Revegetation of Acidic Bauxite Tailing Ponds by Hydroseeding of Nodulated and Mycorrhizal Legume Trees in the Amazon Region, Brazil

Dias, L.E.[2]; Franco, A.A.[3]; Campello, E.F.C.[3]; Faria, S.M.[3]; Castilho, A.F.[4], Henriques, J.C.[4]

[2]DPS/Universidade Federal de Viçosa, Viçosa-MG, [3]Embrapa/Agrobiologia, Seropédica-RJ, [4]Mineração Rio do Norte, Porto Trombetas-PA

Abstract

This paper has the aim of showing the methodology developed by the association of Mineração Rio do Norte S.A. with Embrapa/Agrobiologia and the Soil Department of Universidade Federal de Viçosa to promote the revegetation of tailings ponds of bauxite mining in Porto Trombetas, Amazon region, Brazil. The refuse has a fine size (53% of clay), is poor in nutrients and shows low pH. This technology is based on two-phase process. In the first one, seeds of leguminous trees and shrubs species, inoculated with N-fixing bacteria and MVA fungi, are hydroseeded. In the second one, secondary and pioneer native species are planted, using topsoil, with the objective of ensuring more biologic diversity and sustainability to the system. Among different evaluated species *Sesbania virgata*, *S. exasperata*, *Cecrópia sp.*, *Parkia discolor*, *Styphnodendron guinensi*, *L. leucocephala*, *Hidrocoria corumbosa* and *Chamaecrista flexuosa* hasvebeen used with success in the first phase and, *Sclerolobium paniculatum*, *Clitoria farchildian* (paliteira), canela de garça, azeitona, tatapíririca, *Dalbergia spruceana* (jacarandá do Pará) and *Enterolobium maximum* in the second one.

Introduction

Porto Trombetas, Oriximiná County, is located in the west region of Para State in Brazil. In 1967 was created the Mineração Rio do Norte (MRN) with the aim of mining, the bauxite from that region. The first loading of bauxite, to Canada, took place in 1979 (Lapa, 2000), and after that the Company became the largest bauxite mining company in Brazil. Today it is a Brazilian close corporation held by Vale do Rio Doce Alumínio S.A. (a subsidiary of CVRD), Alcan Alumínio do Brasil Ltda., Biliton Metais, S.A. and others. The MRN´s current installed capacity is around 16.3 million tons per year of bauxite, of which 65% is sold in the domestic market and 35% is exported.

All mining activities are done at National Forest of Saracá-Taquera (429,000 ha), which is managed by the Instituto do Meio Ambiente e dos Recursos Renováveis – IBAMA, a National Environmental Institute that manages and supervises the preservation areas and propose the Brazilian environment policies.

The milling process of bauxite involves grounding, washing and classification. These steps are important to remove the clay to concentrate the alumina, but the tailing produced is an environmental problem that requires a special management to reduce its impact.

From 1979 to 1984 all the tailing produced was launched to Igarapé Caranã, a brook that drains to Batata Lake, a natural lake that receives the water from Trombetas river each rain season. From 1984 to 1989 the tailing was launched by pipe direct to Batata Lake. During these 10 years the lake has received around 24 x 10^6 t of solids, which was enough to impact 630 ha, corresponding to around 30% of the lake surface (Lapa, 2000). Since 1990, the refuse has been launched into deposits specially constructed in mined areas.

In 2001, the Company invested around US$4.6 million in environmental programs (Lapa, 2000) including the Batata Lake Recovery Program, a joint undertaking shared by Rio de Janeiro and Juiz de Fora Federal Universities and the Tailing Tanks Reclamation Program, a joint undertaking shared by Embrapa/Agrobiologia e Federal University of Viçosa, among others that makes the MRN a reference of environmental managing among mining companies not only in Brazil but also in all Latin America.

Tailing characteristics

The refuse produced by the milling process is basically mud, with 7% of solids (clay) formed by silicates (47%), Al_2O_3 (21%) and Fe_2O_3 (21%). Due to its high humidity content and the natural way the material loses water, these minerals are oriented during the drying process. This orientation promotes the formation of a substrate compacted and with high density when dried. The absence of organic material intensifies physical problems because this material has low level of structure and no macro porosity.

