RECLAMATION PRACTICES AT SELECTED BRAZILIAN MINES (1)

Richard C. Barth, Don D. Williams, and James J. Griffith (2)

Abstract.--Reclamation practices at eight Brazilian mines were evaluated in 1987. Although reclamation laws are often vague and poorly enforced, many mines have excellent reclamation programs implemented by a large staff and good equipment. With climatic conditions favorable for plant growth during most of the year, revegetation can be rapid and plant productivity can be high. Some of the problems observed during this field study included a preoccupation with short-term goals, incomplete soil salvage, slope instability, erosion, compaction, poor site preparation, inadequate fertilization, reliance on introduced species, poor seeding practices, inadequate post-revegetation management, and poorly organized research. Many of these problems have been recognized and are now being addressed.

INTRODUCTION

Mineral production in Brazil during 1985 represented slightly over 4% of the GNP, and this industry is a major factor in the incredible growth of Brazil in recent years (Zineski 1986). Mining in Brazil started nearly 300 years ago with the discovery of gold and precious stones, leaving many degraded landscapes as mute testimony to the impacts of mining. The general public is increasingly aware of the scars left by mining and is becoming critical of the mining industry, especially when mining is conducted near urban areas or in biologically sensitive areas.

Because of this criticism, many mining companies are starting to recognize the significance of the environmental impacts associated with mining. In recent years, various mining companies have attempted to develop reclamation programs. However, a lack of knowledge concerning basic reclamation technology, a lack of trained professionals, insufficient research, and conflicting regulations have hampered the development of cost-effective, environmentally sound reclamation programs.

As a starting point to solving these problems, an evaluation of the current reclamation practices in Brazil was conducted in the spring of 1987. This 6-week evaluation consisted of site visits to eight mining companies located in diverse geographic regions of Brazil and having active reclamation programs. These mining sites included the following: Arafertil (phosphate mine) and CBMM (niobium mine) in Araxa, Minas Gerais; COPELMI (coal) in Butia, Rio Grande do Sul; ALCOA (bauxite) in Pocos de Caldas, Minas Gerais; CVRD (iron) in Serra dos Carajas; CVRD (iron) in Itabira, Minas Gerais; MRN (bauxite) in Porto Trombetas, Para; and MBR (iron), Belo Horizonte, Minas Gerais.

R. Barth, often accompanied by D. Williams or J. Griffith, spent from 1 to 5 days at each mining complex talking with the reclamation

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(2) Richard C. Barth is Senior Research Ecologist, Soil-Plant Systems, Golden, Colo.; Don D. Williams is Manager of Mining and Reclamation, ALCOA Aluminio S/A, Pocos de Caldas, Brazil; and James J. Griffith is Associate Professor, Federal University at Vicosa, Vicosa, Brazil.

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personnel and examining the reclamation program in the field. Natural resource, educational, and mining related institutions were also visited. While the mining sites visited can be considered representative of reclamation practices at mines currently engaged in reclamation, it must be noted that a significant percentage of Brazilian (more than 50%) mines are not engaged in reclamation activities at this time.

THE REGULATORY FRAMEWORK FOR RECLAMATION

Although environmental policy has been emerging in Brazil for over 20 years, reclamation is not specifically mentioned in most environmental acts and resolutions. Thus, these laws have little impact on the practice of mine reclamation, and well-defined and workable environmental regulations have yet to emerge.

One regulation requires that, prior to mining, a permit be obtained. While some environmental issues are evaluated during this permitting process, there are no performance standards or specifications for reclamation. Standards are now emerging, especially for water. A recent resolution requires new mining operations to prepare an environmental impact statement, but few professionals know how to prepare such statements and how to apply them to reclamation. Regulations now under consideration address areas such as inspections, role of the states in environmental regulation, documents specifying environmental control and reclamation planning, soil salvage, and other issues.

Compounding the problems are understaffed regulatory organizations that have little experience or training in reclamation. In addition, their legal jurisdiction over reclamation is either not clear or in conflict with other regulations. Enforcement varies greatly, consequently diluting the impact of these regulations. Therefore, the practice of mine reclamation is, for the most part, motivated by forces other than the legal framework summarized above.

