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MINE RECLAMATION - THE PTINCO EXPERIENCE

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ABSTRACT

The shallow lateritic nature of PT Inco's nickel deposits in Indonesia requires a rapidly advancing strip-mining operation. This becomes evident given that current mining activities disturb close to 300 hectares of forestland per year. Therefore, in order to minimize the amount of disturbed forestland area, it is imperative that mine reclamation be an integral part of the mining operation.

Experimentation and research has enabled PTI to address the challenges common to most mine sites, some of which include low plant survival rate and poor growth. To date, PTI has successfully re-vegetated more than 1,900 hectares of post-mining areas and are committed to continue to rehabilitate approximately 300 hectares per year to maintain sufficient workspace for effective mining.

The mine reclamation program was initially established to simply re-vegetate post mining areas for the purpose of erosion control. However, the focus in the last two years has expanded to include restoration of original forest eco-systems and productive forest development of post-mine areas.

Future goals are to not only re-green mined-out areas but to also restore them as close as possible to their original forest eco-system in addition to investigating the growing of productive forest. Although these are ambitious and challenging tasks, we believe given our successes to date, these are achievable longer-term goals. PTI is in the process of developing strategies to achieve these targets.

This paper is intended to summarize the program PTI has established which addresses species selection, soil amendment, fertilizer management and soil reconstruction. It also pertains to the improvements we have made from previous practices, including cover crop selection for better soil control, commercial forest development and native and endangered plant species conservation.

INTRODUCTION

PT. INCO (PTI), an integrated mining and smelting complex, is located in Soroako, South Sulawesi Indonesia. The mine moves approximately 50 million wet metric tons of overburden and run-of-mine annually to produce about 140 million pounds of nickel in matte. The nickel ore, contained in the 4 - 6 meters of saprolite, is capped by about 12 to 20 meters of overburden in an area covering 10,000 hectares. Due to the thin nature of the ore profile, the open-cut method of ore exploitation disturbs approximately 300 hectares of forestland annually. This includes ore recovery, stripping as well as the development and maintenance of waste disposals.

PTI has developed an intensive mine rehabilitation program in order to mitigate the impact of the fast-advancing strip-mine operations. The objective being to re-establish post-mine areas as close as possible to their original state - allowing only enough work area for its stripping, ore recovery and waste disposals. The primary major challenge in mine rehabilitation is dealing with the severe sub-soil condition characterized mainly by the lack of macro and micro plant nutrients, potential toxicity from residual metals and poor soil biological activity. Past experience has demonstrated that the establishment of seedlings has been especially difficult in these post mine conditions, indicated by the low survival rate of the seedlings and plant growth that survived. To improve upon successful plantation, a more methodical approach was implemented at PTI in which includes site and soil appraisal, species selection, top soil uses, soil amendment and mycorrhizal inoculation.

A. NICKEL MINING OPERATION

Nickel ore mining begins with the striping of over burden (OB) to expose the ore. The OB, which typically ranges anywhere from 12 to 20 m in thickness is removed. The Run-of-Mine (ROM) is defined and excavated based on economic cut off grades and later upgraded at screening stations where boulders (>300 mm) are screened out. The screened ore is then smelted in a series of steps including drying, reduction, and converting to produce nickel matte (78% nickel content).

The mined-out areas are used, where possible, as waste disposals, backfilled with the stripped overburden from the advancing mine headings. The landscape is re-shaped and re-graded to manage mine water run-off in preparation for the re-vegetation process.

B. REVEGETATION CHALLENGES

Soil appraisal, including analysis of the chemical, physical and biological soil properties, are conducted in order to determine the appropriate soil amendments necessary to support effective plant growth. Table-1 shows the typical soil properties taken from samples at four PTI mining locations.

Table-1. Physical and chemical properties of different soil types in nickel mine sites

Properties	Konde	Himalaya		Betsy		Kockum		TS
	MGL	OB	1C	MGL	OB	MGL	OB	
PH	5.8	6.3	6.5	5.6	6.7	5.8	6.2	6.1
C-Organic (%)	0.14	0.98	0.92	0.89	1.03	0.51	0.73	2.9
N-Total (%)	0.07	0.09	0.04	0.02	0.08	0.06	0.05	0.18
P2O5-avl. (ppm)	0.11	0.84	0.22	0.42	0.31	0.17	0.21	9.11
Ca (me/l00g)	0.17	0.30	0.52	0.11	0.28	0.75	0.61	3.47
Mg (me/l00g)	1.71	1.48	3.36	1.09	3.25	3.73	0.05	1.05
K (me/l00g)	0.04	0.07	0.03	0.05	0.68	0.07	3.18	0.15
Al (me/l00g)	Nd	nd	nd	nd	nd	nd	Nd	nd
Mn (ppm)	51.07	5.41	6.48	5.68	12.65	2.69	3.18	24.80
Zn (ppm)	6.83	4.13	3.11	1.91	5.33	7.11	4.17	12.10
Ni (ppm)	25.21	9.78	22.54	46.07	40.53	31.12	6.89	3.11
Clay (%)	59.5	37.9	40.6	22.9	27.05	45.7	16.2	26.76
Silt (%)	32.0	48.4	31.3	45.9	56.6	48.18	49.2	37.20
Sand (%)	8.4	13.5	28.0	31.2	16.28	8.10	34.5	36.04

B.I. Soil Physical Properties

Analysis of Table 1 shows that medium grade limonite (MGL) and OB comprise the majority of the soils. These are characterized by high contents of silt and clay (80 - 90%), unfavorable for plant growth, especially root development.

