BX19 - Rehabilitation in a Bauxite Tailing Dam System: A Pilot Project

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Abstract

The study aimed to test plant species and revegetation methods into degraded areas previously occupied as bauxite mining tailings dams in the Brazilian Amazon. To this end, revegetation methods were tested, comparing which technique is best to be employed in the revegetation of degraded areas resulting from dams filled with tailings and sterile soil. The tested techniques were employed in 16 study blocks, where different plant species and soil treatments were used, which considered the addition of organic fertilizers, chemical fertilizers and soil micronutrients, and the results were compared statistically and by visual and ecological evaluation. The study area comprises areas of Paragominas mine operation, installed in the municipality of the same name and owned by Hydro. The success of the result can significantly impact the recovery of degraded areas by mining dams, which create strong adverse environmental conditions, both chemical and physical. The use of Bauxite tailings material to fill dams is not a usual practice and presents great environmental improvement by avoiding the importation of landfill material which result in new environmental impacts. The tree growth obtained with the proposed environmental treatments shows great potential to generate new technical guidelines for the recovery of degraded areas with new technologies focused on dam areas filled with Bauxite tailings material.

1. Introduction

Hydro Paragominas is a project located in the municipality of Paragominas, in the state of Pará, Brazil, which mines and beneficiates bauxite ore, transforming it into pulp (50 % water and 50 % ore), that is sent by pipeline to the municipality of Barcarena (244 km), to transform into alumina and later aluminium (Figure 1).

Figure 1. Hydro Paragominas mining and Alunorte refinery geographical location. Source: Hydro.

Mining activities in the region, have as the first step the removal of vegetation before the excavation of topsoil and overburden to reach the bauxite deposit. After this last stage, the organic rich topsoil, which is removed and stored, is returned to the mined area, following contour reshaping with overburden to initiate forest recovery. Three different techniques are used for reforestation: traditional revegetation with seedlings; foster natural regeneration; and a third and innovative technique, nucleation. Currently, Hydro Paragominas has more than 2 900 hectares of mined areas in the rehabilitation process.

As for the management process of the tailings generated in the ore beneficiation stage, Hydro Paragominas operates on two different fronts. The first is the Vale Tailings System, that has been operational since the beginning of the mining activities (2007). It is currently in the process of operation closure. The second is the Plateau Dike Tailings System, which takes advantage of the mining pit from previous years implementing an innovative solution for drying the tailings and later returning them to the pit where the ore was mined, thus avoiding dam expansions and heightening, resulting in huge environmental and operational gains (this methodology is called Dry Backfill).

Aiming to carry out forest recovery in the dam areas as well, Norsk Hydro Brazil signed a technical cooperation agreement with the Brazilian Agricultural Research Corporation (EMBRAPA), to carry out a pilot project study integrating science and academy to make this action feasible, as detailed in the present paper.

2. The Valley Tailing Dam System

The Valley's tailings system, located on Hydro Paragominas' properties, with a total area of approximately 470 hectares, is basically composed of three dams, Dam B1 which is used for tailings disposal; the B5 which aims to protect the nearby springs; and B6, where the water clarification process in the tailings system takes place. This system began its operations in 2007 and is currently in the final operationalization phase, being gradually replaced by the tailings system called “Plateau Dike” (Figure 2).

As for the characterization of the waste, according to NBR 10004/2004, it is characterized as a Class II B – Inert, that is, non-hazardous and when in contact with water, they do not undergo physical, chemical, or biological transformations, remaining unaltered for a long period of time.

Currently, with the aim of starting tests for the forest recovery process of the tailing ponds, Hydro Paragominas signed an agreement with EMBRAPA, under the supervision of EMBRAPA's researcher PhD. Sergio Miana de Faria.

