BX16 - Tailing Dam Closure with Revegetation: Use of Green Manure for the Improvement of Technosoil Built from Bauxite Tailings

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Abstract

The closure process of tailing dams is today one of the great concerns related to tailing dam management in the mining sector, which can be noticed by the latest changes on international standards and federal legislations (specially in Brazil) regarding the topic. To close tailing dams applying revegetation as a technique of dam recharacterization is a great challenge, mainly because the organic material (OM) in the substrate is very poor or nonexistent. In agriculture one of the techniques used to improve nutrients availability in soil is green manure, based on that, we tested the application of green manure on a pilot area filled with bauxite tailing. The species used were *Crotalaria spectabilis* Röth and *Canavalia ensiformis* (L.) DC, which are mentioned in many studies as great biomass producers. We prepared three different treatments to evaluate the biomass production in different conditions of organic material pre-availability: T1 – OM added; T2 – no OM added; and T3 – control. The biomass production by *Crotalaria spectabilis* was 110 % higher in T1 than in T2. From *Canavalia ensiformis* the biomass production was only 18 % higher in T1 than in T2. Even though biomass production was lower in T2, we count as positive the result obtained considering that no additional OM was included to this treatment, which means we got to have biomass production directly over the bauxite tailing. Additionally, the study shows that green manure is a possibility of improving technosoil quality for the initial phase of tailing dam closure in the bauxite mining industries and it can be tested for other minerals tailing.

Keywords: Tailing, Bauxite, Leguminous cover, Green manure, Technosoil.

1. Introduction

Bauxite is currently the main raw material globally used in the aluminum production chain [1]. For the generation of bauxite pulp that is used in the production of alumina, the ore undergoes a physical processing process of grinding and washing from where two materials are generated: the product (bauxite pulp) and a clay pulp that is not usable in the process (tailings) [2].

Although new technologies for tailings disposal are emerging, according to the Brazilian Aluminum Association - ABAL [3] the main form of bauxite tailings disposal in Brazil still occurs in large reservoirs, in which the tailings go through a drying and accommodation process over time until the end of the reservoir's useful life.

Since 2017, after the occurrence of accidents with tailings dams, both Brazilian legislation and international standards for mining companies have undergone revisions and creation of new requirements, which are linked to the maintenance, operation, and closure processes of these structures. International standards applied to companies in the aluminum chain, such as the performance standards of the Aluminium Stewardship Initiative – ASI and the guidelines that support the principles of the International Council on Mining & Metals – ICMM, have become more restrictive regarding the application of the best environmental practices and long-term stability in the closure and post-closure of tailings dams [4, 5, 7].

Given this scenario, there is a need for companies in the sector to develop dam closure plans that contemplate viable, sustainable practices, in accordance with socio-environmental issues and that meet the new standards imposed by legislation and certification entities, which directly influences financing processes in national and international banks [6].

To apply revegetation as a technique for tailings dam closure, the process of improving the availability of nutrients in the substrate is a key step. In this sense, the application of cover leguminous has been widely applied and indicated as a green technique to increase nutrients in poor or degraded soils, for its fast-growing cycle (fast soil coverage), its capacity of nitrogen fixation into the soil, its contribution for nutrients cycling, and the possibility of using it as additional organic matter input [8, 9].

2. Methods

This study was performed in the city of Paragominas, Pará, Brazil in the bauxite mine of Hydro Paragominas (Figure 1). The experiment was implemented in a pilot dyke filled with bauxite tailing, the height of the tailing was about 1 meter, and the last tailings disposal occurred in December 2016.

