RESTORATION OF IRONSTONES OUTCROPS DEGRADED BY IRON MINNING ACTIVITY IN MINAS GERAIS STATE-BRAZIL[1]

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Abstract: The properties of the soils and underlying substrates of "canga" (ironstones outcrops) in central Brazil have a number of restrictions for the establishment of plant species, and the high specialization of local vegetation contributes to a high rate of endemic adaptations. The close association between the mining of iron and the need for locally adapted vegetation presents a special condition of vulnerability. This study evaluated varied approaches to the restoration of "canga" fields considering technical and economic aspects related to the application of topsoil, re-introduction of plants from local sources and their regeneration. We set up a field experiment on one overburden pile of Capão Xavier iron mine (mined by the Vale Company), composed of eight treatments formed from combinations of two thicknesses of "canga" and associated salvaged soils (20 and 40 cm) and four levels of fertilization. In each plot, we planted the same number of seedlings following the same spatial arrangement. The evaluation of the treatments was made at 10 and 42 months after planting for survival of the planted species. There was no significant difference among the average survival of seedlings planted for the different thicknesses of substrate and fertilization levels. The development of programs for ecological restoration of ferruginous fields should therefore consider, among other factors, the complex soil x vegetation mosaic commonly found in natural settings and thus carry out the "canga" material soil reconstruction sequence in order to reproduce this scenario. Furthermore, in view of the possible reduction in the number of plant individuals over time, there must be a satisfactory amount of individual species selected for reintroduction.

Additional Key Words: revegetation, ecological reclamation.

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Introduction

Brazil is very large country which has great variability in terms of geology, soil, vegetation, and climate. This geo-diversity also occurs on a smaller scale in Minas Gerais State, where we can find great variability in phytophysionomies. Among them, the *Cerrado* (Savannah), *Mata Atlântica* (Atlantic Forestry) and *Campos Ferruginosos* (ferruginous rock fields) currently receive more attention from the Environmental Agencies due to the importance in terms of degradation and biodiversity. "Campos Ferruginosos" are herbaceous and shrubby formations commonly associated with ironstone outcrops located above 900 m. The nature of these outcrops seems to determine the floristic composition of the area and is usually used in its classification (Rizzini, 1979).

The substrate of “canga” (ironstones outcrops) places a number of restrictions on the establishment of plant species, such as shallow soils, low moisture and nutrients, poor structure, and a wide daily temperature range. The high specialization of native-associated vegetation contributes to the high rate of endemic adaptations and site specificity that characterizes the flora of the ferruginous-altitude grassland ecosystems over hemathitic "canga" soils and underlying substrate. This ecosystem has experienced some of the greatest loss of habitat, and has fewer areas of occurrence and representation in protected areas. The close association between the mining of iron and those areas moved this research to focus upon the special conditions and vulnerability of these areas to disturbance.

In Minas Gerais State, the main and most well-documented occurrences of "canga" are located in the Iron Quadrangle region - IQ (Costa, 2003). The geologic and topographic diversity of the region, in fact, is one reason for the existence of a rich biodiversity, which justified the recognition of the IQ region as an "extreme biological importance" (Drummond et al., 2005) and its insertion within the Biosphere Reserve of the Espinhaço by UNESCO in 2005. Besides the legislation establishing mandatory recovery of degraded areas by mining, several sector companies adhered to systems of standardization that evaluate the effectiveness of rehabilitation/restoration projects through environmental audits and certification programs.

Fields of ferruginous ore outcrops do not have specific legislation for their conservation and utilization, and programs for their rehabilitation are incipient (Meirelles et al., 1999). A significant shortcoming concerns the lack of reclamation management of soils typical of this formation, as well as the lack of appropriate cultural practices. The salvage and reuse of topsoil as it has a native seed bank and promotes natural regeneration. In a study of conservation for "ex situ" ferruginous ore body species, Mendonça (2007) suggested that research on seed germination needs to be developed, and the topsoil reserved for restoration activities since they better allow for the dynamics of plant community re-establishment and may ensure the preservation of biological and genetic diversity of many species.

This work aims to propose new approaches to rehabilitation of "Campos Ferruginosos" in the IQ considering several technical aspects related to the application of topsoil and reintroduction of plants from pre-mine or local rescue operations. It is intended to propose management practices combining mineral exploration in IQ and biodiversity conservation of these environments.