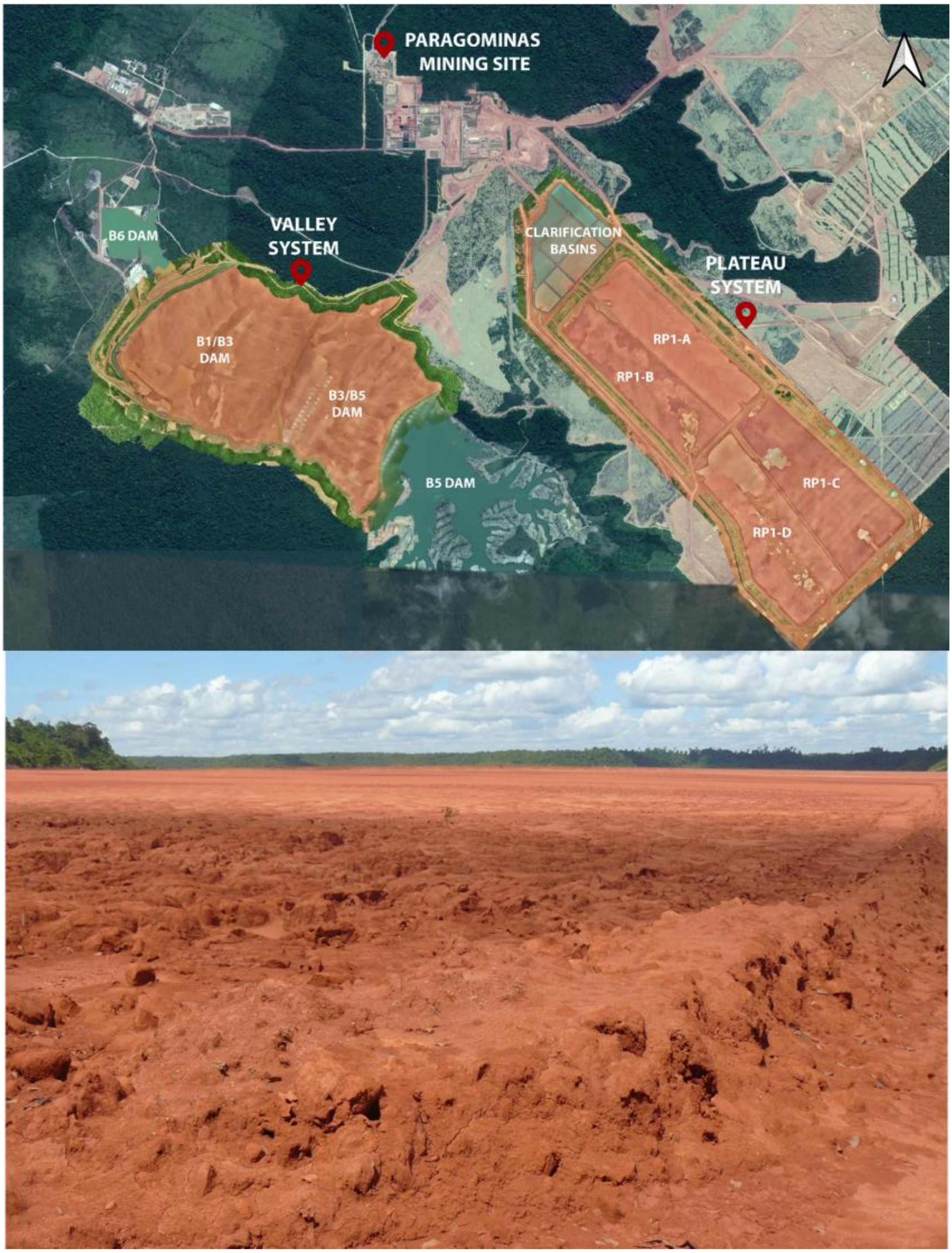


Figure 2. Location and general view of the Tailings System at Hydro Paragominas, Valley and Plateau's Dike. Source: Hydro.

3. Objectives

This experiment was implemented with the purpose of identifying species, rehabilitation strategies, and evaluating the potential use of topsoil in the revegetation of the tailings pond under the influence of different depths of the pond.

4. Area of Study

Hydro Paragominas is currently composed of two bauxite deposits located on the contiguous plateaus called Miltonia 3 (M3) and Miltonia 5 (M5), in the municipality of Paragominas, in the northeastern region of the State of Pará. The current production capacity is 11.1 million tonnes per year (MTPY), which is concentrated only in M3, located between longitude 47°30' W and latitudes 3° S and 3° 0' S. However, the company is licensed to produce 14.85 MTPA.

The implantation site of the demonstrative units was in the area called "Aro do Vale" (Rim of the Valley) in the following geographic coordinates (Figure 3):

- P1 (9638336.9411 N and 195540.0000 E);
- P2 (9638336.9181 N and 195525.0000 E);
- P3 (9638538.4477 N and 195524.6914 E); and
- P4 (9638538.4707 N and 195539.4707 E)