Due to the mineralogy of the material an intense weathering is resulted, which has an acid character with low availability of nutrients (Tables 1 and 2). In this way, due its unfavorable physical and chemical characteristics, the process of establishment and growth of plants is impaired if no interventions are done to reduce these unfavorable characteristics. Because of its origin, the tailing presents very low organic matter content (Table 2). Besides the fact that the material has high clay content, the minerals that form this fraction are of low activity, which is reflected by the cation exchangeable capacity of the material. All these characteristics show the importance of the substrate fertilization to promote the establishment of the vegetation. However, due to its physical characteristics, fertilization only may no guarantee the success of the revegetation. In this way, the carbon incorporation is also very important, because it allows the improvement of chemical characteristics and the presence of micro and meso-organisms that promote the structure of substrate improving its physical characteristics.

Revegetation of the tailing tanks

The tailing consolidation takes around two years due to its characteristics and the way it is pumped into the tanks. Before this period, it is impossible to walk on the tanks and the access only can be done by a special float pulled by tractors.

With the objective of to reducing the tailing consolidation time and incorporating carbon and nutrients to it, different experiments were carried out at the tanks in the way to anticipate the revegetation. Nowadays, the revegetation is done by the principle of two phases or steps, where the first one is done with the objective of preparing the substrate to receive the native species (second phase) that will give conditions to the sucessional process. The two phase principle is in accordance with to Griffith et al. (1966), who proposed a revegetation model for degraded lands where at the first step are used fast grow species to cover the substrate and to introduce carbon and nutrients like a “green carpet”. The second phase has the aim of providing the area with a better quality ecological product using native species.

The researches resulted in a methodology where of leguminous shrubs and trees, inoculated with selected strains of N_2-fixing bacteria and MVA fungi (Franco et al., 1995, Dias et al., 1996, Dias et al., 1999a,b) and fertilizers are applied together by hydroseeding technique. The critical points that took more time and researches were the relation among species and the amount of seeds of each species. Basically, we need a minimal plant density that allows a fast substrate cover, promote its draying, and incorporate C and nutrients without imperiling the establishment and growth of plants. Other tests were carried out involving fertilizer effects over inoculants, amount and form of fertilizers, equipments, and how to apply hydroseeding, which took time, funds and efforts from researchers and MRN´s environmental technicians.

Currently, the hydroseeding is done using 35 to 43 kg/ha of seeds, and species as *Sesbania virgata*, *S. exasperata*, *Senna sp.*(pajamarioba), *Senna reticulata* (mata pasto) e *Acosmium nitens* (itaubarana) form the base of the process representing around 60% of the number of seeds (Table 3). This process allows a fast drying and covering of the substrate (Picture 1), promoting its consolidation. Because most of the species used in hydroseeding are annual or biannual there is a natural process of death of plants during the drying process that increases the level of organic matter and nutrients of the substrate.

After the consolidation of the substrate, the access to add another species and fertilizers can be taken. This is the beginning of the second phase were native plants can be planted because the substrate has no more characteristics as adverse as in the beginning of the process; before the consolidation. In fact, the characteristics are not fully satisfactory, manly due to its high density, but we may have more control over all the procedures in terms of placement of fertilizers and seedlings.

The second phase has the important aim of planting species more suited to the substrate characteristics that will allow the natural ingression and establishment of secondary species from the primary forest surrounding the mined area. We hope that these secondary species will promote the transformation of the substrate in a soil and give sustainability to the area. This transformation involves the formation of organic superficial horizon, with the presence of organisms that are very important to improve the substrate chemical and physical characteristics.

The planting is done by using seedlings of a large number of native species, some of them are showed in Table 4, seizing the clefts that appear during the substrate drying. The planting is done in this way due to the high density of the substrate that impedes the digging of planting holes. By using of rinds of *Cecropia* sp, clefts are transformed in planting holes (Picture 2) were stored topsoil and fertilizers are added with the seedlings.

Among the species used in the second phase, *Sclerolobium paniculatum* (tachi dos campos), *Clitoria farchildian* (paliteira), *Parkia discolor (canela de garça)*, *Eugenia cumine* (azeitona), *Tapirira guianensis (*tatapiririca), *Dalbergia spruceana* (jacarandá do Pará) e *Enterolobium maximum* (fava tamboril) are showing good growth rates.

At the present, the researches are related to different aspects such as the quantification of nutrient initial inputs that may guarantee a biomass formation as close as the native primary forest, according to the possibility of the current climate. With this purpose we set two field experiments with different native species at the presence of four levels of one basic fertilization (Table 5) formed by the combination of fertilizers containing P, K, Ca, Mg, S, and micronutrients.

One year after the planting time, thirteen species were selected to be evaluated for plant height. Table 6 shows the models obtained by regression analysis for plant height as function of nutrient levels. These equations show that most of the species are responding the initial input of nutrients. In fact, some pioneer native species are very responsive to fertilizations, manly the leguminous species to phosphorus fertilization (Dias et al., 1995).

