3.3 Increase Soil Fertility

Areas reclaimed for agriculture or other intensive use will normally require maintenance of the fertilizer programmed. There are also certain amendments which have shown promise for improving spoil as a plant growth medium. Saw dust has been shown to increase the survival rates of certain trees, forbs and shrubs (Uresk and Yamamoto, 1986). Smith et al., (1985) observed that the addition of woodchips to bare spoils was second only to topsoil application for increasing plant establishing and their growth. Gitt and Dollhopf, (1991) observed similar results when wood residue had been used as a spoil amendment. Amendment with wood residue with N increases the effects of fertilizers such as N, P, K or gypsum while amendments with gypsum increases the level of soluble salts (Voorhees and Uresk, 1990; Sheoran et al., 2009).

Majority of N needed to supply plant/soil community comes from N-fixation and subsequent mineralization of organically combined N. Therefore, maintenance of a vigorous legume component within the plant community is critical for reclamation success. Most mine soils do not contain native populations of the essential N-fixing Rhizobium bacteria those enable legumes to capture atmospheric N, so care must be taken to carefully inoculate all legume seeds used in new plantings. Since N is primarily combined in organic matter in soils, the addition of organic amendments to the soil can greatly enhance total soil N and its availability over time. Sewage sludge has been shown to be an effective mine soil amendment in numerous studies, but it may not always be available in sufficient quantities for use on remote sites. Local and state regulations and community attitudes frequently complicate the use of sewage wastes on disturbed lands. Sawdust and bark mulch are also helpful in increasing the initial mine soil organic matter contents but are generally low in N content. Saw dust and sewage sludge have been widely recognized as effective short-term fertilizers and sources of long term slow release nitrogen (Sydnor and Redente, 2002; Munshower, 1994; Hall, 1984), besides serving as microbial inoculums. In addition, organic matter improves soil structure, reduces erosion, and increases infiltration. Furthermore, organic wastes can increase the water holding capacity of minespoils. Therefore, use of these materials as soil amendments will also require heavy fertilization with N- fertilizer. The maintenance of plant available phosphorus (P) in mine soils over time is hindered by two factors: (i) fresh mine spoils are generally low in readily plant available (water soluble) P; (ii) as mine soils weather and oxidize they become enriched in Fe-oxides that adsorb water soluble P which is then "fixed" into unavailable forms. The tendency of mine soils to fix P increases over time. Because organic bound P is not subject to P-fixation, it is critical to establish and build an organic-P reservoir in the soil to supply long-term plant needs through P-mineralization. Large fertilizer applications of P during reclamation will insure that sufficient P will be available over several years to support plant growth and to build the organic-P pool. Some P will also become available to the plant community as native calcium phosphates in the rocks decompose, but this P is not sufficient to meet the needs of a vigorous plant community. Some species, particularly from the family Protease, are reported to be adversely affected by application of P-fertilizers. These adverse affects are likely to be seen principally on sandy soils, and are less likely to occur on finer soils with a greater capacity to adsorb P. The long term productivity of the plant/soil system is dependent upon several major factors: (i) accumulation of soil organic matter and N; (ii) maintaining N-fixing legumes in the sand; and (iii) establishment of an organic-P pool and avoidance of P-fixation (Daniels, 1999; Ghose, 2005).

3.4 Recharging Soil Microbes

3.4.1 Bacteria

In one study, amending replaced topsoil with hay and processed sewage sludge was more effective than topsoil inoculation in stimulating bacterial growth and activity, particularly for bacteria that oxidize ammonia (Lindemann et al., 1984). Bacteria present in the soil require a source of readily oxidizable carbon provided by the hay and sludge to fuel metabolic activity and stimulate nitrogen cycling. Topsoil contains carbon, but it is often in the form of coal or other humic material mixed during soil replacement and is not readily usable (Moynahan et al., 2002).