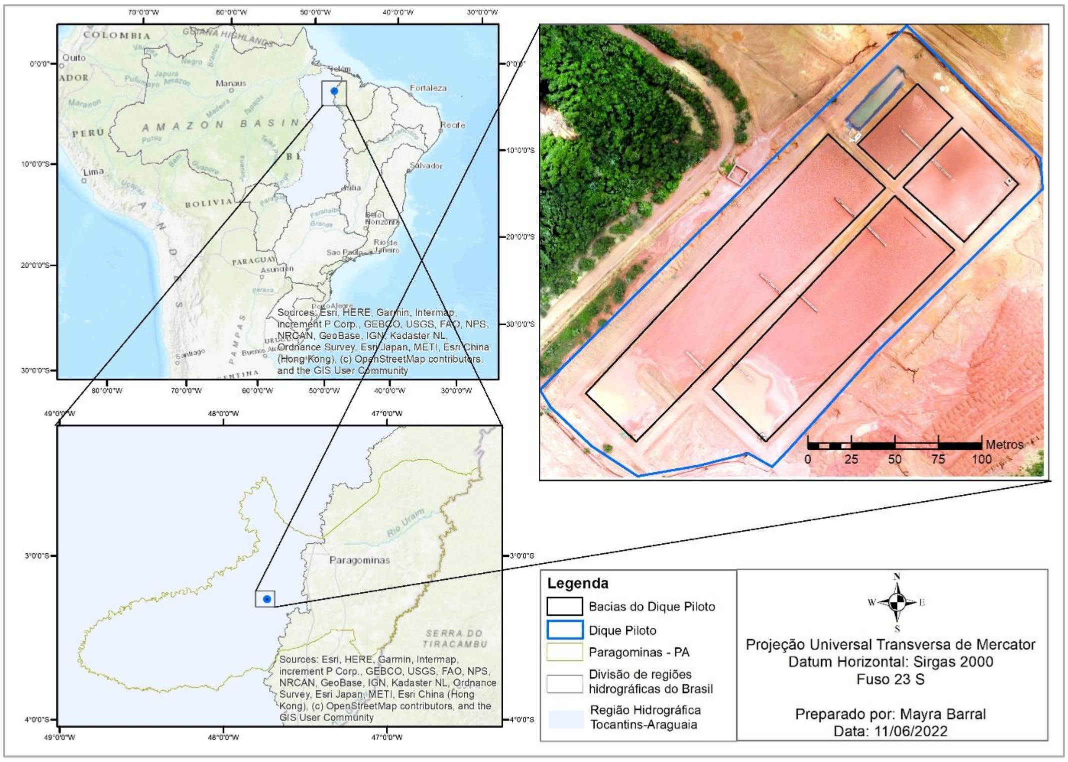

Figure 1. Location of the experiment area

To characterize the chemical attributes of the pilot dyke material before the experiment, we collected samples on August 2nd, 2021. This analysis demonstrated that the tailing has characteristics of acid soil with very low or nonexistent macronutrients and organic material content.

The area was prepared in January 2022, when deposited tailing was submitted to soil decompaction, acidity correction and fertilization. To correct the soil pH, 0.302 t/ha (302 kg ha-1) of dolomitic limestone with 91 % PRNT was applied.

The experiment was organized in random blocks, five repetitions, and three treatments: T1 – leguminous sowing with organic material addition; T2 – leguminous sowing with no addition of organic material; and T3 – control treatment. The organic material added on parcels of the treatment T1 was forest residues from wood in decay process.

For the green manure process, we selected two short life cycle leguminous species, which were *Crotalaria spectabilis* Röth and *Canavalia ensiformis* (L.) DC. These two species are mentioned as great biomass producers in many studies (BARRETO, FERNANDES, 2001; RAYOL; ALVINO-RAYOL, 2013; LOPES, 2000; CARVALHO et al., 2022; PAULINO et al., 2009; ANDRADE et al., 2022). Crotalaria seeds were sown in a straight line with 2 cm between them, while *Canavalia ensiformis* seeds had a spacing of 10 cm between them, as indicated Fernandes, Barreto and Emídio Filho (1999).

We collected biomass from *Crotalaria spectabilis* 77 days after sowing, and from *Canavalia ensiformis* (Pork beans) 141 days after sowing. Both collections dates were guided by the flowering phase of most individuals in each species. After that, all individuals were cut and applied as green manure within the parcels in each treatment.

The biomass production of the cover species (Crotalaria and Pork Beans) was estimated from the total dry mass (TDM), for collection were randomly delimited 3 subplots of 1 m² each, the collection of aerial biomass occurred in the flowering period (May/2022 for Crotalaria and July/2022 for pork beans) from the shallow cutting of the seedlings within the subplots.

To check if chemical attributes were improved, chemical characterization of the tailing technosoil was performed in two moments, the first one six months after sowing, and the second twelve months after sowing. We analyzed the parameters of organic matter, pH in H_2O, potential acidity (H+Al), and exchangeable cations (Ca+2, Mg+2 and K^+), Al^{+3}, P, according to the methodology indicated by Teixeira *et al*. (2017). Thus, it was also possible to estimate the values of sum of bases (SB), cation exchange capacity (CTC), base saturation (V %) and percentage of Al saturation. Soil samples were collected in three depths: 0–5 cm, 5–10 cm, and 10–20 cm.