High bulk-density of soil is a physical problem caused by excessive compaction during soil handling operations. This condition will not only affect the aeration and water movement through the soil but will also significantly restrict root extension and reduce plant growth. Failing to introduce effective soil improvement treatments would significantly inhibit the colonization of soil micro-organisms. This colonization is essential for maintaining the appropriate levels of soil nutrients, some of which include calcium and magnesium.

B.2. Soil chemistry

There have been no significant problems to date in soil reaction (pH) and mineral toxicity. However the P-fixed capacity of the soil (especially MGL) is quite high, affecting phosphate fertilizer efficiency. Soil amendments are required to address these chemical challenges.

B.3. Soil biology

It is generally accepted that the biological components of soils play a vital role in the development and maintenance of vegetation. This is especially true of their role in the nutrient cycle. The presence of microorganisms in the soil is essential for the long-term survival and growth of most plant species and for the establishment of natural ecosystems.

Among the several important soil microorganisms, rhizobium and mycorrhizal fungi are two of the most common and essential. Rhizobium bacteria will associate with compatible leguminous trees or cover crops and will biologically fix nitrogen from the atmosphere to maintain the self sustaining level of nitrogen in the system.

Mycorrhizal fungi are essential for promoting plant growth, especially under mining sites (Gardner and Malaczuk, 1988). It can increase the solubility of mineral, improve nutrient up-take, produce plant growth hormone, bind soil particles into stale aggregates and trans-locate organic carbon and nitrogen compound from one plant to another.

To determine the status of both microorganisms in the mine sites, a simple "trapping technique" is conducted on the different soil types using mycotrophics plant *Pueraria* spp. as the host. The status of rhizobium is measured based on the occurrence of nodules on the roots while mycorrhizal fungi is measured from the degree of root colonization and number of spores. The results have demonstrated that the populations of either rhizobium or mycorrhizal fungi on OB, 1C and MGL are quite low compared with the topsoil.

C. STRATEGIES FOR REVEGETATION OF NICKEL MINE SITES

The re-vegetation strategy is to address and identify the chemical, physical and biological constraints present in the soils.

C.1. Species selection

Proper selection of native species that will adapt with the climatic and local soil conditions is critical for quick plant establishment (fast growing species). The species should also be self-renewing and biologically able to fixe nitrogen from the atmosphere.

More than sixty exotic and native species have been tested and evaluated for revegetation purposes. Paraserianthes falcataria, Pinus merkusii, Acacia mangium, Acacia auriculiformis and Acacia crassicarpa are found to be the most adaptable exotic species, while Kayu angin, Artocarpus sp., Eugenia sp., Tricospermum burettii, Kulahi, Ptelelobium jiringha and ficus sp were found to be the most adaptable native species.

C.2. Soil re-construction/grading

Re-vegetation activities are conducted after re-shaping and grading the sites as the final new landform is finished. Several activities such as the stabilization of landforms, design of reliable slopes to reduce run off and drainage patterns are investigated. During re-grading, the minimization of soil compaction is important. Compaction on level areas can be minimized by end dumping spoil piles and waiting until all piles are in place before lightly leveling them with small bulldozers.

C.3. Soil amendment

a. Liming

The application of lime is usually used to increase the pH of the soil. However, in this case, the application of measured lime has been to increase the status of Ca and Mg in addition to correcting their balance. The long-term effect of lime also contributes to inducing the degradation of organic matter, increasing the deficiency of fertilizer application, reducing the solubility of toxic mineral (Al and Fe) and improving the texture of the soil.

Dolomite lime is applied directly in the holes instead of spreading the material evenly to all re-vegetation sites. The lime is mixed with the soil in the hole. The dosage rate is 0.4 - 0.6 kg/hole. The hole dimension is 0.6 x 0.6 m.

b. Soil conditioner

The Organic Soil Treatment (OST) product is applied in order to give the soil more organic matter and to reduce fertilizer leaching by rain. The long-term effect of OST application is to improve the soil building as a live system that will help soil organism development. The application dosage is 0.3 kg/hole.

c. Fertilizer

Fertlizer application is required due to the soil's low nutrient content. The application rates of 1.8 kg/hole of mixed Urea, Sulfomag (P2O5) and KCL (K2O) has proven to be the best dosage for promoting the growth of newly planted seedlings.

C.4. Plant growth space

As demonstrated in Table 1, bad soil texture and high bulk density are two physical soil problems which directly affect root development and the colonization of rhizobium. Therefore, in order to stimulate improved root growth and development, the distance between holes was increased. Proven effective hole dimensions for promoting effective plant growth range anywhere from 60 cm3 to 100 cm3. Experience has shown that smaller holes can cause stunted plant growth.