The prime motivating forces for mine reclamation are international financing organizations and pressure from the local community. International financing organizations often require environmental protection and reclamation, and if these activities are substandard, funds can be withheld. Local communities can form an environmental advisory council to the mayor. Although this council is only advisory, its recommendations can be politically important and are often the most significant factor in motivating reclamation.

CHARACTERIZATION OF THE RECLAMATION PROCESS

A characterization of the reclamation practices of the mines visited in this study is presented in Table 1. Following is a discussion of these characteristics.

Corporate Commitment

A corporate commitment to reclamation, starting from the top corporate officers and directed downward within the organization, is essential for successful reclamation. When commitment is lacking, short-term economic gain is often realized at the expense of the environment, and reclamation does not take place. When commitment is given begrudgingly, reclamation proceeds, but not with the speed and quality of results that are evident when management enthusiastically supports reclamation. Of the mines visited during this study, five had excellent corporate support and excellent reclamation programs. The remaining three had only moderate support, and their reclamation programs lacked the quality and dedication of the former group. Companies lacking a corporate commitment to reclamation were not included in this study.

Preplanning

Preplanning is essential to mine reclamation in that it allows identification of problem areas before they arise. Such planning can take many forms, but Brazilian regulations indicate that preplanning involves baseline studies, environmental impact statements, and reclamation plans. However, such documents are not in general use in Brazil, and when such documents are prepared, they are often shelved and forgotten. Only four of the mines visited had scattered baseline information, and just one had comprehensive baseline studies. Environmental impact statements were prepared for only three of the mines visited, and most of the time the impact statement covered only a small portion of the mining complex. Some form of written reclamation plan was found at half of the mines visited, but these plans often lacked the detail necessary for proper implementation.

Reclamation Goals

Short-term reclamation goals identified during this study were dominated by the overwhelming desire to create an immediate visual response. Thus, all mines visited indicated aesthetics to be an important, and usually the most important short-term goal. Erosion control and revegetation were other short-term goals mentioned at all the mines visited. One-half of the mines visited indicated that either fuelwood production or establishment of primary forest was among their short-term goals. One mine indicated that crop production was a short-term goal. Although grazing of reclaimed areas is common in Brazil, only two of the mines indicated that forage production was one of their goals.

Only two of the mining companies studied have looked beyond their short-term goals to determine what their long-term goals should be and how the reclamation process should be oriented to achieve the long-term goals. For many of the mining companies visited, reestablishment of a self-sustaining forest is a logical long-term goal because most of the mining areas were covered by forest prior to mining. In order to reestablish native forest, the short-term goals should be directed at enhancing and accelerating natural succession. However, short-term goals dominated by aesthetic considerations and implemented by use of aggressive introduced species may not support the long-term goal. Most mining companies are content to wait and see what happens in the short term before deciding what to do in the long term. Unfortunately, this

Table 1.--Selected characteristics of eight Brazilian mines engaged in reclamation.

Characteristic	Number of Mines	Characteristic	Number of Mines
1. Management Support		9. Species Selection	
Strong Support	5	Native Trees Used	7
Moderate Support	3	Introduced Trees Used	7
2. Preplanning		Native Grasses Used	1
Complete Baseline Studies	1	Introduced Grasses Used	8
Limited Baseline Studies	4	Woody Legumes Used	7
Environ. Impact Statement	3	Herbaceous Legumes Used	2
Reclamation Plan	4	Wildlife Species Used	2
Reference Areas	3	10. Species Propagation	
3. Reclamation Goals--Short Term		Company Nursery	6
Aesthetics	8	Non-Company Nursery	2
Erosion Control	8	Collect Own Seed	6
Revegetation	8	Sterilized Germinator	5
Fuelwood Production	4	Special Soil Mix	4
Primary Forest	4	Macronutrients Added	6
Forage Production	2	Micronutrients Added	2
Crops	1	11. Planting	
4. Reclamation Goals--Long Term		Broadcast Seeding	5
Defined Goals	2	Hydroseeding	5
Undefined Goals	6	Sodding	3
5. Soil Salvage		Stolens	2
Complete Salvage	4	Nursery Seedlings	8
Partial Salvage	2	Tree Planting:	
No Salvage	2	In Groves	2
Off-Site Acquisition	3	In Small Holes	2
6. Reclamation Engineering		In Large Holes	1
Mass Movement Problems	2	No Preparation	3
Terracing Used	7	Grasses Seeded First	3
Improper Terracing	2	12. Management	
7. Ripping and Topsoiling		Enrichment Planting Needed	4
Rip Before Topsoil	2	Enrichment Planting Provided	1
Uniform Application of Soil	5	Thinning Needed	4
Pocket Application of Soil	2	Thinning Provided	1
Rip After Topsoiling	3	Grazing Control Needed	3
Off-Site Acquisition of Soil	3	Grazing Control Provided	1
8. Site Preparation		Refertilization Needed	5
Soil Analysis	3	Refertilization Provided	1
Fertilizer Use	8	Erosion Control Needed	4
Fertilizer Deficiencies	6	Erosion Control Provided	1
Rock Phosphate	3	Ant Control Needed	4
Micronutrient Amendment	3	Ant Control Provided	4
Micronutrient Deficiencies	3	Fire Control Needed	4
Limestone	4	Fire Control Provided	4
Organic Amendments	3	Weed Control Needed	4
Incorporation of Amendments	8	Weed Control Provided	4
Rough Surface	3	13. Research	
Pitting	5	Defined Research Area	2
Creating Diversity	3	Organized Research	3