Material and Methods

The experiment was established on top of a pile of overburden consisting of itabirite rocks which are a nutrient-poor mix of phyllite, dolomite, basic intrusive rock, and clay from Capão Xavier (CPX)-VALE mine, in the metropolitan region of Belo Horizonte, near the city of Nova Lima - MG, Brazil. The experiment area was covered with "canga" (ferruginous concretions and soil) from areas of mining expansion (Figs. 1 and 2). For the physical and chemical characterization of this material, we used bulk materials sieved to 2.0 mm, and the fraction passing was called soil associated with the "canga". We set 32 experimental plots of 50 m^2, with eight treatments (combinations of two thicknesses of "canga" and associated soil, 20 and 40 cm, and four fertilizer levels) with four replications. Nutrient levels were established based on soil chemical properties to establish basic balanced macronutrient levels (Table 1). For the formation of the final soil mixtures, we used the following fertilizers: termalphosphate (P_2O_5 soluble, 2% citric acid (1:100) 20% Ca, Mg 7% B 0.10%, 0.55% Zn, 0.12 Mn % Cu, and 0.05% Mo 0.006%), $MgSO_4$ (9% Mg and 12% S) and a mixture of N-P-K commercial fertilizer at 20-0-8. The planted species selection was made based on floristic surveys and according to the availability of seedlings in the nursery from local pre-mine rescue operations. The group of selected species (Table 2) was planted in each plot, with the same number of plants positioned with the same spatial arrangement. We evaluated the survival of plants at 10 and 42 months after the planting time and evaluated the data via an ANOVA followed by Tukey's test at 5% probability.

Figure 1. General view for the experiment area after setting the treatments.

Figure 2. The experiment after the planting time.

Table 1. Fertilization levels used to set the experiment.

Fertilization level	Termalphosphate	$MgSO_4$	N-P-K 20-0-8
	---------- kg/ha	----------	----------
0.00	0	0	0
0.33	300	183	660
0.66	600	366	1,320
1.00	908	554	2,000

Table 2. Used species to set the experiment.

Family / Species	Seedlings/plot	Growth habit
ARACEAE		
Anturium minarum Sakuragui & Mayo	2	Herbaceous
BROMELIACEAE		
Dickia consimilis Mez	1	Herbaceous
Bilbergia elegans Mart. ex Schult.	1	Herbaceous
Vriesia minarum L.B.Sm	2	Herbaceous
CACTACEAE		
Arthrocereus glaziovii (K. Schum.) N.P. Taylor & Zappi	5	Herbaceous
CLUSIACEAE		
Clusia arrudae	1	Shrubby
GESNERIACEAE		
Paliavana sericiflora Benth.	1	Shrubby
Sinningia rupicola (Mart.) Wiehler	1	Herbáceo
MELASTOMATACEAE		
Tibouchina multiflora Cogn.	2	Shrubby
ORCHIDACEAE		
Epidendrum secundum Vel.	1	Herbaceous
Hoffmannseggella crispata (Thunb.) H.G.Jones	5	Herbaceous
SAPINDACEAE		
Cupania sp	1	Woody
VELLOZIACEAE		
Vellozia caruncularis Mart. ex Seub.	1	Herbaceous
Vellozia compacta Mart.	1	Herbaceous
Vellozia graminea Pohl.	1	Herbaceous

Results and Discussion

The survival evaluation was done only considering plants introduced by seeds and seedlings from rescue operations flora. According to the Tukey test at 5% probability, there was no significant difference between the mean survivals of seedlings planted due to difference in thicknesses of substrate (Table 3). The survival of plants also did not correlate significantly with increased doses of fertilizers. Generally the average survival at 42 months after planting decreased compared to survival at 10 months (Table 4). The overall percentage of survival for all species, except *Vellozia albiflora* also decreased suggesting that beyond the use of conventional methods, we need to develop new techniques for plant establishment and management.

Table 3. Average value of survival at 10 and 42 months after the planting time, from different species used in the experiment as a function of fertilization levels and "canga" material thicknesses.

Fertilization level	10 months	
	20 cm	40 cm
	%	
0.00	93 a†	92 a
0.33	86 a	92 a
0.66	74 a	78 a
1.00	82 a	82 a
	42 months	
	20 cm	40 cm
	%	
0.00	47 a	44 a
0.33	41 a	46 a
0.66	41 a	43 a
1.00	56 a	37 a

† In line, means followed by the same letter do not differ at 5% probability by the Tukey test.

