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Environmental remediation of canga and iron mining waste pile using bee pasture of *Baccharis dracunculifolia*

Recuperação ambiental de solos de canga e pilha de estéril de mineração de ferro com pasto apícola de Baccharis dracunculifolia

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ABSTRACT: Mining is an economic activity known for its significant potential to generate socio-environmental impacts. In the case of iron ore mining in the Iron Quadrangle of Minas Gerais, the areas most frequently affected are typically ferruginous fields, due to vegetation suppression for pit opening and the deposition of waste rocks. Owing to their unique characteristics, these regions exhibit a high degree of endemism, with species adapted to the specific environmental conditions, making them suitable candidates for use in ecological restoration projects. *Baccharis dracunculifolia* is a native plant with significant potential for inclusion in such projects due to its ability to colonize degraded areas and its interactions with pollinators, such as the honeybee *Apis mellifera*. Consequently, environmental restoration efforts can be integrated with apicultural production, providing a sustainable alternative for the productive use of previously degraded land. The objective of this research is to identify and compare the physical and chemical properties of soils from iron mining waste piles and *canga* for potential use in environmental restoration with *B. dracunculifolia* as a bee pasture. Analyses included particle size distribution, bulk density, moisture content, pH, and chemical composition using X-ray fluorescence (XRF). Results indicated that both environments demonstrated similar properties across all tests, supporting the use of native plants such as *B. dracunculifolia* in ecological restoration projects. Furthermore, the establishment of bee pastures composed of this species in degraded areas can help diversify the income streams of local communities near mining operations, thereby reducing their dependency on mining activities.

Keywords: Beekeeping, iron mining, socio-environmental recovery, sustainability.

RESUMO: *A mineração é uma atividade econômica conhecida pelo seu grande potencial de geração de impactos socioambientais. No caso da mineração de ferro no Quadrilátero Ferrífero em Minas Gerais, comumente os locais mais impactados são os campos ferruginosos, tanto pela supressão de vegetação para abertura da cava quanto para o empilhamento do estéril. Por suas características singulares, esses locais possuem alto grau de endemismo com espécies adaptadas para suas condições, apresentando vantagens para serem utilizadas nos processos de recuperação ambiental. A Baccharis dracunculifolia é uma planta nativa com potencial para compor esses tipos de projeto por ser colonizadora de áreas degradadas e apresentar grande número de interações com insetos, como a abelha Apis mellifera. Desse modo, a recuperação ambiental pode ser conciliada com a produção apícola, trazendo uma alternativa de uso sustentável dos locais anteriormente degradadas. Assim, o objetivo dessa pesquisa é identificar e comparar as características físicas e químicas dos solos das pilhas de estéril de mineração de ferro e da canga para recuperação ambiental com pastos apícolas de B. dracunculifolia. Foram realizadas análises de distribuição granulométrica, massa específica, umidade, pH e composição química por Fluorescência de Raio-X. Observou-se que em todos os ensaios ambos os ambientes apresentaram semelhanças, sendo uma vantagem para a utilização de plantas nativas da região, como a B. dracunculifolia, nos projetos de recuperação ambiental. Além disso, a implementação dos pastos apícolas compostos por essa planta nas áreas degradadas pode também auxiliar na diversificação de renda das comunidades alocadas próximas às atividades minerárias diminuindo a minero-dependência.*

Palavras-chave*: Apicultura, mineração de ferro, recuperação socioambiental, sustentabilidade.*

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INTRODUCTION

Mining is an activity that aims to explore, extract and process mineral resources of economic interest. This activity has occupied a significant space in the Brazilian economy since the 16th century, when the exploration of gold and diamonds began in the State of Goiás and, mainly, in Minas Gerais (Júnior, 2017). Currently, the main minerals extracted on Brazilian soil are Iron and Oil. In this regard, Minas Gerais continues to be a main player in mining production, with its main iron mines located in the Iron Quadrangle, a central region of the state with significant deposits. The use of these iron reserves began in the 19th century with the decline of the gold cycle, and high-grade iron ores, composed mainly of compact hematite, were sent to be used in small local forges. However, it was only in the 1940s, with the creation of Companhia Siderúrgica Nacional (CSN) and Vale do Rio Doce (CVRD), in line with the great demand for steel after the Second World War, that the region's production capacity was boosted (Castro; Endo; Gandini, 2020).