3. Results and Discussion

The average dry mass (DM) production by *Crotalaria spectabilis* Röth (crotalaria) was 110 % higher in the treatment plots T1 (equivalent to 7.81 t/ha) in relation to the average result obtained in the plots of the T2 treatment (equivalent to 3.71 t/ha). As for the cover species *Canavalia ensiformis* (L.) DC (pork beans), the average dry mass production was 18 % higher in the treatment plots T1 (equivalent to 1.65 t/ha) in relation to the average result obtained in the plots of the T2 treatment (equivalent to 1.40 t/ha).

Throughout the collections, after green manure process through the application of cover species, it was identified that there was spontaneous germination of *Crotalaria spectabilis*, thus, in the 11th month after the implementation of the experiment, we cut the cover species again and measured biomass production of germinated individuals. In this case, we noticed that DM production in T1 was higher than in T2, equivalent to 0.67 t/ha in T1 and 0.04 t/ha in T2.

The pictures in the sequence (Figure 2) show how the cover species developed over time.

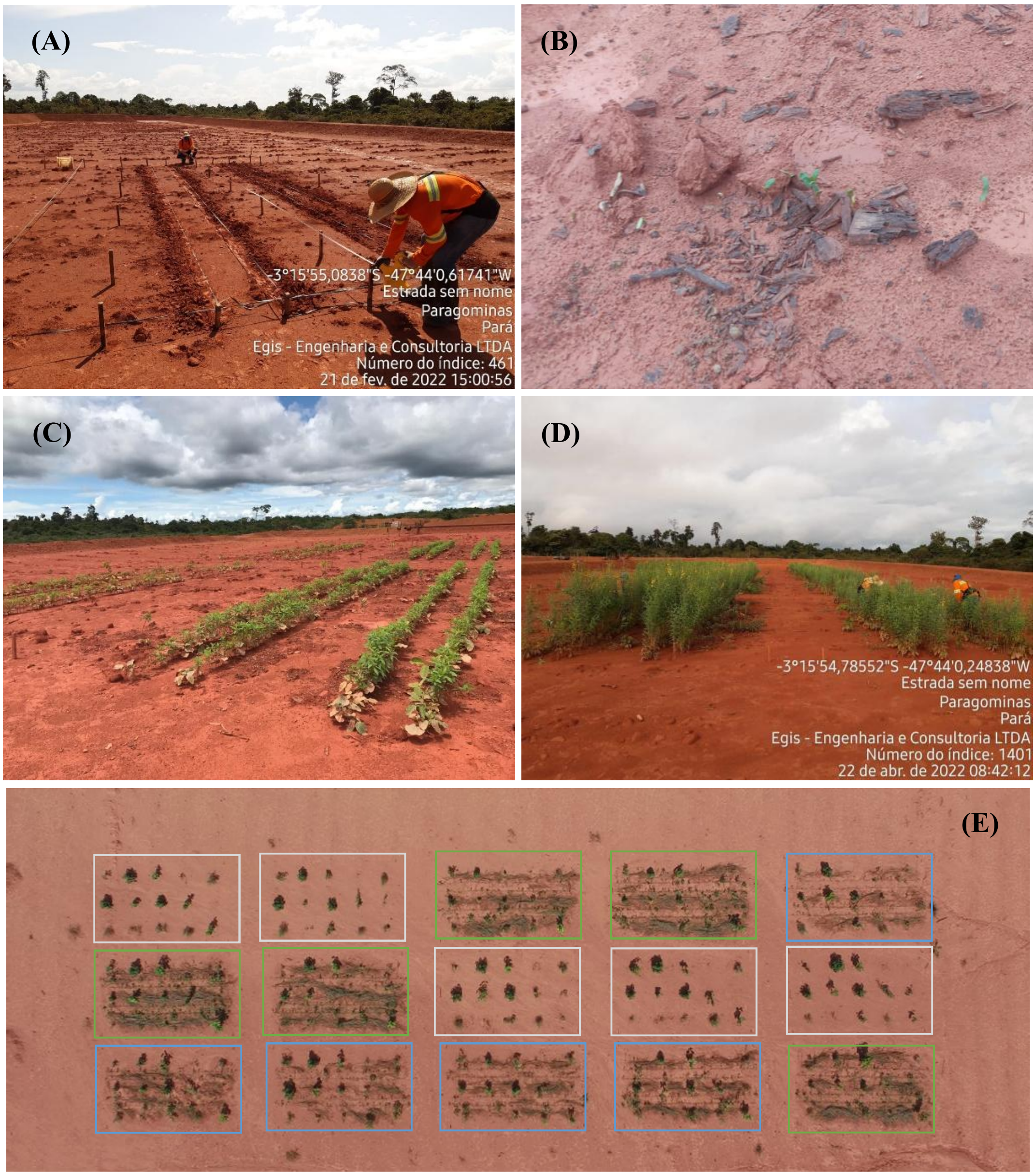

Figure 2. (A) Sowing date; (B) 5 days after sowing date; (C) 23 days after sowing; (D) 60 days after sowing (initial flowering phase); (E) Aerial image after the cut of cover legumes and application as green manure, where green boxes: treatment 1 parcel, blue boxes: treatment 2 parcel, white boxes: treatment 3 parcel.

Regarding technosoil chemical analysis, we noticed that over time there was a reduction in the percentage of Al saturation, and base saturation (V%) increased in the substrate in the treatments and depths evaluated. These results demonstrate the positive response of the substrate to the liming process applied during the preparation of the plots, and that in the upper layer the response time varied according to the treatment applied, so that the greater the induction of the availability of organic matter in the treatment, the better the result 6 months after the implementation of the experiment.