Analyzing the individual species, it is observed that *Paliavana sericiflora, Sinningia warmingii*, and *Vellozia graminea* had lower survival rates at the end of 42 months (Table 5). *Sinningia warmingii* is a plant that loses its leaves during the dry season, and at ten months, it was observed that with the beginning of rains, 50% of the plants showed regrowth. The visual value of the species *Epidendrum secundum* and *Catleya crispata*, and easy access to the site for surrounding residents to the experimental area may have contributed to the decreased survival of these plants. Despite the decrease in the survival percentage we identified many stems of *Tibouchina multiflora* that established from natural regeneration, which may indicate that this species propagates well by seed. In contrast, *Arthrocereus glaziovii* is present in the Brazilian Flora Endangered List and our results of survival of this species corroborate its vulnerability, pointing to the need for further studies of reproductive biology and management. The seedlings of the tree species *Cupania* sp. received nursery fertilization and irrigation for one year before out-planting, and this may explain their higher percentage of survival. The use of 20 and 40 cm of "canga" material in the construction of the plots established a mosaic situation very commonly seen in local grasslands. The species of *Vellozia, Tibouchina multiflora*, *Vrisea minarum* and *Paliavana sericiflora* had higher survival percentage in the plots with a thickness of 20 cm and are probably the species best adapted to environments where the "canga" is present as a continuous surface outcrop formation with associated soils. It is possible that the Bromeliaceae *Bilbergia elegans* is more adapted to environments more shaded and humid and it had a higher percentage of survival in plots with 40 cm of soil cover where individuals had already developed via natural regeneration and had created a conducive environment for their establishment.

Table 4. Survival rate of different species at 10 and 42 months after the planting time.

Species	Evaluation	
	10 months	42 months
	%	
Paliavana sericiflora	38	16
Sinningia warmingii	50	0
Epidendrum secundum	63	25
Anthurium minarum	67	59
Tibouchina multiflora	69	34
Vellozia albiflora	69	69
Vellozia compacta	69	53
Hoffmannseggella crispata	74	50
Arthrocereus glaziovii	75	33
Vrisea minarum	78	38
Bilbergia elegans	84	69
Clusia sp.	88	53
Cupania sp.	88	84
Dickya consimilis	88	27

Table 5. Survival rate of different species at 42 months after the planting time as function of "canga" material thicknesses.

Species	"Canga" thicknesses	
	20 cm	40 cm
	- - -- - - - % - - - - -	
Arthrocereus glaziovii	31	35
Sinningia warmingii	0	0
Anthurium minarum	56	63
Hoffmannseggella crispata	48	53
Bilbergia elegans	56	81
Epidendrum secundum	19	19
Tibouchina multiflora	63	50
Vellozia compacta	63	44
Vellozia albiflora	94	75
Vrisea minarum	47	28
Clusia sp.	56	50
Dickya consimilis	50	44
Paliavana sericiflora	25	6
Cupania sp.	81	88

The average of the area of vegetation cover as a function of the thickness of the substrate presented a significant difference for all doses of fertilization and it was possible to adjust regression model relating doses to vegetation cover. The thicker layer (40 cm) favored the increase of vegetation cover, especially when there was no fertilization application. In general, the layers of 40 cm presented a higher quantity of vegetation cover, and this result can be associated to different factors such as fostering of the development of the root system, greater availability of water, and nutrients associated to higher volume of substrate. Furthermore these layers may have received the greatest amount of seeds and propagules (Fig.4).

A

B

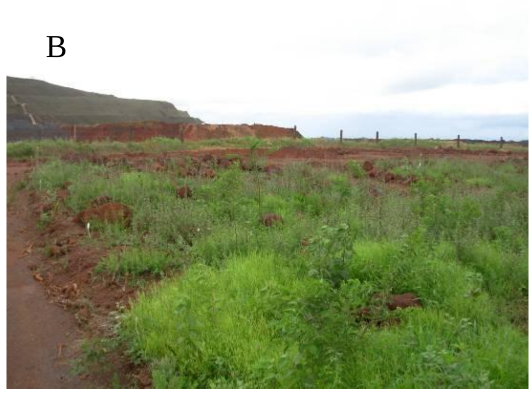

Figure 4. Vegetation cover over layer of 20 cm (A). Vegetation cover over 40 cm (B).

Conclusions

The development of programs for ecological restoration of ferruginous areas in Minas Gerais State should consider, among other factors, the natural soil x vegetation mosaic commonly found and thus carry out the "canga" material reapplication in order to reproduce this scenario. Furthermore, in view of the possible reduction in the number of individuals over time, revegetation practitioners should use higher amounts of the plant species selected for reintroduction.

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