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REVEGETATIONAL STRATEGIES AND CRITERIA FOR SELECTION OF PLANT SPECIES FOR AFFORESTATION OF IRON ORE MINE WASTELANDS IN GOA

B.F. RODRIGUES
Department of Botany, Goa University, Taleigao Plateau, Goa – 403 206

ABSTRACT

Although the mining and metallurgical industries play an important role in the national economy, the wastes produced during the operation are a serious threat to environment if appropriate measures are not taken to re-establish vegetation at the degraded mine sites. The paper discusses various strategies undertaken for revegetation of the freshly degraded mining sites and focuses on the criteria for selecting the plant species for this purpose.

Open-cast mining of iron ore deposits causes disfigurement of landscapes by creating depressions and elevations in the otherwise sloppy terrain. The tailing basins may occupy up to 40% of a mine site land area[44] and can detract from the aesthetic quality of the landscape. Essentially, open-cast mining involves the excavation and movement of large volumes of earth's crust. One tonne of iron ore mined produces 2-3 tonnes of waste. Dean and Havens[15] estimated that the mine wastes in United States cover about 200 million acres, with accumulation exceeding 1 billion tonne engulfing an area of 2 million acres. In the Western states, nearly one-half million tonnes are being produced daily[32]. The state of Goa with an area of 3,702 sq.km. contributes to about 40% of the total iron ore production in the country. With an estimated iron ore reserve of about 400 million tonnes, mining at the present rate is expected to last for another 25-30 years. The excavation of iron ore exposes large chunks of earth's crust to the atmosphere that intrude upon the landscape. Mining operations produce two classes of wastes, viz. piles of surface overburden waste rock and lean ore, which constitute the reject dumps, and a fine grained waste resulting from the ore beneficiation process and deposited in large basins called tailing ponds. Although Goa's economy is largely dependent on mining industry, the wastes produced by mining activities are a serious threat to environment if no proper measures are taken to re-establish vegetation at the mining sites.

REVEGETATIONAL STRATEGIES

The most commonly used means for stabilization of tailing areas involve physical, chemical and vegetative methods. Of these, vegetative stabilization offers a more viable perspective being more effective, economical and long-lasting. Following are some of the revegetational strategies to be followed while afforesting mine wastelands.

Angle of slope: The angle of slope is an important physical factor and in higher rainfall areas, the slopes devoid of vegetation may affect water courses far downstream[5]. It has been suggested that 35° slope may be suitable for afforestation[25]. For vegetation establishment, Armiger *et al.*[5] describes a lateral groove technique with terracing, serving to hold water and improve the local microclimate.

Removal and storage of top-soil for reuse: The management of top-soil is of special importance and is universally accepted as a sound technique in rehabilitation. It involves the removal of top-soil prior to mining activity, temporary storage and then replacement in the original sequence. Some loss of soil characteristics is inevitable. However, organic matter and associated plant nutrients are retained. With this technique, the re-establishment of vegetation is relatively easier, and the subsequent growth is likely to be good as the fertility of original soil is retained. The use of forest top-soil enhances the potential for rapid cover production[17]. It has been used as an amendment[2] and may provide a source of mycorrhizal spores[4]. In addition to organic matter and plant nutrients, top-soil is valued for its seed store and physical characteristics. The top 5 cm of soil contains bulk of seed and may give better regrowth than bulked material from the top 40 cm of soil. It may be necessary to store the 5-40 cm layer for logistic reason, but direct return can give a 12-fold increase in the number of seedlings established after 18 months[47]. The stockpiling of top- soil has adverse effects on various physical, chemical and biological properties of soil. This includes decreased number of soil microbes[31] which include vesicular-arbuscular mycorrhizal (VAM) fungi[30]. A slight modification of this technique is the use of top-soil taken from another site to cover the degraded land surface. Although practised on a smaller scale, it is expensive and there may be difficulty in obtaining good quality of top-soil.

Soil compaction: The major rehabilitation problem of mining sites is usually excess compaction, caused due to high clay content in the reject and tailings, and the widespread use of heavy machinery. The compaction tends to reduce moisture infiltration and results in poor plant growth[20]. This problem is overcome by ripping the surface with deep lines drawn by a crawler tractor, followed by cultivation. Ripping is known to improve aeration, water retention, better root penetration and erosion control[34]. However, the effect of ripping is nullified if ripping is followed by rainfall and subsequent drying prior to planting.