attitude is not conducive to cost-effective and problem-free reclamation.

Soil Salvage

Half of the mines visited removed and salvaged all of the topsoil (or the organically enriched surface material) present in the area to be mined, following removal of large trees and burning at some locations. A portion of the soil resource was removed at two of the mines and the remaining two of the mines did not salvage topsoil. The reason for not salvaging topsoil was either the shallow depth of the topsoil or its excessive rock content. While these reasons were valid in some portions of a given mine, topsoil suitable for salvage was found at all mines, and at three of the mines a significant portion of this valuable resource was not salvaged.

Most Brazilian soils are highly weathered, acid, low in cation exchange capacity, and high in aluminum saturation (Sanchez 1976). In addition, these soils are not the nutrient reservoirs that are found in temperate soils. For example, Jordan (1985) estimated that only 6% of the soils in the Amazon Basin have no major nutrient limitations. However, these soils do contain some plant nutrients, especially micronutrients, that are often essential to the reclamation process. Of greater importance than these nutrients are the microorganisms present in the topsoil. These microorganisms are essential for nutrient cycling, conservation, and absorption by plants (Prance and Lovejoy 1985). Highly dependent and intricate relationships have developed in the tropics between these microorganisms and plants (Jordan 1985; Deshmukh 1986). Although much of this microbial life appears destroyed during topsoil salvage, sufficient numbers appear to survive to be of significant, and often decisive, value in reclamation.

Because of the microbial value of topsoil, direct transfer of topsoil is highly desirable, but only one of the mines visited did this on a routine basis and another mine did it on an occasional basis. The remaining four mines that salvaged topsoil stored the soil from 3 months to over 4 years. The value of stored topsoil rapidly decreases due to nutrient leaching (especially Ca, Mg, K, and nitrate N) (Jordan 1987), and due to the death of microorganisms. Some reclamation personnel are of the opinion that topsoil stored longer than 6 months has lost most of its value for reclamation use.

Reclamation Engineering

During the mining process, overburden is removed and deposited in some manner. This waste deposition creates the basic landscape for subsequent reclamation processes. In many areas of Brazil, mining is conducted on steep slopes, annual precipitation often exceeds 200 cm/year, and prolonged wet periods are common. Thus, stability of the waste cannot be taken for granted and thorough engineering is required to ensure slope stability. Such engineering may not take place, and at two of the mines visited, mass movement of mining waste was a major problem; it was a potential problem at several other mines.

Controlled overburden deposition appears to be the best method to stabilize large waste deposits in steep terrain. This generally involves as drain blanket at the base of the waste dump, internal drainage, a rock-stabilized base tied into bedrock, benches that drain both inward and to the side of the deposit, stabilized drainage chutes along the sides of the deposit, compacted fill, and in some cases a compacted clay cap on the benches. All mines operating in steep terrain visited during this study had controlled overburden deposition in at least one of their waste disposal areas, but only one of these mines deposited all of their overburden in a controlled manner. The cost of controlled overburden deposition was estimated at 12% more than uncontrolled deposition; thus, this basic reclamation requirement is not expensive.