3.4.2 Mycorrhiza

Mycorrhizal propagule densities remain low immediately after reclamation on uninoculated sites, but re-establish themselves after couple of years (Williamson and Johnson, 1991). This coincides with the appearance of host plants, such as tall fescue, that are more conducive to mycorrhizal colonization than those first appearing on the site (winter wheat) (Gould et al., 1996; Gould and Hendrix, 1998). Mycorrhizal propagules existing in the topsoil may be stimulated by the presence of suitable host plants. Lindemann et al., (1984) found that covering re-spread soils with 30 cm of topsoil (without mycorrhizal inoculum) also stimulated host colonization by mycorrhizal fungi whereas using hay, topsoil with inoculum, or sewage sludge had no effect. Sewage sludge may suppress mycorrhizal development by increasing the phosphorus available to host plants (Daft and Hacskaylo, 1976). Soil microbe population persists in stored soil and can be stimulated during reclamation by charging the system with a source of organic carbon or by adding suitable host plants. Many plant species, particularly those that are mycorrhizal (e.g. *Sericea lespedeza*), are able to draw P from difficultly available sources.

Managing the microbial population in the rhizosphere - by using an inoculum consisting of a consortium of plant growth promoting rhizobacteria, mycorrhiza-helping bacteria, N-fixing rhizobacteria, and arbuscular mycorrhizal fungus as allied colonizers and biofertilizers; could provide plants with benefits crucial for ecosystem restoration. It is important to use indigenous arbuscular mycorrhizal fungus strains which are best adapted to actual soil and climatic conditions to produce site-specific arbuscular mycorrhizal fungus inocula (Mummey et al., 2002b; Khan, 2004).

3.5 Re-establishing Nutrient Cycles

Nutrient cycling is very closely linked to soil microbe activity. It is the process by which carbon, nitrogen, and phosphorus are reused within an ecosystem due to the metabolic activity of plants and soil microbes. Carbon and nitrogen cycles in particular are disrupted as soil microbe populations decline and must be re-established during reclamation.

3.5.1 Carbon Cycle

Organic carbon fuels the metabolic activity of many soil microbes. Microbes obtain carbon through their symbiotic relationships with suitable host plants or from organic carbon available in the soil resulting from decomposition of plant and animal matter. Removal of topsoil from a mining site and mixing it with underlying soil considerably reduces the relative proportion of organic carbon (Visser et al., 1984). Little additional change in this proportion results from extended storage of soil.

Researchers frequently found the amount of organic carbon to be the limiting factor in stimulating microbial metabolic activity (Williamson and Johnson, 1991). Amending soil with bark (Elkins et al., 1984) or fertilizing and planting ryegrass (Williamson and Johnson, 1991) provides bacteria with enough organic carbon to stimulate metabolic activity, which can be measured by increased microbial carbon. Plant like *Dalbergia sissoo* improves the field moisture content (7%), pH (5.5), organic carbon (85%), and NPK. The increase in organic carbon level is due to the accumulation of leaf litter and its decomposition to form humus (Maiti and Ghose, 2005).

3.5.2 Nitrogen Cycle

Soil organic matter has a very important influence on soil physical and chemical properties, on biological activities, and as a source of plant nutrients, especially nitrogen. Nitrogen in organic form is converted by microorganisms into ammonium (NH_4^+). Under certain conditions specific microbes in the soil use ammonium N in the soil for energy and in doing so oxidize ammonium N(NH_4^+) first into nitrite N(NO_2^-) and then into nitrate N(NO_3^-) which plants can then use to grow, a process referred to as nitrification. Some of that nitrogen is taken in by plants in that area, and some of it escapes into the atmosphere. Free-floating atmospheric nitrogen can in turn be “fixed” by plants which will eventually be eaten or die, starting the cycle all over again. Amending the stockpiled soils with 15 cm topsoil during re-spreading stimulates nitrification and reduces leaching. Davies et al., (1995) reported that during the first two years after reclamation, nitrification rates in reclaimed sites were less than those in undisturbed sites, but approached levels similar to undisturbed sites after two years.

Nutrient recycling and availability on reclaimed sites is reflected in part by the rate of decomposition of plant material. Litter decomposition in mined land versus unmined land is often retarded during the initial months after reclamation (Lawrey, 1977). Presence of heavy metals which reduce soil pH and lack of an existing litter layer create an unfavorable microclimate for soil microbes responsible for breaking down organic matter. Decomposition rates begin to equalize after six months suggesting increased microbial activity, but the initial death of recycled nutrients could impede establishment of new plants. Elkins et al., (1984) demonstrated that amending mine spoils with bark rather than topsoil significantly increases soil microbe activity and consequently decomposition rates but results in less available NO_3 than in the spoil which is not amended. Oxidation of soil nitrogen to NO_3 may be impeded by acidic soils or by the time length required by certain bacteria to become established.