The mining business is a key sector of the economy for maintaining the lifestyle of today's society, however it is also one of the economic activities with the most significant impact on the environment. These impacts are multiple, involving aspects of the lithosphere, hydrosphere, biosphere and atmosphere, in addition to social impacts. They begin from the moment of prospecting for mineral resources, growing significantly throughout the exploration process and extending even after the mine is closed. The magnitude and type of impacts are closely related to the type of ore and the exploration model (Bomfim, 2017). In the Iron Quadrangle, most of the mines are open-pit. In this method of extracting mineral resources from underground, it is also necessary to remove the material covering the ore. This material is called waste rock because, in most instances, it is not made up of materials of economic value. When extracted, it is stored in piles near the mine and can cause several negative impacts in these locations, such as wiping out the vegetation and the increase in the transport of sediments to water bodies (Silva, Viana, Cavalcante, 2012).

Generally, the impacted areas in the Iron Quadrangle region are the ferruginous fields. These environments are characterized by developing on substrates that are rich in iron, commonly associated with large deposits of this substance (Jacobi; Carmo, 2008). These sites are made up of minerals derived from these deposits, such as compact hematite and fragments of itabirite cemented by limonite, generating a thick and cohesive armor, also known as *canga* (Dorr, 1964). The ferruginous fields are found mainly in the Iron Quadrangle and in the Serra de Carajás, in the State of Pará (Silva *et al*., 1996). Due to their discontinuous distribution motivated by the dependence on the occurrence of ferruginous substrate and the high degree of endemism of the plants that develop in these locations, ferruginous fields are recognized worldwide as centers of biodiversity (Alvez; Kolbek, 1994).

Since 1989, the recovery of areas degraded by mining became mandatory with the publication of Decree 97.632/89, which regulates the Degraded Areas Recovery Plan (Brasil, 1989). This legal instrument aims to ensure that those in charge of exploring mineral resources recovers the impacted areas, allowing these locations to once again perform a relevant role in society. There are several methods that allow the recovery of impacted areas, with natural regeneration being the simplest of them. However, due to constant interventions, the restoration of environmental conditions can take a long time, or even it may not happen. Therefore, human intervention is often necessary in these processes (Lima *et al.,* 2020). Hence, knowledge of the characteristics of the substrate and the conditions of

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the area that suffered the impact are key for the success of projects to recover degraded areas. Revegetation is one of the most common practices in places impacted by mining because the establishment of vegetation cover mitigates the visual and aesthetic effects of the impact, helps to restore the natural conditions of the soil and reduces surface runoff and erosion, in addition to being essential for restructuring the ecosystem (Zhao *et al.*, 2013; Zhang *et al*., 2015). One of the techniques in this process is called phytoremediation, when plants are used to improve the environmental conditions of the soil, and consequently the environment (Santos; Novak, 2013). The development of this vegetation cover is facilitated when the deposit to be recovered has similar characteristics to the natural environment, such as granulometry and moisture. However, the success of environmental recovery also depends on the correct choice of species, the presence of pollinators and the effects of these plants on the soil (Chaer *et al*., 2011; Mukhopadhyay *et al*., 2013).

Baccharis dracunculifolia DC., for example, is a native Brazilian plant widely distributed in the southeast and south regions of the country (Faria; Fernandes; Fagundes, 2001). It is typified by being a shrub 2 to 3 meters tall with high growth capacity, high achene production and few nutritional requirements. It is also known for being a plant that colonizes pasture or degraded areas (Gomes *et al.*, 2002). The species has trichomes on its leaves that help it capture moisture from the air and is responsible for the production of resins and oils, which have great medicinal value (Oliveira; Bastos, 1998). Furthermore*, B. dracunculifolia DC* also develops several interactions with insects, and one of its main pollinators is the *Apis mellifera* bees. These bees use the resin produced by the plant and vegetative fragments to manufacture green propolis, used for sealing and microbial control of hives, with high added economic value (Bastos *et al*., 2011) Studies conducted by Gilberti (2012) also demonstrated the ability of this plant to retain potentially toxic elements present in the soil in its roots. Thus, *B. dracunculifolia DC* can be a good alternative of a native plant to compose the vegetation of projects for the recovery of degraded areas due to its several advantageous characteristics, such as the potential for soil phytoremediation and the possibility of establishing local arrangements for the development of beekeeping.

In turn, beekeeping is an economic activity typified by the breeding of *A. mellifera* bees to obtain bee products such as honey, wax and propolis, among others. Due to its low initial cost and easy maintenance, it has been an alternative for obtaining income in rural communities, especially when linked to family farming (Freitas; Kan; Silva, 2004). Beekeeping is also known for being an activity that meets the three pillars of sustainability: environmental, economic and social. Environmental, as it is necessary to preserve forest fragments or to the planting of diverse bee pastures to provide pollen, nectar and water for bees. Economical, as it generates income for beekeepers, often greater than when compared to other agricultural activities. Social, as it generates employment for beekeepers, and because it is an activity generally carried out in groups, it also strengthens community relations in the region (Lourenço; Cabral, 2016). That said, beekeeping can be a great ally in environmental recovery processes involving mining, as it reconciles environmental preservation with job creation for affected communities, helping to diversify income and reduce mining dependence.

