INITIAL GROWTH OF LEGUMINOUS TREES AND SHRUBS IN A CUT GOLD MINED AREA IN MINAS GERAIS STATE, BRAZIL[1]

by

Luiz E. Dias, Eduardo F.C. Campello, Emerson S. Ribeiro Jr., Jaime W. V. Mello[2]

Abstract: In an opencast gold mining in Minas Gerais State, Brazil, leguminous trees and shrubs were used to revegetate an acid cut mined area. The substrate was high in pyrite content (3%) and received 50 cm of covered material in two layers: 1) insulating layer of 20 cm where clay or a mining refuse (MR) was used to prevent the pyrite oxidation, and 2) an upper layer with 30 cm formed by topsoil or topsoil + urban compost (3:1 v/v). After the application of the cover materials, planting holes were manually made spaced by 1 x 1 m. Each hole received limestone (100 g), rock phosphate (150 g), potassium chloride (45 g) and cattle manure (2 L). Fifteen leguminous species were planted an each plot (15 x 8 m), spaced by 1.0 x 1.0 m (one specie per row). Sixteen months after the planting the plants were evaluated and the results showed an effect of substrate on the plants survival, height and diameter. The use of clay as insulating layer was better than mining refuse and the plants did not respond to the addition of urban compost to the topsoil. Among the evaluated species, *Thephrosia sinapau, Erytrina verna, Dipterix alata* and *Stryphnodendrum guyanensis* showed a mortality rate of 100 % after 16 months while *Sesbania marginata, Acacia holosericea, Mimosa pellita, Acacia crassicarpa, Acacia mangium* and *Acacia angustissima* exhibited more adaptation capacity to the acid substrate. Analyses from the substrate showed higher exchangeable acidity (Al^{3+}) for the plots receiving MR as insulating layer.

Additional Key Words: Pyrite, revegetation, trees, topsoil.

Introduction

Studies involving pyritic substrates and acid mining drainage (AMD) are incipient in Brazil, but this problem has been observed in coal mines in Rio Grande do Sul and Santa Catarina States. Minas Gerais State also has large areas where the presence of sulfides is known, manly associated with gold, nickel, zinc, lead, and uranium mines. All these sites pose large acid mine drainage hazards. Fortunately, some mining companies are working to find better ways to avoid the occurrence of AMD, but due the many variables surrounding the process, each site requires its own solution and the companies need to test different approaches to find the best solution. One example is the Rio Paracatu Mineração, a gold mining company in Minas Gerais State which began research in 1991.

Since that time, assays with lysimeters were performed to predict the AMD potential, and to tests the effect of different cover materials, for avoidance of pyrite oxidation to create a good environment for plant establishment and growth (Pinto and Nepomuceno, 1998).

The use of leguminous trees to reclaim tropical degraded mined areas has been tested in different conditions with good results (Dias et al., 1996; Franco et al. 1995 and 1998) and the use of this methodology is growing with the scientific support of the National Center of Agrobiology Research (EMBRAPA/CNAPB). Field surveys to collect and identify native forest legumes with potential for land reclamation and greenhouse experiments to select the more efficient strains of rhizobia for each species were done by researches from this EMBRAPA'S Center (Faria, 1995).

To prevent formation of acidic drainage, the usual approach is to isolate the pyrite-containing material from water, which can inhibit the pyrite oxidation and prevent the dissolution of the products of oxidation to water (Richards et al., 1993). At the same time, in order to maintain the stability of the cover materials and to improve the landscape quality, the surface soil must provide conditions suitable for plants growth. The use of organic residues to improve the quality of cover materials has been a research and application focus in mined land reclamation for a long time. Most of the work reported to a date shows a beneficial effect, primarily from increased the water holding capacity (Joost et al., 1981 and

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[2] Luiz E. Dias and Jaime W. V. Mello are Associate Professor and Emerson S. Ribeiro Jr. is Graduate Student, in the Soils Dep., Univ. Federal de Viçosa, Viçosa, MG, 36571-000, Brazil. Eduardo F. C. Campello is Researcher III in the Agrobiology Research Center-EMBRAPA, Seropédica, RJ, 23851-970. Brazil.