Terracing is another method of increasing stability and enhancing reclamation. At seven of the mines visited terracing was used to some extent. Terrace widths averaged 10 m and the vertical distance between terraces also averaged 10 m. Unfortunately, at two of the mines using terracing, the terraces were improperly designed and provided little water control and slope stability. Water intercepted by the terrace must be drained along the terrace and down drainage structures at the edge of the terraced deposit. Without this drainage, the terrace quickly fills with water during intense precipitation and overflows.

Ripping and Topsoiling

In most areas of Brazil, the overburden is high in clay and prone to compaction during backfilling. Although ripping is not possible in all locations (due to the presence of clay caps, drainage systems, or steep slopes), overburden ripping was possible at six of the mines visited, but only two of the mines engaged in this practice. Reclamation efforts at the remaining mines were often hampered by compacted overburden.

Topsoil was applied in a uniform manner at five of the mines. The depth of topsoil applied ranged from 3 to 50 cm and averaged 20 cm. At two of the mines, topsoil was applied only in pockets dug for tree planting. Following topsoil application, three of the mines ripped, disked, or harrowed to relieve compaction and to incorporate amendments. At the mines where this was not practiced, revegetation efforts were often hampered by compacted soil.

At three of the mines visited, topsoil availability was insufficient to meet perceived reclamation needs. To overcome this problem, the mines obtained topsoil from undisturbed areas, usually from farmers willing to sell topsoil from their pastures. This practice should be discouraged. Not only is it costly, but creating a disturbance in one area to solve a disturbance in another gains little as far as the environment is concerned. In most cases where topsoil appears insufficient for reclamation, the overburden can likely be modified (by application of fertilizers and incorporation of organic matter) to serve as an acceptable growth medium.

Site Preparation

Basic to revegetation is an understanding of the chemical traits of the growth medium and how these traits affect plant growth. However, only three of the mines visited analyzed the growth medium, and in most cases the analyses were incomplete and of little use. As a result, there was little scientific basis for the application of amendments.

At all of the mines visited, fertilizer was applied, generally a NPK fertilizer, but there was no consistency in nutrient composition or application rate among the mines and often at the same mine. Because of the lack of a quantitative approach to fertilizer application, nutrient deficiencies were common and six of the mines visited had at least a portion of the revegetated area deficient in macronutrients, particularly nitrogen.

Rock phosphate was used at three of the mines, especially in conjunction with tree planting. Rock phosphate is slowly soluble and is used to provide a long-term supply of phosphorus; however, the effectiveness of this practice is not known.

Although micronutrients are often deficient in the highly weathered soils in Brazil, only two of the mines visited analyzed the growth medium for micronutrients. However, three of the mines applied B, Zn, or a micronutrient mix to the growth medium. In at least three of the mines visited, vegetative growth appeared restricted due to inadequate micronutrients, especially B.

Another common amendment was limestone and four of the mines applied this amendment. Soil pH was often in the 4.0 to 5.0 range, and sufficient limestone was applied to increase the pH to the 6.0 to 6.5 range. In one case, ash from a paper mill was being used on an experimental basis as a neutralizing agent.

Organic amendments were also important, especially for Brazilian soils which typically have a low organic matter content. However, only three of the mines visited used organic amendments. Organic amendments such as manure, composted garbage, grass and tree clippings, sewage sludge, sugar cane pulp, rice hulls, waste from paper pulping, and sawdust are readily available in many parts of Brazil. Unfortunately, there seems to be a general reluctance to handle waste products in Brazil, thus depriving reclamation of a very beneficial amendment.

Amendment incorporation depth is often shallow, usually 15 cm. Deeper incorporation of amendments would likely be beneficial, especially if amendment application rates were increased proportionally.

Another part of site preparation was creating a rough surface that would hold seeds and restrict erosion. At three of the mines visited, this type of surface was created by ripping or disking the surface. Pitting was also a common method to produce a rough surface, especially on slopes. The pits were made by hand, usually using some type of hoe, and were made in a random manner or oriented along the contour. While these pits can interrupt surface flow and are of some value in erosion control, their primary benefit is in providing a flat area, generally from 10 to 20 sq cm, where seeds can reside during germination. Pitting was used at five of the mines visited.