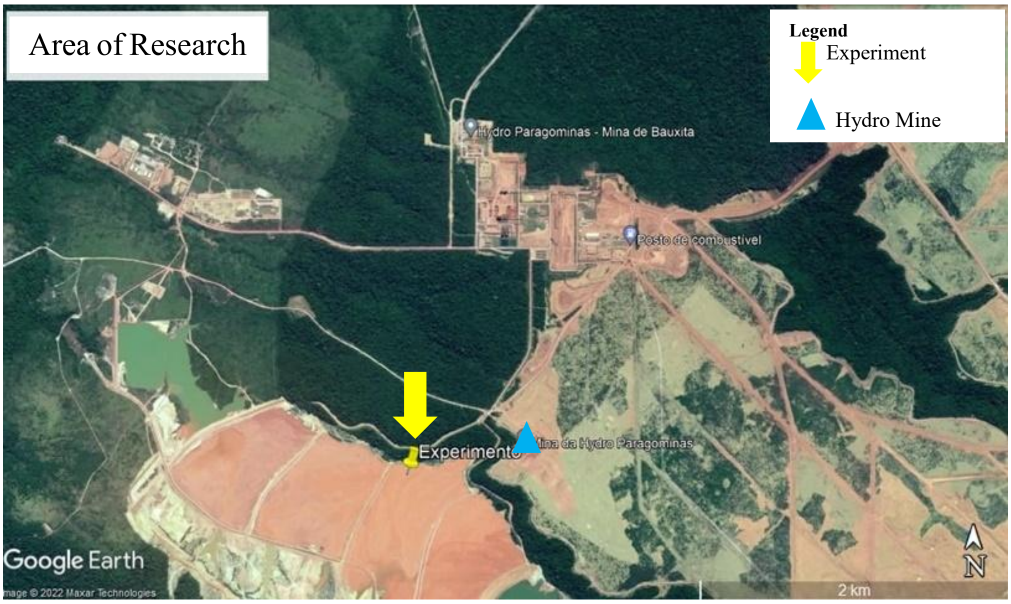


Figure 3. Location of the Vale Tailings System at Hydro Paragominas.

5. Methods (Methodology)

The experiment at Hydro Paragominas began to be implemented in March 2022 and the site chosen for implementation was the tailings basin, a basin located in "Aro do Vale" (Embrapa, 2022a). The experimental design adopted in this experiment was randomized blocks with subdivided plots, where the topsoil was allocated in the plots and in the subplots the species tested in 16 treatments and 4 blocks. The blocks were allocated at different depths of the bauxite washed tailings pond (Figure 4). Tho original fertilized substrate analyses have shown 0,05 % of C, 0,01 % of N, 0,00 (cmol/dm^3) of Al, 0,08 (cmol/dm^3) of Ca, 0,03 (cmol/dm^3) of Mg, H+Al 0,50 (cmol/dm^3), 5,4 mg/L of K and 1,04 mg/L of P.

All blocks have plots with and without topsoil, and the pits were opened 1 m from the ends and approximately 2 m between plants and received the fertilizer mixture[1] composed by 2 L of "manure"/pit; 200 g/pit of NPK 10:28:20; and 10 g/well of FTE BR 12 (Figure 5).

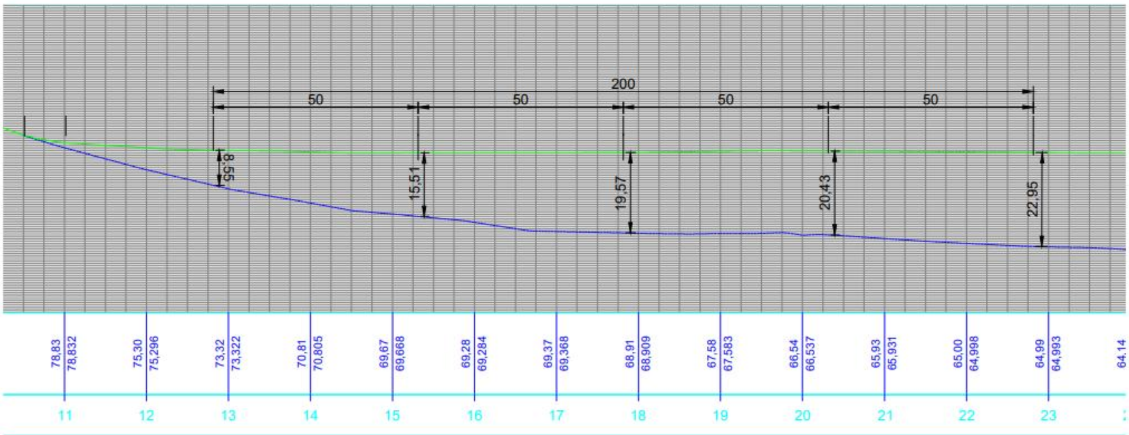


Figure 4. Relationship between block distribution and depths of the tailings disposed in the tailings tank.

The fertilizer mixture was chosen considering the chemical composition of the tailings as it follows:

Table 1 - Chemical composition of the bauxite tailings of Valley Dam System.