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Schneider et al., 1981), availability of nutrients like N and P (Peterson et al., 1982 and Kerr et al., 1979), and cation exchange capacity, and decreased bulk density in high compacted mine spoils (Peterson et al., 1979).

The objective of this project was to evaluate the effect of four different approaches to form a cover material in a gold mined pyritic substrate, and to determine the initial growth response of 15 leguminous trees and shrubs.

Material and Methods

The site

The field trial was set up in 1997 on a cut gold mined area in Paracatu, Minas Gerais State, Brazil, 230 km South from Brasília. The substrate is formed from gray-dark phyllite with quartz structures, carbon, sulfides (around 3 % of pyrite and arsenopyrite) and 1 – 2 % carbonates (Table 1). The natural soil of the mining site is very thin and during the gold exploration it was mixed with the overburden and stored in open piles.

The field trial

A randomized complete split plot experimental design with four replications of four treatments was prepared to test four different approaches to covering the high pyrite content substrate. The cover materials effect was studied at the plot level and the comparison among species was studied at the sub-plot level. Each of the 16 plots was 15 m long and 8 m wide, with 8 plants of each species planted in lines spaced by 1.0 m.

The four treatments tested as cover materials were made from clay (B horizon of an Oxisol - Ustox) or mined refuse – MR as a seal layer (20 cm), plus an upper layer (30 cm) made from topsoil and overburden – TPO, or TPO mixed with urban compost – UC (3:1 v/v).

After the cover materials were applied planting holes were opened manually (40 x 40 x 30 cm) and they were filled as follows: 100 g of calcitic limestone at the bottom previously mixed zone with TPO plus 150 g of rock phosphate + 45 g of potassium chlorite + 2 L of cattle manure were mixed with enough quantity of TPO to complete the hole volume. The limestone was mixed separately to avoid direct contact of rock phosphate with it, which would decrease the solubilization reaction of the phosphorus fertilizer.

The species evaluated were: *Acacia mangium, A. crassicarpa, A. polyphilla, A. holosericea, A. angustissima, Stryphnodendron guianensis, Sesbania marginata, Erythrina verna, Mimosa pellita, Samanea saman, Albizia lebbeck, Dipteryx alata, Mimosa bimucrunata, Thephrosia sinapu, Calliandra calothyrsus.* The seedlings were inoculated with selected strains of *Rhizobia* (obtained at EMBRAPA/CNPAB - Rio de Janeiro, strain bank) and a mixture of two MVA fungi (*Glomus clarum* e *Gigaspora margarita*).

Sixteen months after the planting the treatment effects were evaluated by survival and by measuring height and diameter of the four central plants of each line. Samples of the cover soil materials were also taken in four depths (0-10; 10-20; 20-30 and 30-40 cm) and characterized for pH (water 1:2.5), exchangeable Al, Ca and Mg and available P and K (Melich-1).

Table 1. Chemical characteristics of the pyritic substrate and the clay and mined refuse (MR) used to form the insulating and the surface layer to cover the substrate

Material	pH (H_2O)	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	P	K	Pb	Cd	Cr	Ni
		-------- $cmol_c.dm^{-3}$ --------				-------------- $mg.dm^{-3}$ ------------					
clay	4.8	0.9	0.2	0.2	5.0	2.9	160	*	*	*	*
MR	4.2	0.1	0.1	0.1	0.4	6.1	49	29	1	**	**
substrate	2.0	0.0	0.4	4.1	10.6	15.3	6	12	11	**	8

* Value not determined.

** Value below to detection limit.

Ca^{2+}, Mg^{2+} and Al^{3+} extracted by KCl 1.0 mol/L

H+Al extracted by $Ca(OAc)_2$ 0.5 mol/L

P, K, Pb, Cd, Cr and Ni extracted by Melhich-1

Results and Discussion

Plants survival

Analysis of variance for the survival at 16 months showed an effect of substrate (treatments), species, and the interaction of these factors. The higher survival values (Table 2) where obtained with the use of clay as an insulating layer and soil (TPO) as upper layer, following by the use of clay as insulating layer and soil + urban compost (TPO + UC) as upper layer. In terms of general effects, the ANOVA results indicate that the use of MR as insulating layer caused more plant death and the addition of urban compost to the TPO to form the surface layer did not effect the plants survival.