3.6 Top Soil Management

The top soil is severely damaged if it is not mined out separately in the beginning with a view to replace it on the filled void surface area for reclamation in order to protect the primary root medium from contamination and erosion and hence its productivity (Kundu and Ghose, 1998a, b). Sendlein et al., (1983), however, indicate that systematic handling and storage practice can protect the physical and chemical characteristics of top soil while in storage and also after it has been redistributed into the regarded area. Ghose, (2005) advised to avoid topsoil storage, especially in long term, for a time length by which the mine spoil can not maintain its sustainability for suitable plant growth without biological reclamation and also, maintenance of growth of aerobic bacteria. The following steps are; however, need to be followed for keeping the soil in good condition if storage is unavoidable:

(a) The surface of the stockpile should be thoroughly ripped with suitable sub-soiling machinery for the purpose of

- Relieving surface compaction caused by the passage of scrapers and other machines.
- Aeration of soil.
- Encouragement of deep-rooting plants by introduced vegetation.

(b) Following ripping, the heap should be cultivated with suitable low-maintenance species (like dwarf grasses) immediately to prevent erosion and gully formation.

(c) The surface vegetation should be actively maintained with seedling and weed control operations.

After final grading and before replacement of the top soil, slippage surface should be eliminated to promote root penetration. Top soil should be redistributed in a manner that achieve an approximate uniform and stable thickness consistent with the approved post mining land uses, contours, and surface water drainage system. It prevents excess compaction of top soil and protects it from wind and water erosion. It is of greater importance than any other factor in achieving successful reclamation of surface mined land. The top soil must be uniformly redistributed in a manner which assures placement and compaction compatible with the needs of the species those will be used to restore the distributed area to its pre-mined potential (Ghose, 2005). Nitrogen losses can be reduced by preventing the development of anaerobic conditions in the soil mound. Soil storage is for very short periods, periodically opening up and aerating the soil while stockpiled or permanently aerating, allowing drainage with a network of pipes and use of nitrification inhibitors after restoration are the operations that may in part ameliorate the problem (Davies et al., 1995). Vast majority of surface mines today employ some form of controlled overburden placement techniques and utilize top soil substitutes derived from blasted mine spoil materials. This occurs because natural soils tend to be thin, rocky, acidic, and infertile often making it impractical to salvage and re-spread topsoil on surface mined areas. The plant species used in active reclamation therefore are grown in mine spoils composed of freshly blasted overburden materials. The properties of these mine spoils are directly controlled by the physical and geochemical properties of the rock strata from which they are derived (Nagle et al., 1996; Daniels, 1999). Sydnor and Redente, (2002) reported that topsoil if amended with addition of organic wastes increased above ground biomass influence trace element uptake. Even waste rock if properly neutralized, fertilized and amended with organic matter could also be directly revegetated.

4. RE-VEGETATION AT ABANDONED MINE LAND

Vegetation has an important role in protecting the soil surface from erosion and allowing accumulation of fine particles (Tordoff et al., 2000; Conesa et al., 2007b). They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter, lower soil bulk density, and moderate soil pH and bring mineral nutrients to the surface and accumulate them in available form. Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients redeposit them on the soil surface in organic matter from which nutrients are much more readily available by microbial breakdown (Li, 2006; Conesa et al., 2007a; Mendez and Maier, 2008a).

The revegetation of eroded ecosystems must be carried out with plants selected on the basis of their ability to survive and regenerate or reproduce under severe conditions provided both by the nature of the dump material, the exposed situation on the dump surface and on their ability to stabilize the soil structure (Madejon et al., 2006). Normal practice for revegetation is to choose drought-resistant, fast growing crops or fodder which can grow in nutrient deficient soils. Selected plants should be easy to establish, grow quickly, and have dense canopies and root systems. In certain areas, the main factor in preventing vegetation is acidity. Plants must be tolerant of metal contaminants for such sites (Caravaca et al., 2002; Mendez and Maier, 2008b).

Role of exotic or native species in reclamation needs careful consideration as newly introduced exotic species may become pests in other situations. Therefore, candidate species for vegetation should be screened carefully to avoid becoming problematic weeds in relation to local to regional floristic. For artificial introduction, selection of species that are well adapted to the local environment should be emphasized. Indigenous species are preferable to exotics because they are most likely to fit into fully functional ecosystem and are climatically adapted (Li et al., 2003; Chaney et al., 2007).