Site preparation also involves creating landscape diversity, and this process is usually started during backfilling. Creating such diversity was taking place at three of the mines visited. Techniques included the use of boulders, creation of ponds, and species manipulation.

Species Selection

The selection of species used in revegetation has been substantially influenced by a preoccupation with short-term goals and the desire to produce a landscape that has immediate visual appeal. This has led to the use of aggressive, fast growing introduced grasses. Roughly estimated, 40% of the rehabilitated areas in Brazil are dominated by a single species of introduced grass. This species, grease grass (Melinis minutiflora), also excludes other species and is highly flammable. For these and other reasons, two of the mines that planted this species in the past no longer plant grease grass, and at one mine this species was being removed.

Woody species used in revegetation are dominated by native trees. This is not surprising when one considers that within or adjacent to the mining sites involved in this study, the number of native woody species ranged from 90 to over 1000. Percentage of native trees used in revegetation ranged as high as 100% and averaged 70% for the mines visited. Only one mine was not planting native trees at the present time. Fast growing introduced trees, particularly eucalyptus, were also important, especially for fuel production, and seven of the mines planted introduced trees. Two of the visited mines planted tree species specifically for wildlife use.

In contrast to the use of native trees, only one of the eight mining sites used native grasses, and all of the mining sites used introduced grasses. This reliance on introduced grasses should not imply a shortage of native grasses in Brazil. A recent botanical study at one of the mines identified 67 species of native grasses in the mining area, and it was estimated that over 200 species could be found in adjacent areas. The lack of seed availability, a lack of knowledge concerning species suitability, and germination problems have discouraged the use of native grasses.

Because of the nutrient-poor soils, legumes are important in species selection. Recognizing this, seven of the mines visited were planting an average of 24 species of woody legumes. Unfortunately, only two of the mines were planting herbaceous legumes at this time.

Longevity is also an important consideration in species selection. Some of the best growing and most widely planted trees used in revegetation have a life span of only 20 years. Because of the preoccupation with short-term reclamation goals, the question of what will happen when these trees start to die has not been addressed.

Species Propagation

Species propagation refers to the raising of wood species in a nursery for subsequent planting in areas being revegetated. Of the mines visited, six produced their own seedlings in a company operated nursery, and the remaining two obtained seedlings from private nurseries. Annual seedling production averaged 60,000, with two of the nurseries producing more than 80,000 seedlings.

Many aspects of seedling production have become standardized. All of the nurseries collect their own seed and germinate the seeds in shaded areas. A sterilized medium is used for germination at five of the nurseries, and the remaining nurseries will likely use this method to avoid mold and fungus problems during seed germination. Once germinated, the seedlings are generally transferred to soil-filled plastic bags. At four of the nurseries, a special soil mixture was used to assure proper seedling nutrition, proper microbial activity, and ease of handling. This special mixture used topsoil amended with such materials as manure, worm mulch, sawdust, plant litter, and the surface 2 cm of forest soil. All nurseries applied NPK to the soil mix, and two added a micronutrient fertilizer. Seedlings generally were field planted 6 months after germination; height at the time of planting was approximately 50 cm.

Most nurseries visited were very well managed and seedling quality was high. Perhaps the most serious problem observed was a reluctance to discard seedlings that were growing poorly and that would probably not survive field planting regardless of how long they stayed in the nursery. In one nursery, a micronutrient deficiency appeared to be restricting seedling growth.

Planting

Planting by Seed

All of the mines visited planted grasses by seed, and one of the mines planted shrubs and trees by seed. Broadcast seeding was practiced at five of the mines; hydroseeding was likewise practiced at five of the mines. There appeared to be no inherent advantage of one seeding method over the other, and there were no observable differences in revegetation success. One company expressed the opinion that both seeding methods produced the same results, except that broadcast seeding was easier because there were fewer things to break down. Seeding takes place throughout the wet season and establishment is usually good except when a dry period follows seed germination.

A grass cover can also be obtained by vegetative means, and three of the mines visited have used sod in some areas and two have used stolens. These vegetative techniques are generally limited to highly visible and sensitive areas.