Sample	% C (%)	Al ($cmol/dm^{-3}$)	Ca ($cmol/dm^{-3}$)	H+Al ($cmol/dm^{-3}$)	K (mg/L)	Mg ($cmol/dm^{-3}$)	N (%)	P (mg/L)	pH (unid)
Tailings	0,05	0	0,08	0,5	5,4	0,03	0,01	1,04	5,82

Figure 5 – A. Pits; B. Seedling implantation work fronts.

The study consists of 8 plots measuring 12 m × 8 m and containing 16 subplots of 6 m × 6 m with 9 plant seedlings, totaling a total area of 28 m × 204 m or 5 712 m² (Figure 6). Within the blocks, individuals of the same species, combinations of two species or seed mix planting were distributed in each treatment (Table 1). The growth of some species after 11 months is shown at Figure 7.

[1] The compositions of the fertilizers are: Mixed Mineral Fertilizer 13-11-21 (13 % N; 11 % P_2O_5; 21 % K; 8.6 % SO_4); Simple Mineral Fertilizer - Magnesian Thermophosphate (17 % P_2O_5; 18 % Ca; 7 % Mg; 0.1 % B; 0.05 % Cu; 0.3 % Mn; 10 % Si; 0.55 % Zn) and Mineral Fertilizer Complex Gr. FTR Br 12 (1.8 % B; 0.8 % Cu; 2 % Mn; 9 % Zn).

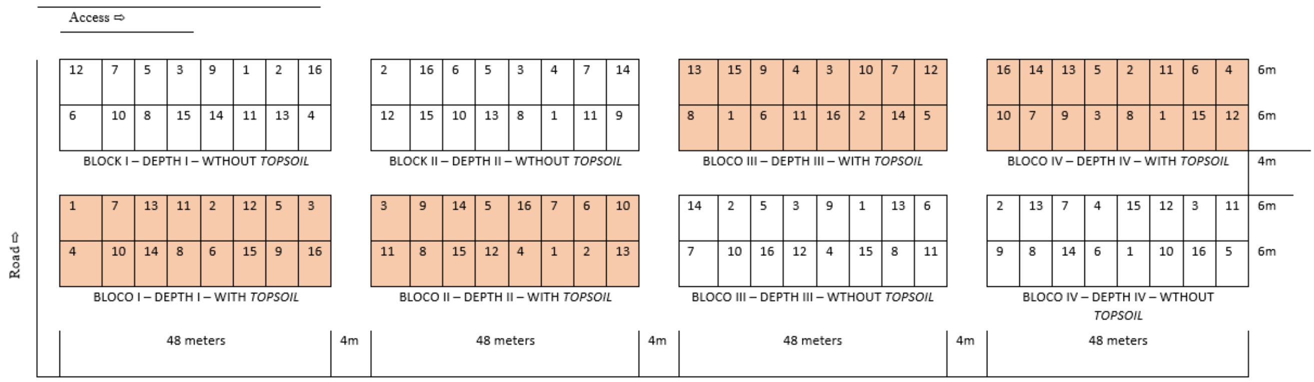


Figure 6. Sketch of the Experiment in "Aro do Vale".

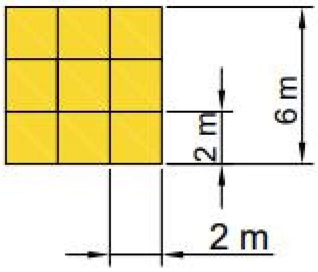
Regarding the plant species, 14 species planted from seedlings were tested, and in 2 treatments the planting was carried out from the combination of two species in different proportions and a single treatment with direct sowing (Figure 7).

Figure 7. Photographs of the implemented experiment. A, Pau-de-Balsa (*Ochroma pyramidale)* and *B,* Jenipapo (*Genipa americana)* after 11 months of planting.

As for the establishment and growth of the plants, the monitoring of the total height (using a graduated telescopic pole and a measuring tape), the crown area (using a measuring tape), the survival rate and the diameter at ground level (from the use of a digital caliper). The subplots where the seed mix was sown are photographed using an Unmanned Aerial Vehicle of the Drone type.

Table 2. Example of treatment draw within the blocks and spacing between seedlings.