Grasses are considered as a nurse crop for an early vegetation purpose. Grasses have both positive and negative effects on mine lands. They are frequently needed to stabilize soils but they may compete with woody regeneration. Grasses, particularly C4 ones, can offer superior tolerance to drought, low soil nutrients and other climatic stresses. Roots of grasses are fibrous that can slow erosion and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. The initial cover must allow the development of diverse self-sustaining plant communities (Shu et al., 2002; Singh et al., 2002; Hao et al., 2004).

Trees can potentially improve soils through numerous processes, including - maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below and reach of roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve physical properties, reduce soil acidity and improve soil biological activity. Also, new self-sustaining top soils are created by trees. Plant litter and root exudates provide nutrient-cycling to soil (Pulford and Watson, 2003; Coates, 2005; Padmavathiamma and Li, 2007; Mertens et al., 2007).

On mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation (Yang et al., 2003; Song et al., 2004). An alternative approach might be to introduce legumes and other nitrogen-fixing species. Nitrogen fixing species have a dramatic effect on soil fertility through production of readily decomposable nutrient rich litter and turnover of fine roots and nodules. Mineralization of N-rich litter from these species allow substantial transfer to companion species and subsequent cycling, thus enabling the development of a self-sustaining ecosystem (Zhang et al., 2001). Singh et al., (2002) reported that native leguminous species show greater improvement in soil fertility parameters in comparison to native non-leguminous species. Also, native legumes are more efficient in bringing out differences in soil properties than exotic legumes in the short term.

5. DETERMINING EFFECTIVENESS OF SOIL RECLAMATION

Some assessment should be made to determine once the reclamation plan is complete and vegetation has established. It is to determine how closely the reclaimed site functions, in comparison to similar undisturbed sites, as an ecosystem. Reclamation of abandoned mine land is a very complex process. Most researchers agree that reclamation success must be measured by more than the presence of vegetation on the site. Several parameters must be considered in order to determine the state and functionality of the soil system since no individual parameter provides sufficient information for ecosystem reclamation. Both the activation of basic soil biological processes and the rearrangement of soil particles into stable aggregates are key factors related to the soil functionality (Filip, 2002; Sourkova et al., 2005; Heras, 2009).

Bentham et al., (1992) developed a three-dimensional system measuring ATP, dehydrogenase activity, and ergosterol to classify habitats based on microbiological and physico- chemical characteristics. While their entire dataset include other factors, such as soil moisture content, type of ecosystem, restored versus undisturbed site, they found that using the selected three-dimensional system allowed distinction of different habitats. The results can then be used in conjunction with reference databases of undisturbed sites to evaluate success of restoration.

Microbial activity is a key factor affecting the functioning of all terrestrial systems. It has an important role in decomposition and nutrient cycling. Measurement of process rates governed by the soil microflora and general metabolic activities of these organisms is used to evaluate the reclamation efforts (Mummey et al., 2002a; Izquierdo et al., 2005). Edgerton et al., (1995) found a positive linear correlation between soil aggregate stability and microbial biomass carbon suggesting that measuring the productivity of the microbial community leads to reasonable assumptions about the quality of soil structure. Further, it was suggested that evaluating soil microbe populations and their metabolic activity may be utilized to determine the stability of a restored ecosystem.

A mycorrhiza is a mutualistic association between plants and fungi that affects all terrestrial communities. By affecting the success of individual plants, the association may play a role in the success of reclamation efforts by their presence (improving the growth and fitness of desirable species) or in failure by their absence. Several methods currently are used to assess mycorrhizal activity. These include both direct and indirect methods. Bioassays of soils for mycorrhizal fungi have been commonly used for a long time. There are two indirect techniques for quantifying mycorrhizal activity based on bioassays for mycorrhizal fungi. These have primarily been used to test soils prior to planting to estimate the potential for recovery of mycorrhizae. Mycorrhizal inoculum potential (MIP) is used as a mean to determine the potential for mycorrhizae to reestablish following a disturbance. Another procedure is called most probable numbers estimate (MPN) of mycorrhizal fungal densities. In both types of procedures known amount of test soil is mixed into a standard, sterile soil and seeded with a given mycorrhizal plant. After a known period, the plant is harvested and the number of propagules (MPN) or mycorrhizal inoculum potential (MIP) estimated by the percentage of root length infected by mycorrhizal fungi (for VA mycorrhizal) or by the proportions of root tips infected (ectomycorrhizae). Direct method involves determining the percentage of the root length containing VA mycorrhizae or the percentage of root tips that are ectomycorrhizae using plants collected from the field at different times following the replacement of the growth medium (Allen and Friese, 1992).