The species *Mimosa pellita, Dipterix alata, Thephrosia sinapau* and *Erytrina verna* showed low capacity of adaptation to the substrate conditions and local clime. The mined area is located under "cerrado" vegetation (Brazilian phytogeographic region similar to savannas in Africa) which has, at least, three months of hydric deficit. But, in the other hand, species as *Acacia crassicarpa, Acacia angustissima, Mimosa pellita, Sesbania marginata, Acacia holosericea, Acacia mangium, Albizia lebbeck* and *Samanea saman* showed high value of survival, mainly when the insulating layer was formed by clay (Table 2).

Table 2. Survival rate of the species for the different treatments, sixteen months after planting

Specie	TPO Clay	TPO+UC Clay	TPO MR	TPO+UC MR
	%			
A. crassicarpa	100	100	50	68
A. angustissima	100	79	43	36
M. pellita	100	96	71	79
S. marginata	100	100	68	50
A. holosericea	96	100	68	93
A. mangium	93	100	61	56
A. lebbeck	93	100	96	96
S. saman	90	100	96	86
A. polyphilla	74	70	50	21
C. calothyrsus	50	9	50	39
M. bimucronata	50	0	50	50
M. pellita	0	0	0	0
D. alata	0	0	0	0
T. sinapau	0	0	0	0
Erytrina verna	0	0	0	0

Plants height and diameter

Similar to the survival results, the treatments also affected the height of the plants (Table 3). The larger values were obtained for plants growing in treatments where clay was used as an insulating layer, but we did not observe any effect of the mixture of urban compost to the surface layer. In spite of the fact that species like *S. marginata, A. holosericea, A. angustissima, A. cracicarpa, M. pellita, A. polyphilla* and *A. mangium* showed reasonable growth, a comparison of these data with other results obtained in other kind of substrates (Dias et al.1995, and Franco et al., 1998) leads us to the conclusion that some species did not express their growth potential in this experiment. Certainly, there is not only a substrate effect, but any comparison with others results must also consider climatic effects. Nevertheless, we may consider the fact that most of these species could be used in a revegetation program for this site, mainly if the insulating layer is formed from clay.

Table 3. Plants height for the different treatments at 16 months after planting

Specie	TPO Clay	TPO+UC Clay	TPO MR	TPO+UC MR
	m			
S. marginata	2.50	2.73	1.45	1.46
A. holosericea	2.27	2.45	1.69	1.91
A. angustissima	2.26	1.81	1.28	0.86
A. crassicarpa	2.17	2.08	1.16	1.47
M. pellita	2.10	1.81	1.57	1.56
A. polyphilla	2.05	1.54	1.01	0.74
A. mangium	2.04	1.96	1.09	1.31
A. lebbeck	1.49	1.46	1.45	1.02
S. saman	1.30	1.33	1.43	0.69
C. calothyrsus	0.84	0.27	0.99	0.82
M. bimucronata	0.81	-	0.59	0.91
Average	1.80	1.74	1.24	1.16

The best growth was observed to the shrub *S. marginata* which had been tested before in a bauxite mining refuse pond showing very fast growth. This species also showed great adaptation capacity because originally it is found in poorly drained soils in West-Center regions of Brazil. On the other hand, in spite of the current scientific debate about the use of native versus introduced species (Griffith et al., 1996; Moore et al., 1977), the acacia's growth confirms the high potential of these species to be used in land reclamation programs, supporting other reports (Franco et al., 1989; Kang et al., 1997)

In terms of plant diameter, our general results follow the same trends of as plant height, but this variable more clearly shows the negative effect of MR use on plant growth (Table 4). Despite the fact that we did not observe a general effect from the addition of organic matter to the surface layer, comparison between the treatments with clay as an insulating layer reveals a slight positive trend due to urban compost use. Possibly, the addition of this source of organic matter may provide more nutrients and water hold capacity for the substrate.