Treatment	Common Name	Scientific Name
1	Tapiricica	*Tapirira guianesis*
2	Jenipapo	*Genipa americana*
3	Sombreiro	*Clitoria fairchildiana*
4	Ingá-cipó	*Inga edulis*
5	Pau-de-Balsa	*Ochroma pyramidale*
6	Fava-bolota	*Parkia platycephala*
7	Paricá	*Schizolobium parahyba*
8	Jatobá	*Hymenaea courbaril*
9	Samaúma-brava	*Cochlospermun orinocense*
10	Ipê	*Hondroanthus serratifolius*
11	Ingá-branco	*Inga edulis*
12	Muruci	*Byrsonima crassifolia*
13	Fava-rosa	*Cassia grandis*
14	Sombreiro e Janaúba	*Himantanthus drasticus* (6:3)
15	Sombreiro e Janaúba	*Himantanthus drasticus* (8:1)
16	Seeds Mix	*Swietenia macrophylla* (0.225 kg), *Tachigali vulgaris* (0.1125 kg), *Canalia ensiformis* (2.25 kg) and *Crotalaria spectabilis* (0.1875 kg)



6. Results and Discussions

In October 2022, the researchers responsible for the study issued a report (Embrapa, 2022b) in which they presented results on a) individual survival; b) total height, height increment and regrowth; and c) diameter at ground level (DGL), which will be presented in the topics below. And in April 2023, a technical report was issued, where some partial results related to plant growth and fauna return in the experiment area were presented.

6.1 Field Survey and Analysis of Results (October 2022)

6.1.1 Survival of Individuals

In this experiment each living individual and the survival rate per block were also classified (Figure 8).

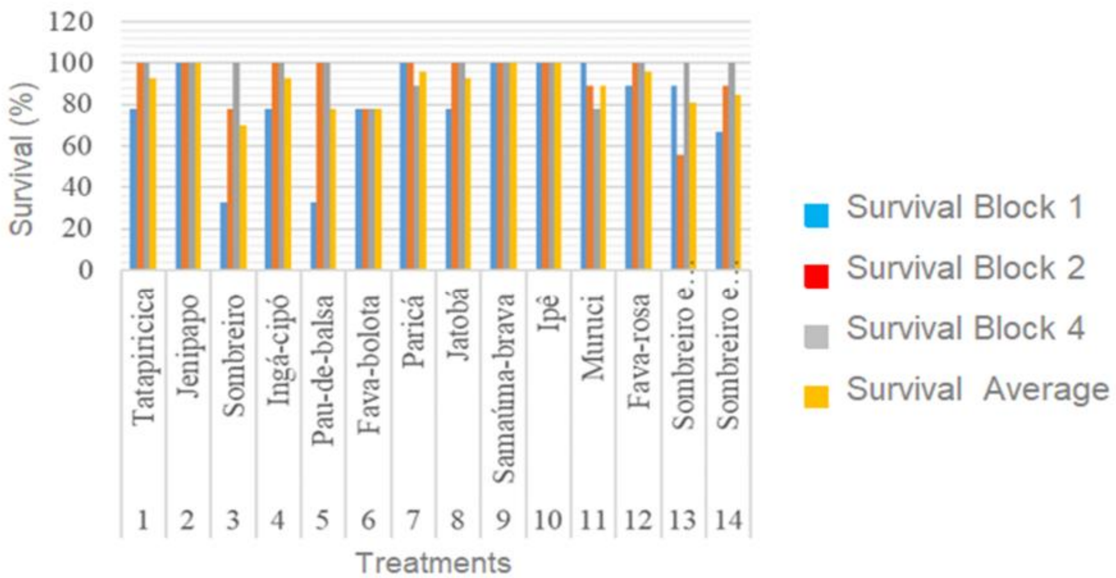


Figure 8. Survival rate (%) by treatments in each block (01, 02 and 04) and the average of survival rates.

It can be seen from Figure 8 that most treatments achieved an average survival rate above 80 % in 11 of the 14 treatments. Out of the treatments with a lower survival rate, Sombreiro (*Clitoria fairchildiana*) and Pau-de-balsa (*Ochroma pyramidale*) had, in block 01, 33 % survival, that is, of the nine individuals planted, only three survived. Treatment 6, Fava-bolota (*Parkia platycephala*), obtained 78 % survival in the three blocks.

6.1.2 Total Height, Height Increment and Regrowth

The total height (cm), diameter at ground level (DGL) and classification according to regrowth was measured. Regrowth consists of losing of the apical bud and the birth of a subsequent bud on the plant. Therefore, it is still alive but may present a lower height than the initial one, demonstrating how the plant is adapting to face some local adversity, be it attack by insects or strong winds.

The total height (cm) is described in Figure 9 and the increment in height (cm) was also calculated from it, in Figure 10.

From Figure 9, it can be observed that species such as Sombreiro, Pau-de-balsa, Paricá (*Schizolobium parahyba* var. *Amazonicum*), Ipê (*Handroanthus serratifolius*) are having better growth responses in Block 04.