Besides biomass formation, the experiments are also monitored by the substrate transformation in soil. A number of variables are used, manly the ones that give the chemical, physical and biological soil quality characteristics. The monitoring program also looks at the sucessional vegetal process by the identification of natural ingressed species. Periodically, surveys are done to characterize the soil-organism activity and other insects, animals, and birds. All the information is processed with others coming from the revegetation of overburden and other materials in order to compare them. With this comparison, the company may have a diagnosis of all reclamation programs.

Conclusions

The joint among Mineração Rio do Norte S.A., Embrapa/Agrobiologia and Universidade Federal de Viçosa has allowed the development of a revegetation model for tailing tanks. This two-phases approach has permitted to accelerate the substrate drying process, and at the same time, to incorporate carbon and other nutrients at the substrate improving its physical, chemical and biological characteristics to facilitate the natural ingress of secondary sucessional species from the surrounding primary forest.

The preliminary results from the monitoring program do not allow us to have the assurance about the biomass that will be formed and the sustainability of the system. But as the base of

the revegetation program uses nodulated N-fixing leguminous shrubs and trees, we believe that we are building a system where the vegetation, organisms and the biogeochemical cycling will work together toward the sustainability of the environment.

References

Griffith, J.J.; Dias, L.E. & Jucksch, I. 1996. Rehabilitation of Mine Sites in Brazil Using Native Vegetation. In: *Forests - A Global Perspective*. Majumdar, S.K.;. Miller, W. E & Brenner, F.J. (Eds.). The Pennsylvania Academy of Science. Pennsylvania, USA. (Cap. 31) p. 470-488.

Lapa, R. P. 2000. A bauxite e o rejeito da bauxite. In: Bozelli, Esteves, F.A. e Roland, F. (Eds.) Lago Batata. Impacto e recuperação de um ecossistema amazônico. IB-UFRJ/SBL. Rio de Janeiro. (Cap. 3) p. 25-36.

Franco, A.A.; Campello, E.F.C.; Dias, L.E. & FARIA, S.M. 1995. Revegetation of acidic residues from bauxite mining using nodulated and mycorrhizal legume trees. *Nitrogem Fixing Trees research reports (special issue):* 313-320.

Dias, L.E. Franco, A.A.; Campello, E.F.C.; Faria, S.M. de & Silva, E.M. da 1995. Leguminosas forestales: aspectos relacionados con su nutrición y uso en la recuperación de suelos degrados. *Bosque* 16(1):121-127.

Dias, L. E.; Franco, A.A.; Campello, E.F.C., Faria, S.M. de 1999a.. The use of nitrogen-fixing trees to revegetate bauxite and gold mined areas in the tropics: Can trees substitute topsoil return?" In: Beijing International symposium on Land Reclamation (ISLR), Beijing, China, 1999. Proceedings..., China Coal Industry Publishing House. p:317-325.

Dias, L.E.; Campello, E.F.C.; Ribeiro JR E.S. & Mello, J. W. V. 1999. Initial growth of leguminous trees and shrubs in a cut gold mined area in Minas Gerais State, Brazil. In: Annual Meeting of American Society of Surface Mining and Reclamation – ASSMR, XVI, Phoenix, Arizona, USA. Proceedings… ASSMR 1999. p.316-321.

Dias, L.E.; Franco, A.A.; Campello, E.F.C. & Faria, S.M. de. 1996. The use of leguminous trees in reclamation of tropical mined soils. In: Annual Meeting of American Society for Surface Mining and Reclamation-ASSMR, XIII, Knoxville-USA, Proceedings.... ASSMR and Powell River Project of Virginia Tech, USA. 1996. p.601-612.

Table1. pH values, P and K available, Al, Ca and Mg exchangeable, and potential acidity at pH 7.0 (H+Al) of the bauxite tailing in Porto Trombetas, Para State, Brazil

pH H_2O	P	K	Al^{3+}	Ca^{2+}	Mg^{2+}	H + Al	SB
	---- mg dm^{-3} ----		---------- $cmol_c$ dm^{-3} ----------				
4,9	0,0	4	0,0	0,08	0,02	0,33	0,11

P and K available by Mehlich-1.