Use of organic materials : Without the availability of top-soil, mine surfaces tend to possess little physical structure. Organic matter is usually absent, and the surface tends to crust after rain and dry out rapidly. Surface temperatures are found to be quite high. Organic materials help plant establishment by improving the moisture regime, moderating the surface temperature, decreasing the erosion, improving the fertility, increasing the cation exchange capacity and detoxifying the toxic metals[26]. Aery and Tiagi[1] have shown that after cropping and addition of litter, and its subsequent humification in tailings, there was an absolute increase in the organic carbon and percentage nitrogen content, a substantial increase in the water-holding capacity, extractable potassium, sodium, calcium and phosphorus, and a decrease in the bulk density due to the increment of organic matter.

Hydromulching: On the surfaces, such as steep slopes or rock faces, where it is difficult or even impossible to use normal sowing or plantation methods, a useful technique called hydromulching is employed. It is a technique, whereby seed, fertilizer and mulch are applied in one operation. Seed, fertilizer, mulch and water are agitated in a large tank to produce a homogeneous slurry which is pumped under pressure through a spray gun or poured over the area to be covered. Seeds germinate wherever the slurry settles. But the establishment is best achieved if the receiving surface is rough and the season is moist. Mulch is known to provide some initial protection prior to vegetational establishment, as it serves to hold the seeds and fertilizer to the soil surface, and also reduces the erosive action of the rain drop impact and overland flow on the prepared surface. Mulching materials will alter the surface microclimate and help to conserve the soil moisture during seedling establishment[5]. Hydromulching is very successful if the mulch gets sufficient time to bind itself, followed by rain or irrigation. However, this technique can drastically fail if high intensity rainfall is received immediately after hydromulch application, thereby not giving sufficient time for the mulch to bind itself, or if there is no rain or irrigation even after the mulch has bound itself. Various types of organic materials are used as mulches. These include pulp fibre, straw, saw-dust, wood-chips, curved hay, etc. The selection of material depends upon the cost and proximity of supply to the area to be treated. This technique is most useful for the establishment of grass species which are otherwise planted manually.

Sewage sludge: Municipal sewage sludge is another attractive waste which is being used in reclamation of wastelands. It acts partly as a physical ameliorant, but it may also render many toxic ions innocuous by chelation[25]. It tends to be high in nutrient contents and buffering capacity[26]. The sewage effluent tends to be slightly alkaline, pH 6.8-7.2, and is rich in nitrogen, phosphorus and potassium[46].

Sea weeds: Sea weeds have been used as source of organic matter and manure for paddy and coconut plantations, because they contain many growth-promoting hormones, trace elements and micronutrients[12]. Beneficial effects from the use of sea weeds have been obtained on plants, their crop yield and their resistance to fungal and insect attack[9].

Soil microbes: Numerous studies have shown that soil microflora is a crucial factor in plant nutrient availability and uptake, either through organic matter decomposition or mineral weathering. Microorganisms are also known to influence plant root morphology, root to shoot ratios, as well as supplying essential growth factors and vitamins to the plants[6,8]. Microorganisms, viz. algae, fungi, bacteria and protozoa, are involved in many key ecological processes, such as, primary production of organic food materials and in cycling of nutrients. Some microbes are more resistant to metal pollution than higher plants and animals, and play a vital role in the recovery of polluted area. Wilson[50] has postulated that the lack of suitable microorganisms might be a deterrent to the development of vegetation on mine tailings. Hence, the development of suitable microflora and microfauna on mine wastes is an important criterion for successful rehabilitation. It would result in adequate nutrient regime with a circulation of nutrients. The decomposition through the activities of microorganisms results in mineralization and liberation of essential nutrients to become available again for plant uptake. Jeffrey *et al.*[23] reported that no fungi were isolated from unamended tailings, and the number of bacterial isolates was very low as compared to normal grasslands, both in number and diversity. They further stated that the addition of an organic matter substrate (peat 10%) and plant cover, and the occurrence of active fungi isolated increased by as much as 27 times over three winter months. The corresponding increase in bacterial population was also reported. An assessment of the release of available nutrients by decomposition can be obtained from the loss of substrate weight of plant litter, standard cellulose and other suitable substrates, and also from the evolution of carbon dioxide from soil.