Figure 10 describes the results of the height increment, that is, how much the plants grew between March and July, subtracting their initial height. From Figure 10 it is easier to observe the positive performance of species such as Jenipapo (*Genipa americana*), Sombreiro, Ingá-cipó (*Inga edulis*), Pau-de-balsa, Fava-bolota, Paricá, Jatobá (*Hymenaea courbaril*), Ipê, Murici (*Byrsonima crassifolia*), Fava-rosa (*Cassia grandis*). Particularly noteworthy is the average increment of Paricá, close to 30 cm in 4 months, as well as Pau-de-balsa and Murici, close to 20 cm. Increase in height with negative result, in all blocks, only Tatapiririca. Other treatments such as Samaúma-brava (*Cochlospermum orinocense*) obtained a negative increase in blocks 01 and 04. The Sombreiro and Janaúba combination, treatments 13 and 14, showed a negative increase in block 01.

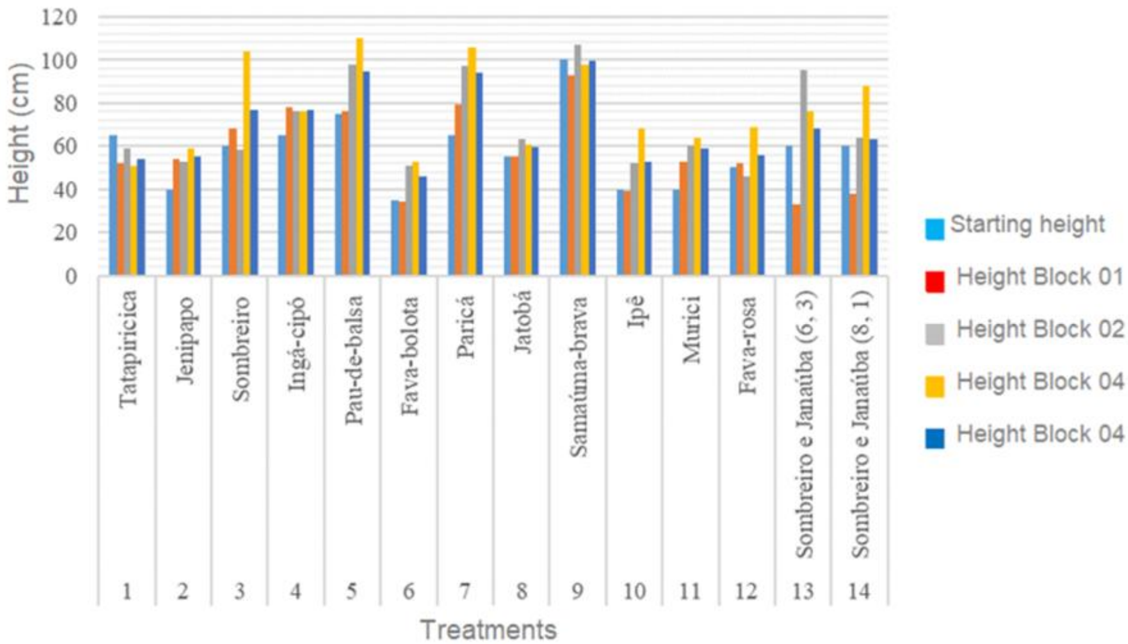


Figure 9. Average of initial height of individuals when they were planted, how much was measured in total height per block in July 2022 and the mean height of blocks by treatments.