Table 2. Effective and total cation exchangeable capacity (CEC), organic matter (OM), bases saturation (V), aluminium saturation (m), remaining phosphorus (P-rem) e available content of Zn, Fe, Mn, and Cu of the bauxite tailing in Porto Trombetas, Para State, Brazil

CEC		OM	V	m	P-rem	Zn	Fe	Mn	Cu
Efet.	Total								
$cmol_c$ dm^{-3}		g kg^{-1}	---- % ----		mg L^{-1}	---------- mg dm^{-3} --------			
0.11	0.44	2.0	25.0	0.0	28.9	0.36	28.7	0.8	0.38

Zn, Fe, Mn, and Cu available by Mehlich-1.

Table 3. Amount of seeds of used species in the first phase of revegetation (hydroseeding) of the tailings ponds at Porto Trombetas, Para State, Brazil

Specie	**Amount**	**Specie**	**Amount**
	kg/ha		kg/ha
Acacia holosericea	0,25	*Senna sp.*	4,00
Cecropia sp	2,00	*Aeschynomene sensitive*	2,00
Pakia discolor	2,00	*Hidrochorea corymbosa*	2,00
Cajanus cajan	3,00	*Chamaecrista flexuosa*	2,00
Acosmium nitens	4,00	*Crotalaria juncea*	2,00
Vismia guianensis	0,50	*Sesbania exasperate*	4,00
Leucaena leucocephala	2,00	*Sesbania virgata*	4,00
Senna reticulate	4,00	*Sclerolobium paniculatum*	1,00
Senna occidentalis	4,00		

Table 4. Used species in the second phase of the revegetation (enrichment) of the tailings ponds at Porto Trombetas, Para State, Brazil

Specie	Specie
Clitoria fairchildiana	*Inga heterophylla*
Campsiandra comosa var. *laurifolia*	*Acosmiun nitens*
Dalbergia inundata	*Cecropia sp.*
Dalbergia spruciana	*Parkia discolor*
Copaiferamultijuga	*Eugenia cumine*
Euterpe oleracea	*Catostema albuquerquei*
Mabea caudata	*Sclerolobium paniculatum*
Dalbergia spruceana	*Enterolobium maximum*
Genipa americana	*Senna multijuga*
Tapirira guianensis	*Tabebuia barbata*
Eugenia cumine	*Mabea caudata*

Table 5. Amount of fertilizers applied at each treatment of the first field experiment of nutrients input at the tailing ponds

Treatment	Rock phosphate*	KCl	Micronutrients**
	---------- kg ha^{-1} ----------		
1	0	0	0
2	250	40	25
3	750	80	50
4	1250	120	75
5	2250	160	100

* Natural rock phosphate with 4 % of P_2O_5 citric acid soluble (20g L^{-1}).
** 1.8 % of B, 0.8 % of Cu, 3.0 % of Fe, 3.0 % of Mn, 0,1 % of Mo, and 9.0 % of Zn.

Table 6. The models obtained by regression analysis for plant height as function of the applied nutrients levels at the field experiment at the tailing pond in Porto Trombetas - PA

Specie	**Equation**	R^2
Eugenia cumine Azeitona	$Y = 8.309 + 113.822 X^{1/2} – 27.245 X$	0.892
Dipterix odorata Cumaru	$Y = - 23.251 + 87.450 X^{1/2} – 24.484 X$	0.725
Myrciaria dubia Camucamu	$Y = 64.839 + 2.093 X$	0.587
Capitari	$Y = 49.329 + 2.321 X$	0.646
Parkia discolor canela de garça	$Y = 77.906 + 6.919 X$	0.857
Genipa americana Jenipapo	$Y = 39.398 + 4.472 X$	0.965
Palmeira real	$Y = - 2.815 + 20.331 X^{1/2} – 5.881 X$	0.724
Tatapira guianensis Tatapiririca	$Y = 41.368 + 33.025 X – 4.252 X^2$	0.985
Enterolbium maximum Fava tamboril	$Y = 74.861 + 15.809 X$	0.980
Esclerolobium paniculatum Tachi	$Y = 37.056 + 7.931 X – 1.438 X^2$	0.821
Inga edulis Ingá	$Y = 11.268 + 92.248 X^{1/2} – 16.841 X$	0.912
Dalbergia spruceana Jacarandá	$Y = - 141.715 + 267.665 X^{1/2} – 71.186 X$	0.864
Clitoria forchildiana Palheteira	$Y = 18.836 + 75.062 X – 8.339 X^2$	0.986

Picture 1. Overview of one tailing tank one year after the hydrosseding process in Porto Trombetas, Para State, Brazil.

Picture 2. A detail of the planting hole made with rinds of *Cecropia* sp at formed clefts during the substrate drying.

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