Mycorrhizae: Mycorrhizal fungi by virtue of their symbiotic associations with roots of virtually of all vascular plant system are among the most significant microbes in terrestrial ecosystems. Mycorrhizae are not only more efficient in the utilization of available nutrients from soil but are also involved in the transfer of nutrients from the components of soil minerals and organic residues to solution and in the nutrient cycling in ecosystem. Application of ectomycorrhizal technology to reclamation programmes may be a promising option in this regard in future. Endomycorrhizae are sometimes reported as important associates of pioneers[24], as many plants may require endomycorrhizal infection in order to survive on disturbed land. They are particularly useful in detoxifying heavy minerals by chelation[27]. VAM seem to provide a primary mechanism of phosphorus uptake from soil and may, thus, perform an important function in mineral cycling[18]. The increase in uptake of phosphorus is due to increased absorptive surface area of roots[45]. The hyphae have the ability to act as a substitute for a more extensive root system[7]. The importance of introducing VAM fungal inoculum into soil respread on reclaimed land has been recognized[3,4,49]. Rodrigues[39] and Rodrigues and Bukhari[40] reported the occurrence of VAM fungi in various plant species found growing on iron ore mine wastelands in Goa. Helyer and Godden[22] have estimated that the introduction of VAM fungi would decrease the amount of fertilizer required in the establishment phase.

Other organisms: Development of suitable microflora on wastes could be an important element of a successful rehabilitation attempt. In addition to microflora, microfauna is also important. The recolonization of invertebrates is important for successful rehabilitation of reclaimed areas. It helps in soil aeration, soil drainage, litter decomposition, nutrient cycling, pollination, seed dynamics, plant predation and vertebrate food web. The recolonization of appropriate invertebrate fauna is, therefore, necessary for the developing ecosystem to reach sustainable state. Majer[29] has described the role of ants and termites in aeration and efficient soil turnover. It has been suggested that ants may act as good bioindicators of the abundance, species richness and species composition of other invertebrate taxa, and also of the nature of the flora. It is well established that earthworms play a significant role in incorporation and decomposition of plant litter in pasture ecosystems[42]. The rate of mineralization of crop residue is significantly increased by the activity of earthworms[16]. Vimmerstedt and Finney[48] demonstrated the feasibility of introducing earthworms into revegetated acid coal spoils to increase the rate of incorporation of organic matter.

Fertilizer amendments: Ecosystem

development requires the accumulation of sufficient concentration of nutrients to allow efficient recycling[36]. Mine wastes are deficient in plant nutrients, since they come from below the soil surface. It is seen that the addition of normal agricultural fertilizers results in considerable improvement in plant growth. The amounts to be applied can be calculated from proper soil chemical analyses. Initial applications may have both short and long-term influences on establishment, persistence and growth. Minimum soil capital of nitrogen for a self-sustaining ecosystem[37] may be of the order of 750 kg ha^{-1}. The phosphorus component, in particular, requires a careful handling[14]. The fertilizer treatments are known to restore fertility and normal cycles broken by mining. Slow-release fertilizers should be preferred and fast-release compounds should not be used in excess[43]. Rapid growth following fertilization properly leads to earlier and more severe competition. Many species of inherently infertile sites show a decline with time and there is a tendency for dominance by those species which are able to respond to fertilizers[13]

CRITERIA FOR SELECTION OF PLANT SPECIES

The establishment of a permanent cover of vegetation involves not only growing plants but also necessitates bringing into being a plant community that will maintain itself indefinitely without further attention or artificial aid, such as, irrigation, fertilizers, etc. Such permanence might be achieved most advantageously by carefully selecting species which would grow, spread and reproduce under the severe environmental conditions prevailing on the dumps and tailings. While selecting plant species for revegetation, the local conditions of the site should be taken into account. Plants selected should be tough, drought and high temperature resistant, and should adapt to the local conditions. Current selection of species is based on a number of attributes, the most important being the ability of the species to colonize new land surfaces; to survive flooding, drought and strong winds, and to tolerate infertile soils, fires and insect attack. The other attributes considered important include longevity, timber quality and value to native fauna. These may be native or non-native species which can bring about rapid cover establishment and build up soil organic matter, especially when fertilizers are not used or are discounted. The following categories of plant species should be taken into consideration while selecting plant species for revegetating the mine wastelands.