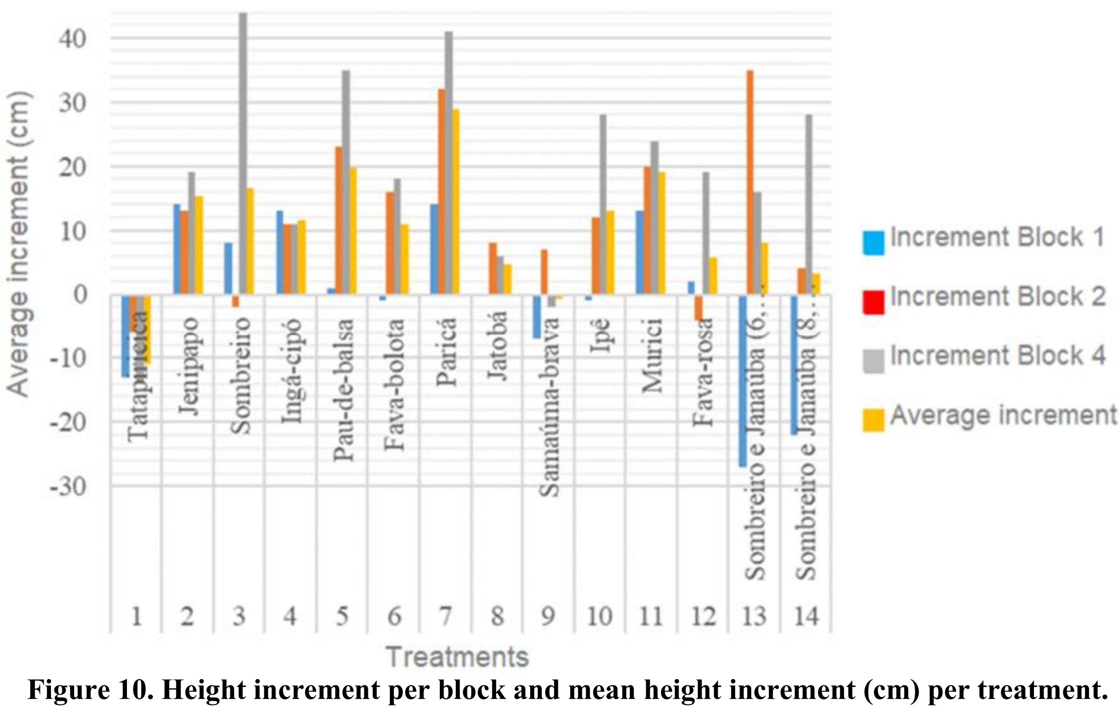


Figure 10. Height increment per block and mean height increment (cm) per treatment.

The height increment data can be explained, in part, by characterizing the presence of regrowth in the field (Figure 11).

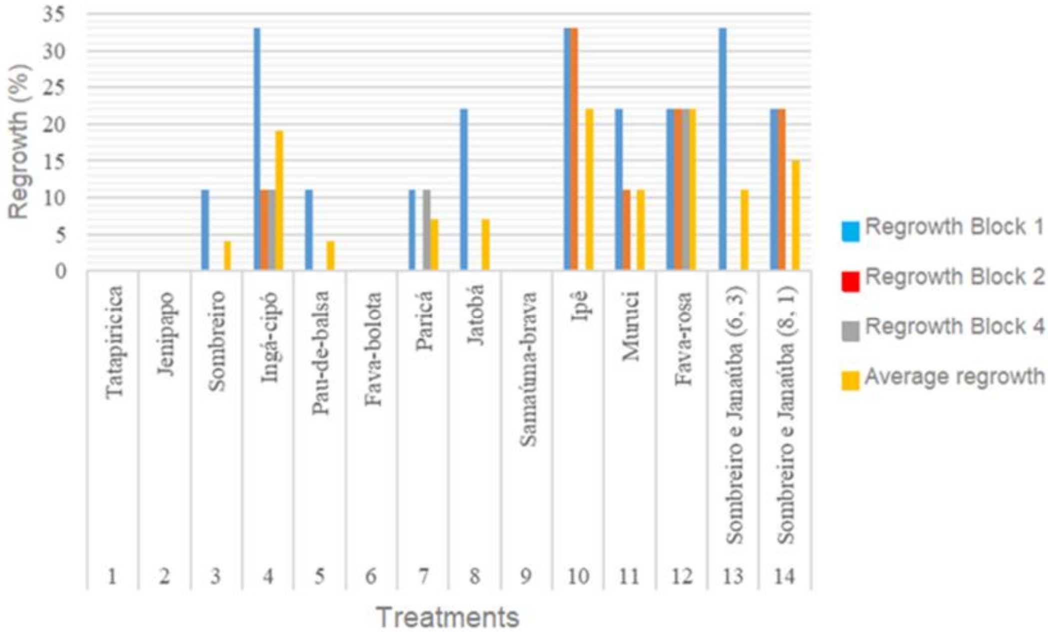


Figure 11. Regrowth by treatments in each block and the average of the results.

It is observed, in Figure 11, that, in general, the incidence of regrowth stands out more in block 01 and occurs in 10 of the 14 treatments. It was verified to be expressive in treatments 10, 13 and 14, which obtained a negative increment in block 01.

6.1.3 Diameter at Ground Level (DGL)

For each treatment, the diameter at ground level (DGL) was also measured (Figure 12).