The results of the fertility analyses indicated that in all treatments and depths evaluated there was an increase in pH between the campaigns of August/2022 and February/2023.

It was possible to verify that the effective CTC was higher in the dry period (August 2022 collection) and reduced in the rainy season in February 2023. The reduction of effective CTC may be related to the leaching of nutrients in the rainy season and the acceleration of OM decomposition in the presence of moisture [10]. In any case, when the treatments are compared, it is noticed that there is a significant increase of effective CTC in the T1 treatment (which was prepared with the addition of organic matter at the beginning of the experiment) when compared to the control treatment (T3), which presented a difference of 274 % in the surface layer (0–5 cm) and 71 % in the depth 5–10 cm in the dry season campaign. The T2 treatment showed no significant difference in effective CTC in relation to T3 in any of the layers and periods analyzed.

In this same context, it was possible to observe that over time there was a reduction in the percentage of Al saturation and an increase in base saturation (V%) in all treatments and depths evaluated. It is interesting to point out that Al saturation presented results inversely proportional to the results of effective CTC, so that the lower the Al saturation in a layer or treatment, the greater the result of effective CTC (Figure 3).

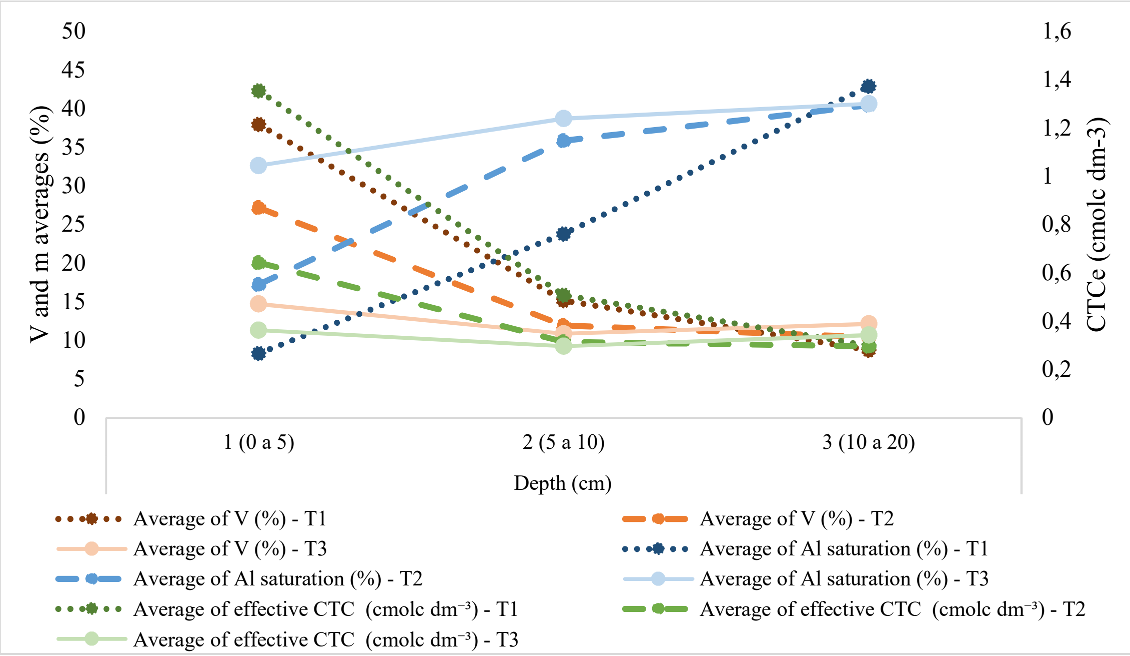

Figure 3. Comparison between V%, Al saturation (%), and effective CTC - August/2022 (dry season).