Table 4. Plants diameter for the different treatments at 16 months after the planting

Specie	TPO Clay	TPO+UC Clay	TPO MR	TPO+UC MR
	---------------- cm -----------------			
S. marginata	3.55	4.22	2.57	2.47
A. holosericea	3.10	3.15	2.35	2.57
A. angustissima	2.26	2.40	1.73	0.99
A. crassicarpa	3.69	3.80	1.87	2.44
M. pellita	3.88	4.11	2.98	3.24
A. polyphilla	1.86	1.49	1.00	0.59
A. mangium	3.70	3.73	1.76	2.05
A. lebbeck	2.50	3.20	2.31	2.24
S. saman	2.81	2.96	2.77	2.11
C. calothyrsus	1.36	0.59	1.96	1.75
M. bimucronata	1.74	-	1.31	1.81
Average	2.77	2.97	2.06	2.02

The mixture of urban compost in a ratio of 3:1 is equivalent (for one 30 cm layer) to 300 Mg ha^{-1}. For different mined substrates rates around 200 Mg ha^{-1} has been shown to have positive effects on yield of grasses and trees (Sopper and Seaker, 1984). One possible explanation for the lack of response to UC is the large size of the planting holes and the addition of fertilizers and cattle manure. Trenches opened beside some of the plantings showed that the majority of the rotting system was confined to the planting hole. This evaluation was done 16 months after planting, so it is likely that with more time the root systems will reach the substrate (external from the hole plants) and the UC effects will be more clear.

Substrate characterization

All the treatments showed a high levels of acidity below 20 cm (Table 5). The low value of pH is a consequence of the absence of liming around the planting hole area. The limestone was applied only into the planting hole, while the composite samples were taken from different places around the plots. The lower subsurface pH values were observed from the plots with MR as an insulating layer, indicating that the material is acidified by capillary rise of water from pyritic substrate. In response, the plants growth response showed the same trend.

The results also show that UC addition led to higher pH values at the surface in when compared with treatments without organic matter addition. Both treatments that received UC showed more exchangeable Ca and Mg, and it also worked to maintain the surface pH values higher than treatments without compost. This result may support the observed trend where plants growing at the TPO+UC/Clay plots produce greater diameter in a comparison with TPO/Clay plots. However, the most important point is the fact that at all depths the pH allowed exchangeable Al to be present in more soluble forms (pH < 5.5), directly affecting root system growth and the plants nutrition.

We did not have control of the urban compost process, mainly because we wanted to test the original product sold in the market. This particular product was prepared by the municipal waste composting plant at Brasília, and during processing received limestone and fertilizers application. Certainly, this helps explain the higher TPO pH and exchangeable Ca and Mg values.

Conclusions

Our preliminary results clearly show that topographic reconstruction of mining wastes such as these must consider the use of clay as an insulating material and the necessity of a broadcast application of limestone to reduce the acidity. Most part of the species tested showed a reasonable potential to be used on this particular site, but superior response was seen in *Sesbania marginata, Acacia holosericea, Mimosa pellita, Acacia crassicarpa, Acacia mangium* and *Acacia angustissima.*

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Table 5. Values of pH, exchangeable Al, Ca, and Mg and available P and K at the different depths and treatments

Treatment	depth	pH	Al^{3+}	Ca^{2+}	Mg^{2+}	P	K
	cm			------$cmol_c.dm^{-3}$ ------		---- $mg.dm^{-3}$ ---	
	0-10	4.17	2.5	0.65	0.50	5.7	34.3
TPO/Clay	10-20	3.80	3.5	0.80	1.20	5.7	26.0
	20-30	3.50	12.3	1.10	0.93	4.7	20.7
	30-40	3.60	16.1	0.57	0.83	2.3	32.3
	0-10	4.73	1.9	2.37	1.30	55.7	172.3
TPO+UC/Clay	10-20	3.67	5.5	4.30	1.70	42.0	18.7
	20-30	4.40	8.7	1.53	0.90	33.3	62.3
	30-40	3.60	13.6	0.20	1.80	6.7	14.7
	0-10	3.90	10.2	0.63	0.57	7.0	25.0
TPO/MR	10-20	3.40	10.3	1.10	1.80	4.0	21.3
	20-30	3.10	11.1	0.73	0.40	33.3	9.0
	30-40	3.00	10.8	-	-	34.7	8.3
	0-10	4.40	5.1	3.50	1.23	38.0	163.0
TPO+UC/MR	10-20	4.60	6.0	1.10	0.70	34.0	76.0
	20-30	3.40	6.1	-	-	15.3	5.7
	30-40	3.30	11.6	-	-	9.3	4.3

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