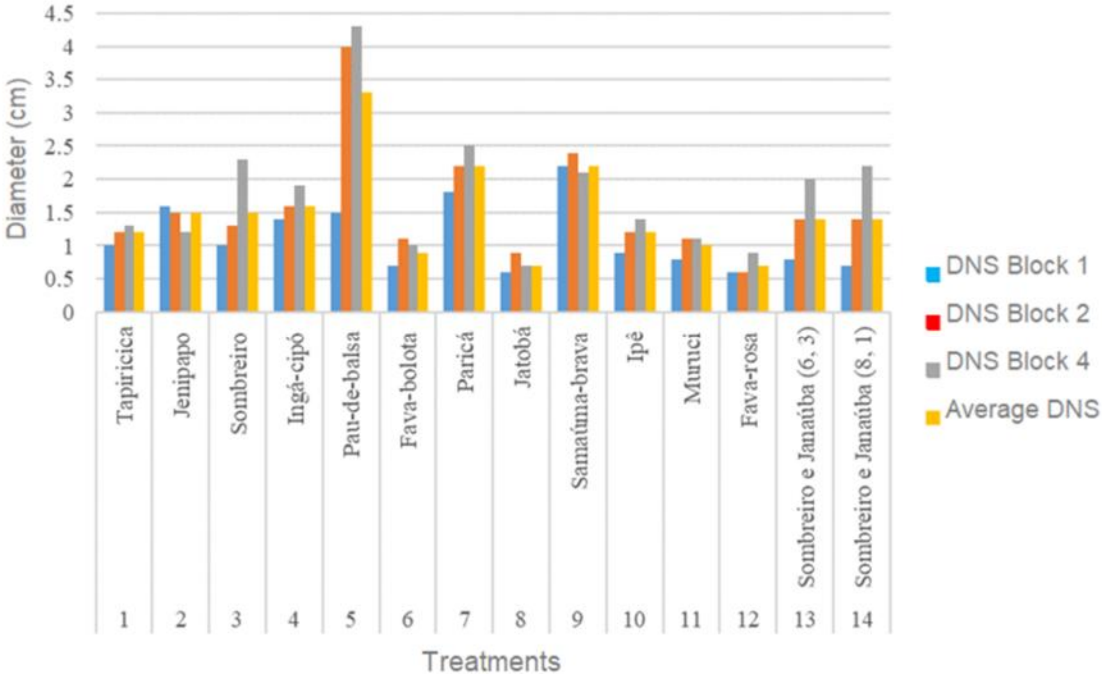


Figure 12. Diameter at ground level (DGL) for each treatment per block and general mean value.

Diameter at ground level is measured approximately 5 cm above the ground and shows growth in stem diameter. This first measure will be an important piece of data along with others taken in regular monitoring of planting. In general, it can be observed that, as well as the growth in height, the growth in diameter has been greater in block 04 and smaller in block 01. However, these differences tend to stabilize in the next monitoring campaigns.

6.2 Technical Note (April 2023)

In April 2023, the EMBRAPA team issued technical report (Embrapa, 2023) in which they observed that the species introduced in the Vale I experiment have been attractive to the local fauna. It was possible to confirm the presence of tapirs that have been visiting the environment and feeding on the Embaúba species and, through its excreta, Murici seedlings emerged (Fig. 13 – D). In addition, the presence of bird nests (Fig. 13 – E) and two species of wasp (13 – F) were verified.

Figure 13. Observations on the Vale I Experiment. A – Height of the balsa tree; B – Tapir paw prints; C – Tapir bite on the apical bud of Embaúba; D – Murici regeneration in places where the tapir defecated; E – Bird's nest in Paricá planted; F – Wasp box in Ingá-cipó.

The following are the photographic records taken in the recovery area in April 2023.

Figure 14. EMBRAPA researcher and Hydro's geologist visiting the experimental study.

7. Conclusions

As for the mining experiment in Paragominas, it was possible to observe that the planted species had a high percentage of survival in the field. Species such as Sombrero (*Clitoria fairchildiana*), Pau-de-balsa (*Ochroma pyramidale*) and Paricá (*Schizolobium parahyba* var. *Amazonicum*) are standing out from the others in terms of height growth.

It was observed that block 04 has presented the best conditions for the development of plants so far. Monitoring the establishment and development of species in this substrate is of great value, as the dry period may delay the growth of species or even lead to the loss of some individuals and/or species.

The results are innovative and promising because they present the use of techniques that allow revegetation of areas with initially sterile soils, considering that they are areas landfilled with Bauxite extraction tailings. The tree growth obtained with the proposed environmental treatments shows potential to generate new technical guidelines for the recovery of degraded areas focused on dam areas filled with Bauxite tailings material.

It is important to highlight that, as this is a study carried out through technical-scientific cooperation between EMBRAPA, NHB and MPSA, the knowledge generated from the experiments will be transformed into publicly accessible scientific products (publications, undergraduate work, master's dissertation, doctoral theses) that can support and promote new methodologies and technologies for the recovery of systems that have similar scenarios or characteristics.

Finally, it is important to reinforce the partnership of the Environmental Agency of Pará State (SEMAS - Pará) for the technical support in the several scientific projects that Hydro proposes and carries out in its operations. The Hydro's continuous improvement process, aligned with current ESG and Sustainability pillars, aims to reduce the environmental footprint of the aluminum value chain, engaging relevant stakeholders as: scientific institutions, universities and environmental agencies, in line with Sustainability Development Goals (SDG).

8. References

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