Soil enzymes activities have been used as sensitive indicators for reflecting the degree of quality reached by a soil in the reclamation process (Caravaca et al., 2003). A direct measurement of the microbial population is the dehydrogenase activity. Dehydrogenase is an oxidoreductase, which is only present in viable cells. This enzyme has been considered as a sensitive indicator of soil quality in degraded soils and it has been proposed as a valid biomarker to indicate the changes in soil management under different agronomic practices and climates. Measurement of soil hydrolases provides an early indication of changes in soil fertility since they are related to the mineralization of such important nutrient elements as N, P and organic carbon (Ceccanti et al., 1994).

6. CONCLUSION

Reclamation is an essential part in developing mineral resources in accordance with the principles of ecologically sustainable development. The goal of surface mine reclamation is to restore the ecological integrity of disturbed areas. Revegetation constitutes the most widely accepted and useful way of reclamation of mine spoils to reduce erosion and protect soils against degradation. The revegetation must be carried out with the plants selected on the basis of their ability to survive and regenerate in the local environment, and on their ability to stabilize the soil structure. Revegetation facilitates the development of N-fixing bacteria and mycorrhizal association, which are fundamental for maintaining the soil quality by mediating the processes of organic matter turnover and nutrient cycling.

Reclamation of overburden dumps can be managed effectively once the chemical, physical and biological properties of soil have been correctly determined. Compaction, low water holding capacity, bulk density, deficiency of micro and macro nutrients and associated rooting restrictions are the major factors limiting the productivity of mine soils. High level of potential acidity (low pH) severely restricts the productivity of some mine soils but this problem is much more limited in extent than mine soil compaction. Stockpiling of top soil not only decreases the microbial activity but also disturbs the structure of soil. Top soil is an essential component for land reclamation in mining areas. Stockpiling should systematically handle and store the top soil so that its physical and biological characteristics can be protected. Productive topsoil substitutes can be generated from hard rock overburden of fresh soil, but care must be taken in selection and placement. Productivity of soil can also be increased by adding various amendments such as hay, saw dust, bark mulch, wood chips, wood residues, sewage sludge, animal manures as they stimulate the microbial activity (bacteria and mycorrhiza), which provides the nutrients (N, P) and organic carbon to soil. Acidic dumps can be restored by planting the metal tolerant plants, which can grow in nutrient deficient soil with elevated metal content. Planting of different grass, trees species, rotating with legumes and native species because of their adaptation to deficiency of nutrients and fast growing traits, shall be able to restore the soil fertility and accelerate ecological succession. Once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use will begin and offsite damages will be minimized. In addition, establishment of vegetation also improves the aesthetics of the area.

Reclamation of overburden dumps is not an operation, which should be considered only at, or just before mine closure. Rather, it should be a part of an integrated program of an effective environmental management through all phases of resource development - from exploration to construction, operation, and closure. Mining organizations are developing the expertise to reassemble the species that have chance to grow, develop, and rebuild the local biodiversity. They are achieving this through careful attention to all aspects of reclamation and revegetation: from initial planning, clearing, soil removal, storage and replacement through species selection and re-establishment of vegetation with its associated organism; to maintenance of areas for future. The initial vegetation efforts must establish the building blocks for a self-sustaining system so that successive processes lead to the desired vegetation complex. The best time to establish vegetation is determined by the seasonal distribution and reliability of rainfall. All preparatory work must be completed before time when seeds are most likely to experience the conditions, which are needed for germination and survival, that is, reliable rainfall and suitable temperature.

Reclamation must go beyond planting a new landscape by considering the land as an integrated system that function above and below the ground. Researchers have demonstrated techniques that appear successful over periods of several years and have indicated that there is much more to learn about their long-range effects.

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