Planting by Seedling

Methods used in planting tree seedlings varied from mine to mine. At two of the mines visited, trees (about 30 cm tall) were planted in groves that resulted from ripping the surface. At two other mines, slightly larger trees were used (about 50 cm tall) and planting consisted of (1) excavating small holes (less then 0.5 cu m), (2) mixing soil, fertilizer, limestone, and organic matter with the substrate, (3) filling the hole, and (4) planting the seedling in this enriched pocket. At another location the same technique was used, except that the excavation approached 1 cu m and tree height at the time of planting was approximately 1 m. At the remaining three of the mines, trees from 30 cm to over 1 m tall were planted in soil or overburden without any special treatment other than fertilizer. One mine tried using an auger to make the planting holes, but this technique compacted the soil and reduced seedling survival.

Tree spacing depended on the species involved and the intended use of the area. Eucalyptus (Eucalyptus spp.) plantations had the closest spacing while native trees had the widest spacing. The species sequence in planting was dependent on the objective. When a strong visual response was desired, seedlings of the same species were usually planted in small groups, often with reduced spacing within the group and large spacing between groups of different species. When native forest was the objective, the species sequence was usually random.

At most mining locations visited, grasses and trees were planted at the same time if a mixed community was the goal. At three of the mines, grasses were seeded before the trees were planted. This sequence gave an immediate visual response, but resulted in severe competition between the grasses and trees.

Management

Once an area has been planted and a pleasing green landscape created, reclamation is often considered complete. However, some management is required to ensure that reclamation is self-sustaining. All mines visited found it very difficult to provide this management.

Following revegetation with grasses and/or trees that provide the desired visual impact, an enrichment planting was often planned where more permanent vegetation was planted. Such enrichment plantings were part of the reclamation strategy at four of the mines visited, but only one of the mines had started this process. At four of the mines visited, thinning was necessary, but this process had taken place at only one of the mines. Revegetated areas can tolerate grazing if the proper species are planted and if grazing is managed; at three of the mines visited grazing was allowed. However, at two of these mines, this grazing was not controlled and often occurred immediately after planting. This resulted in severe damage to the trees and grasses in localized areas. Nutrient deficient vegetation was observed at five of the mines visited, but only one of the mines had a refertilization program. Accelerated erosion of reclaimed areas was a problem at four of the mines. Such problems were usually attacked with a hydroseeder with the idea that a green slope could not possibly erode. A permanent solution to the problem would likely involve hand excavation to reestablish proper drainage followed by hand recontouring and revegetation. Only one of the mines visited provided this type of follow-up erosion control. Unnecessary use of bulldozers appeared to be a problem at many mines. Probably the best solution to this problem is a systematic effort to sensitize equipment operators about reclamation.

Some management needs were receiving proper attention. Fire, weed, and ant control were needed at four of the mines visited, and this type of management was generally provided.

Research

Research was recognized as part of the reclamation process, and research programs of some type were found at all mines visited. However, only two of the mines visited had well-defined research areas and only three of the mines had a well organized research program. Some of the more serious problems encountered included a lack of control areas, lack of adequate replication, poor records, lack of statistically valid experiment designs, uncontrolled variation, and inadequate data collection. Any one of these problems can invalidate the research effort or give erroneous results. Therefore, some of the research now taking place will be of little value to the company and to colleagues faced with similar problems.

SUMMARY

Although reclamation following mining in Brazil is a relatively new concept and programs are just in their infancy, all of the mines visited during this study are doing a commendable job at reclamation and the results obtained thus far are impressive. Reclamation personnel are taking advantage of the experience and research in other countries, and are quickly learning both the art and practice of reclamation. Given the warm climate and abundant rainfall in Brazil, reclamation is often rapid and large areas of mined lands have been transformed from ugly scars to green hillsides within the last few years.

As expected, there are problems in some areas of the reclamation process. Perhaps one of the more serious problems is a preoccupation with short-term goals that seek little more than to establish a pleasing landscape. Technical problems include incomplete soil salvage, slope instability, accelerated erosion, poor site preparation, inadequate fertilization, over use of introduced species, poor seeding practices, inadequate post-reclamation management, and poor research techniques. Most reclamation personnel are aware of these short comings and are working hard at correcting the problems.

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