Therefore, this project aims to evaluate the physical and chemical characteristics of the waste rock pile and compare them with the characteristics of the *canga*. By assessing the similarities and differences of these environments, the project aims to determine the

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potential use of these areas for environmental recovery with species native from the ferruginous field environment, such as *B. dracunculifolia* combined with beekeeping.

METHODOLOGICAL PROCEDURES

Soil samples were collected from a waste rock pile derived from iron mining and in a *canga* environment in the district of Antônio Pereira, Ouro Preto, Minas Gerais, in the winter (August 2022) and summer (April 2023) periods. Five subsamples of 20 and 40 centimeters in depth were collected in each sampling area in order to compose a final representative sample for the waste rock pile and the *canga*. The *canga* samples were called C00-20 for those that went from 0 to 20 centimeters in depth and C20-40 for those with 20 to 40 centimeters in depth. The same applied to the waste rock pile samples that were named P00-20 and P20-40.

PHYSICAL CHARACTERIZATION

Granulometric Distribution

The main objective in analyzing the granulometry of a material is to describe the size of the grains that compose it. Therefore, the particle size distribution tests were conducted in accordance with NBR 7181. Consequently, the samples were subjected to a column of sieves with openings of 4.74; 2.36; 1.18; 0.592; 0.296; 0.148 and 0.074 mm consecutively. After 10 minutes of agitation with the aid of a mechanical agitator, the material retained in each sieve was weighed to construct the granulometric curve.

Specific Mass

The specific mass tests were carried out following NBR NM 52. First, the volume of the bottle was calculated. Once this was done, a certain quantity of material of known mass was added and the volume of the vial was completed with water. Thus, it was possible to determine the volume occupied by the sample added to the vial. With this data, the specific mass of the material was calculated using Equation 1.

$$\rho = \frac{m}{V_f - V_a} \tag{1}$$

Where m is the mass of the oven-dried sample, V_f is the volume of the vial, and V_a is the volume of water used.

Moisture

To determine the moisture content of the samples, tests were carried out following the EMBRAPA Soil Analysis Manual. Thus, the initial mass of the wet material was measured, then taken to an oven at 105°C for 24 hours. Subsequently, the mass of the dry material was measured. To obtain the moisture content, Equation 2 was used.

$$U = \frac{m_u - m_s}{m_u} \times 100 \tag{2}$$

Where U is the moisture content, m_u is the mass of the wet sample, and m_s is the mass of the oven-dried sample

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CHEMICAL CHARACTERIZATION

pH in dissolution

This test was also carried out following the EMBRAPA Soil Analysis Manual (2017). To do this, 10 ml of distilled water was added to the sample, then stirred for approximately 20 seconds. The sample was taken to measure the pH in dissolution using a pH meter, PECNOPON brand, model LUCA-210.

X-ray Fluorescence

For the X-ray Fluorescence test, the protocol produced by the RECICLOS/CNPq Group was used. Thus, the sample was crushed with the aid of a mortar until all the material passed through the 0.075 mm sieve. Once this was done, the material was packaged in the appropriate capsules to be sent for analysis on the Panalytical Epsilon 3X equipment.

RESULTS AND DISCUSSIONS

PHYSICAL CHARACTERIZATION

Granulometric Distribution

It can be observed that the granulometric curves of the sampled regions are more elongated, that is, they show a well-distributed granulometry (**Figure 1**). This characteristic of the material has a direct influence on the compaction and permeability of a soil, according to Santana *et al.* (2021). The greater the number of fines, the easier the soil will be compacted and the lower the permeability. This occurs because the fine material occupies the space between the larger grains through which water flows (Aldaood, 2019).

These two factors are important when considering the recovery of degraded areas, since soil compaction and water permeability in this substrate can be decisive for the development of vegetation cover. In this study, both the *canga* environment and the waste rock pile had a similar granulometry. Therefore, the natural plants of the *canga* environment could adapt to the granulometric conditions of the waste rock pile in processes of recovery of degraded areas. This occurs because the species that develop in ferruginous fields on the *canga* substrate are already adapted to this compact soil with little water availability, as is the case of *B. dracunculifolia*. These adaptations can be seen in the stronger, more resistant roots that are able to penetrate the compact substrate. Furthermore, some plants have trichomes to capture water from the atmosphere, overcoming the lack of water in the substrate (Duringan *et al.*, 2018).