C.5. Mycorrhizaal fungi application

The inoculums of three species of mycorrhiza i.e. Glomus manihotis, Gigaspora margarita. and Acaulospora sp. were introduced to the plant seedlings prior to planting them in the field. Improved growth was experienced by the seedlings inoculated with mycorrhiza. Currently, starter inoculums are mass produced using locally available serpentinized crushed rock of pebble size mixed with local river sand containing shorgum as host following established green house preparation protocol. The harvested inoculums are applied to the seedlings during seed germination. Approximately 20g of harvested inoculums are introduced into small seedling polybags.

D. IMPROVEMENTS TO RE-VEGETATION

D.I. Research on alternative ground cover species.

More than 1,800 ha of revegetated areas have been exclusively planted with uraso (graminae fam.) as a cover crop. Uraso is an indigenous grass species, a bamboo-like grass that grows 2 -3 meters tall and are most commonly found in riverbanks. This species grows well in the mine sites regardless of the, severe conditions (i.e. rocky areas, low soil nutrient, high silt levels and low organic matter content). Uraso have been planted in strips, 5 m spacing between trees. This particular grass reaches full growth in about 3 months.

Uraso grass is however quite dominant in growth and has been known to inhibit tree regeneration competing for the same nutrient source. Also due to its height and dense cover, it deprives light to tree seedlings, consequently hampering tree growth. One other disadvantage of uraso grass is the slow decomposition of its biomass possibly due to its high lignin content.

PTI is now experimenting with other grass and legume species i.e. Paspalum notatum, Chloris gayana, Cynodon dactylon, Stylosanthes sp, Chrotalaria incana, Pueraria javanica, Calopogonium muconoides, Centrosema pubescens and several native flowers. These species, although slower in growth, provide better erosion control. Studies are currently underway to determine the role of grass-legume plantation in accelerating soil organism colonization and the rate of their organic matter's decomposition.

D.2. Native species conservation

A portion of PTI's re-vegetation program is dedicated to bre-establishing mined out areas to their original forest state. This effort includes seed and seedling collection, mother tree selection, silviculture and field planting trials. To date, four native species are grown at the nursery and makeup part of the trees selected for transplantation at the mined out areas. Close monitoring of the plant growth is ongoing to determine the proper treatment to support seedling plant growth. Table 2 shows the list of plant species currently being tested.

Table-2. Plants species tested at PTI.

No.	Local name	Botanical name
1.	Sengon	*Paraserianthes falcataria*
2.	Akasia-1	*Acacia mangium*
3.	Akasia-2	*Acacia crassicarpa*
4.	Akasia-3	*Acacia auriculiformis*
5.	Balsa	*Ochroma bicolor*
6.	Eukaliptus-1	*Eucalyptus urophylla*
7.	Eukaliptus-2	*Eucalptus urograndis*
8.	Mahoni	*Swietenia macrophylla*
9.	Tanjung	*Mimusops elengi*
10.	Gmelina	*Gmelina arborea*
11.	Cemara	*Casuarina equisetifolia*
12.	Pinus	*Pinus merkusii*
13.	Angsana	*Pterocarpus indicus*
14.	Bungur	*Lagerstroemia speciosa*
15.	Nyamplung	*Calophyllum inophyllum*
16.	**Damar**	***Agathis damara***
17.	Jati	*Tectona grandis*
18.	Rambutan irian	*Pometia piñata*
19.	Mangga	*Mangiefera indica*
20.	Jeruk	*Citrus*
21.	**Nangka**	***Artocarphus heterophylla***
22.	**Durian**	***Durio zibethinus***
23.	Jengkol	*Pithelelobium jiringha*
24.	**Langsat**	
25.	Jambu air	*Eugenia aqueum*
26.	Rambutan	*Nephelium lappacheum*
27.	**Ketapi**	***Sandoricum koetjape***
28.	Sirsak	*Persea Americana*
29.	Beringin	*Ficus sp.*
30.	Jambu monyet	*Anacardium occidentale*
31.	Kedondong	
33.	Jambu biji	*Psidum guava*
34.	Trembesi	*Samanea saman*
35.	Dadap	
36.	**Bonu**	***Tricospermum burettii***
37.	**Kayu angin**	***Casuarina sp.***
38.	**Sepatodea**	***Spatodea camphanula***
39.	Johar	*Casia siamea*
40.	Gamal	
41.	Asam	*Tamarindus. Sp*
42.	Randu	*Ceiba pentandra*
43.	Bambu	*Bambusa sp*
44.	**Kulahi**	
45.	**Aren**	***Arenga piñata***
46.	**Dengen**	
47.	Ketapang	*Terminalia kattapa*
49.	**Kemiri**	***Aleurites moluccana***

No.	Local name	Botanical name
50.	Salam	
51.	Alpukat	
52.	Mindi	*Azadirachta indica*
53.	Eboni	*Diospyros sp.*
54.	Kenari	
55.	Kedaung	
56.	Rasamala	
57.	Saga merah	
58.	Galinggem	
59.	Nam-nam	
60.	Bisbul	
61.	Menteng	
62.	Glodokan	

Note: bold fonts are native species.