Naturally colonizing plant species: Fresh reject dumps are deficient in nitrogen, phosphorus, potassium and other essential macro- and micronutrients. There is no organic matter, as there is hardly any microbial activity[41]. Even under such inhospitable environmental conditions, some plant species having wide ecological amplitude, phenotypic plasticity and genetic flexibility are able to thrive and colonize mine rejects and tailings naturally. This initial vegetation by invader species has beneficial effects on environment. They are known to improve the site through their rooting and incorporation of organic matter, thereby gradually improving soil conditions so that successional species of higher orders can be established. Hence, a survey of plant species that appear on abandoned and fairly established mine rejects, dumps and tailings would provide a source of potential species for revegetation. Attempts have been made to use algae, lichens and mosses in tailing stabilization[26], as their presence would accelerate the rate of pioneer establishment. Among early colonizers include grasses which are known to bring about reduction in surface temperature extremes[34,35], followed by legumes[21]. There is a significant correlation between the number of species colonizing and the substrate pH[11]. Slight changes in the chemical characteristics of waste are also known to affect the distribution of pioneer species.

Native plant species: While selecting plant species for revegetating mine reject and tailing sites, many of the native species which are already adapted to climatic regions of the area, are often overlooked in preference for the most sophisticated, exotic species. Native plant species demonstrating the ability to thrive in post-mining environment and the ones already present in the adjoining areas are most valuable, as they are adapted to the local conditions.

Exotic plant species: At times, it may be worthwhile to introduce exotic species possessing special characteristics, such as, nitrogen-fixing legumes. But such new introductions must be made with great care and only after experimentation, as these species may be very successful and escape out into the neighbouring areas, and may turn out to be a serious nuisance. Many of the exotic plant species, viz. *Acacia auriculiformis*, *A. mangium*, *Casuarina equisetifolia*, etc., which thrive well on the mines, may be used as nurse plants. These are fast-growing fuel trees and their leaves are not usually preferred by cattle. Initially, a thick plantation (1x1 m) of these species would protect the land against erosion and, thus, would help in soil stabilization and building up of soil organic matter. However, it is essential to replace these species by native species in the later stages.

Grasses, herbs and shrubs: Certain varieties of grasses, herbs and shrubs that exhibit tolerance, have potential use in mine waste revegetation. Native grass species are known to perform better than introduced species and also respond to fertilizer treatment[10].

Legumes: Leguminous plant species, having nodulating ability, are able to fix atmospheric nitrogen. Hence, their selection would increase the nitrogen levels in soil. This would help other plant species to grow and survive. Legumes play an important role in the initial build-up and long-term maintenance of nitrogen levels of mine wastelands. It is potentially feasible and quite economical compared to other methods. Their presence in nitrogen-deficient soils results in increased dry matter production for their growth and also for the growth of other plants. Rodrigues[38] reported a total of 44 legume species belonging to 24 genera found growing (naturally and cultivated) on iron ore mine wastelands in Goa. Nitrogen fixation in legumes is dependent on successful infection of legume root by *Rhizobium* strain, thereby resulting in formation of nodules. Agronomists have developed techniques of pelleting cultivar seeds with effective *Rhizobium* strains. However, the selection of effective Rhizobial strains for legume species found suitable for mine wastes needs more attention. The relationship between acidity and growth is indirect. When soil pH is raised, root growth increases due to increased availability of toxic elements. As a result, nodulation and hence nitrogen fixation also increase. Some legume species require a relatively higher pH along with the availability of calcium for the best growth[19]. In some legumes, soil acidity directly affects growth and survival of Rhizobia. Armiger *et al.*[5] suggested that the use of *Rhizobium* inoculant is beneficial at pH 4.5 and above but, below pH 4.0, nodulation is poor. Low acidity will inevitably give less growth than plants grown in soils of optimum pH range. Two options are available, viz., to alter conditions by the addition of lime and fertilizer, and to select strain which grows well and fixes nitrogen under acidic conditions[26]. It is estimated that 80% of legume nitrogen becomes available through decay of root nodules[28]. Nitrogen-fixing legumes are found to be sensitive to nitrogen fertilizers. Orghoghorie and Pate[33] showed that with increasing nitrate, there is a progressive inhibition of nitrogen fixation and the balance of nitrogen assimilation is deflected from that based on nodulated roots to that based on the above ground portions of the legume.

CONCLUSIONS

The aim of almost all rehabilitation programmes of mine wastelands is to achieve a self-sustaining ecosystem capable of developing by itself, even if it is left unaltered. Achieving a self-sustaining ecosystem in degraded areas requires a careful planning prior to the start of mining activity. 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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