In February/2023, during the rainy season, the results of V (%) and Al saturation showed no significant difference between the treatments in the layers 0–5 and 5–10 cm. In the 10–20 cm layer there was no significant difference between the treatments for V (%) and Al saturation, this can be observed in Figure 4. In this period, as previously mentioned, there was a reduction in Al saturation and an increase in base saturation (V %) in all treatments and depths evaluated in relation to the previous collection (August/2022).

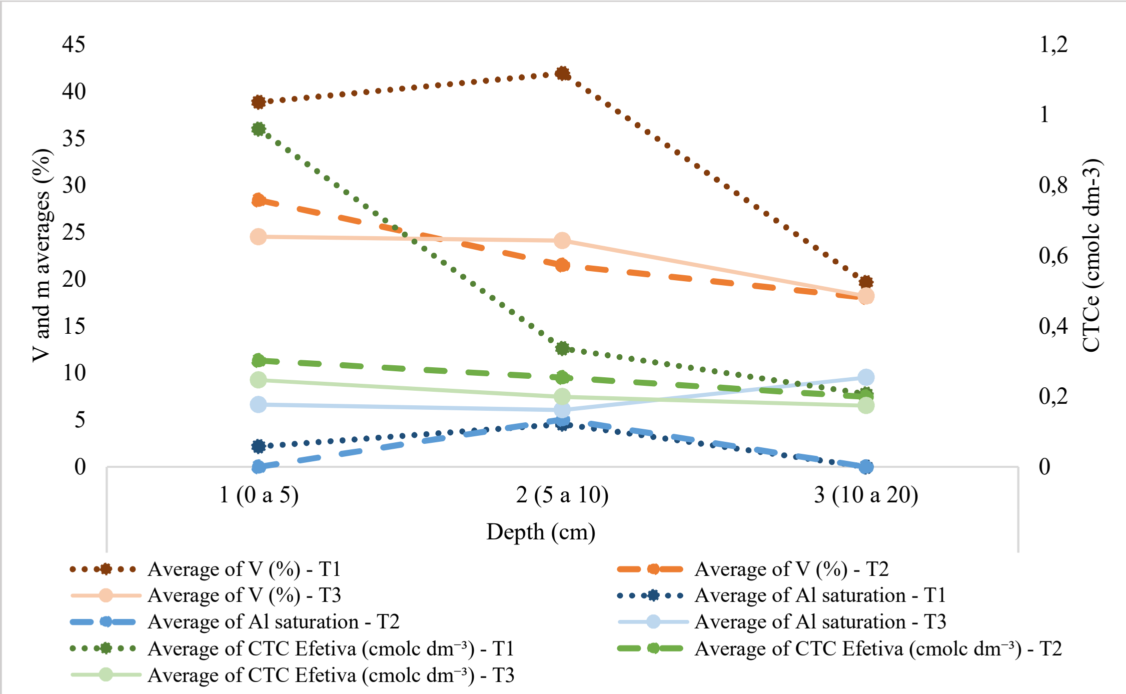

Figure 4. Comparison between V%, Al saturation (%) and effective CTC - February/2023 (rainy season).

In both collection campaigns, the T1 treatment stood out regarding the availability of organic matter in the upper layer (0–5 cm). This result is consistent with the previous addition of organic matter to the T1 treatment at the beginning of the experiment. On the other hand, the results of the 2nd collection showed an increase of organic matter in the T2 treatment, equivalent to 159 % (from 4 to 10.34 g/kg between the 1st and 2nd collections).

The significant increase in the amount of organic matter in the upper layer of technosoil in the T2 treatment can be attributed to the incorporation of biomass in the substrate, resulting from the green manure process. It is worth mentioning that the second sample collection was carried out between 6 and 8 months after the cutting the cover legumes, a period in which there was enough time for the decomposition of the biomass to occur [11].

4. Conclusions

The cover species presented satisfactory results of biomass production considering the conditions of the substrate at the time of sowing, so that the species *Crotalaria spectabilis* produced a greater amount of biomass in T1 and the species *Canavalia ensiformis* presented similar performance in the production of biomass in T1 and T2. Also, the application of green manure demonstrated to be an adequate technique for the enhancement of soil fertility and organic matter content during the initial phase of bauxite tailing dam closure.

In addition, for the proper management of cover species, it is recommended to evaluate how many production cycles it is intended to obtain considering the high germination capacity, and from this proceed with the total slaughter of the species at the apex of flowering and before the seed dispersal cycle. This last recommendation might be applied for different results seek with bauxite tailings and other minerals tailings.

5. References

1. CRU Consulting. *Opportunities for aluminium in a post-Covid economy*. Prepared for the International Aluminium Institute (IAI). CRU Reference: ST2342-21. 28/01/2022. Available at: https://international-aluminium.org/resource/opportunities-for-aluminium-in-a-post-covid-economy/?_thumbnail_id=6715. Access 09/06/2022.
2. ABAL, Associação Brasileira do Alumínio. *Alumínio. Cadeia Primária*. Available at: http://abal.org.br/aluminio/cadeia-primaria/. Access 09/06/2022.
3. ABAL, Associação Brasileira do Alumínio. *Bauxita no Brasil. Mineração Responsável e Competitividade*. São Paulo, SP: Gráfica Mundo. Abril/2017. 66 p. Available at: http://www.abal.org.br/downloads/ABAL_Relatorio_Bauxita_2017_1.pdf.Access 08/06/2022.
4. ICMM, International Council on Mining & Metals. *Global Industry Standard on Tailings Management. GISTM*. August 2020. Available at: https://www.icmm.com/en-gb/our-principles/tailings/global-industry-standard-on-tailings-management. Access 10/06/2022.
5. ICMM, International Council on Mining & Metals. T*ailings Management. Good practice guide.* May 2021. Available at: https://www.icmm.com/website/publications/pdfs/environmental-stewardship/2021/guidance_tailings-management.pdf. Access 10/06/2022.
6. IFC, International Finance Corporation. *Environmental, Health, and Safety Guidelines for Mining.* December 10, 2007. Available at: https://www.ifc.org/wps/wcm/connect/595149ed-8bef-4241-8d7c-50e91d8e459d/Final%2B-%2BMining.pdf?MOD=AJPERES&CVID=nPthex1&id=1323153264157.Access 10/06/2022.
7. ASI, Aluminium Stewardship Initiative. *ASI Performance Standard. Version* 3 – May 2022. 33 p. Available at https://aluminium-stewardship.org/wp-content/uploads/2022/05/ASI-Performance-Standard-V3-May2022-2.pdf. Access 09/06/2022.
8. Selma Regina de Freitas Coelho et al., *Crescimento, nutrição e fixação biológica de nitrogênio em plantios mistos de eucalipto e leguminosas arbóreas*. Pesquisa Agropecuária Brasileira [online]. 2007, v. 42, n. 6 [Access 26/07/2021], pp. 759-768. Available at: https://doi.org/10.1590/S0100-204X2007000600001. ISSN 1678-3921.
9. Vitor moreira et al., *Características adaptativas da associação simbiótica e da fixação biológica do nitrogênio molecular em plantas jovens de Lonchocarpus muehlbergianus Hassl., uma leguminosa arbórea nativa do Cerrado*. Rodriguésia [online]. 2014, v. 65, n. 2 [Access 26/072021] , pp. 517-525. Available at: https://doi.org/10.1590/S2175-78602014000200013. ISSN 2175-7860
10. J. A. ACOSTA et al., *Decomposição da fitomassa de plantas de cobertura e liberação de nitrogênio em função da quantidade de resíduos aportada ao solo sob sistema plantio direto.* Ciência Rural, 44(5), 801–809. (2014). Available at: https://doi.org/10.1590/S0103-84782014005000002. Access 02 Jun. 2023.
11. R. A. ANDRADE et al., *Taxas de cobertura e decomposição de adubos verdes na Amazônia Sul Ocidental*. Revista em Agronegócio e Meio Ambiente, [S.L.], v. 15, n. 1, p. 1-15, 21 fev. 2022. Centro Universitário de Maringá. Available at: https://doi.org/10.17765/2176-9168.2022v15n1e8600. Access: 28/02/2022.