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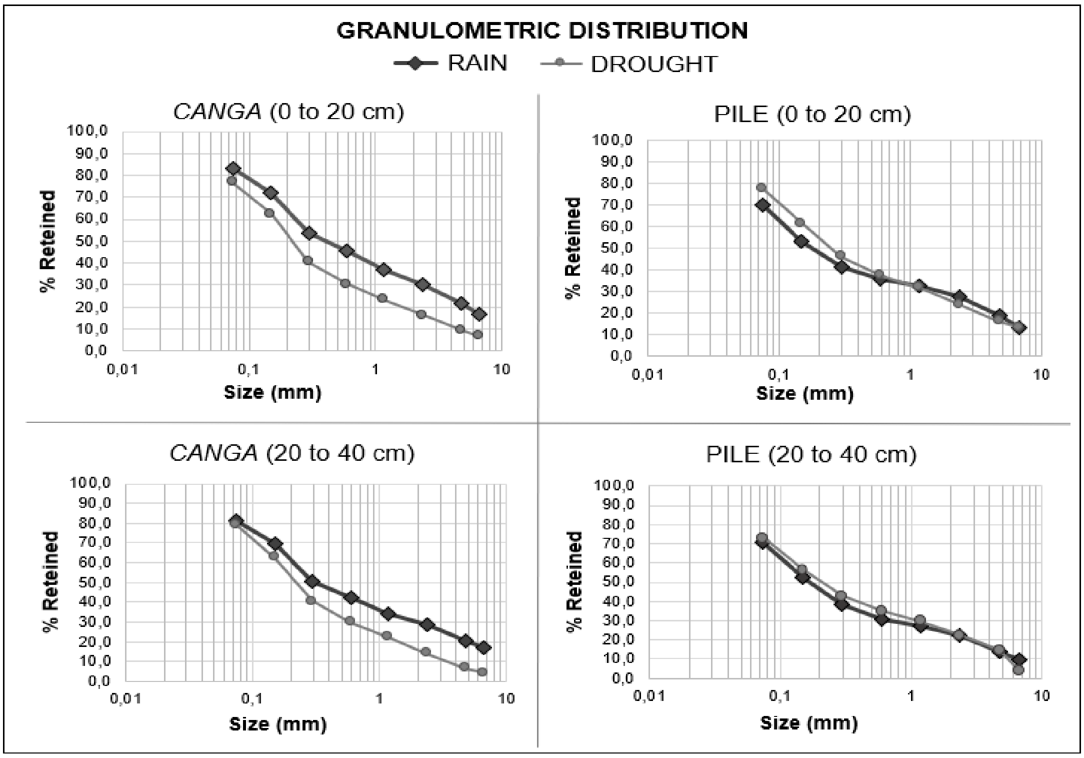
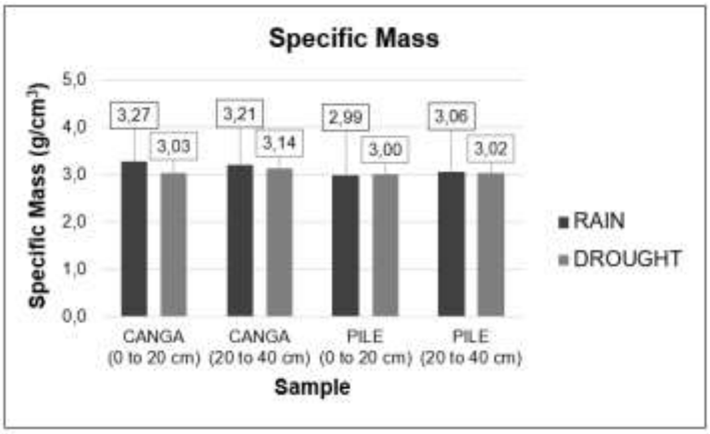
Figure 1. Granulometric Distribution Curves of the samples analyzed in the dry and humid seasons of the year



Specific Mass

From the analysis of the graph in **figure 2**, it is noticeable that the specific mass of the *canga* samples is slightly greater than the samples from the waste rock pile. This difference can be attributed to the different composition of the *canga* and the pile. The *canga* has a higher concentration of iron oxides whose density is higher than silicon oxides, for example, which are more present in the waste rock pile. These results are consistent with what is known about the composition of the rocks and soils in the Iron Quadrangle, as discussed by Castro *et al*. (2020).

Figure 2. Specific Mass of the analyzed samples in the dry and humid seasons of the year



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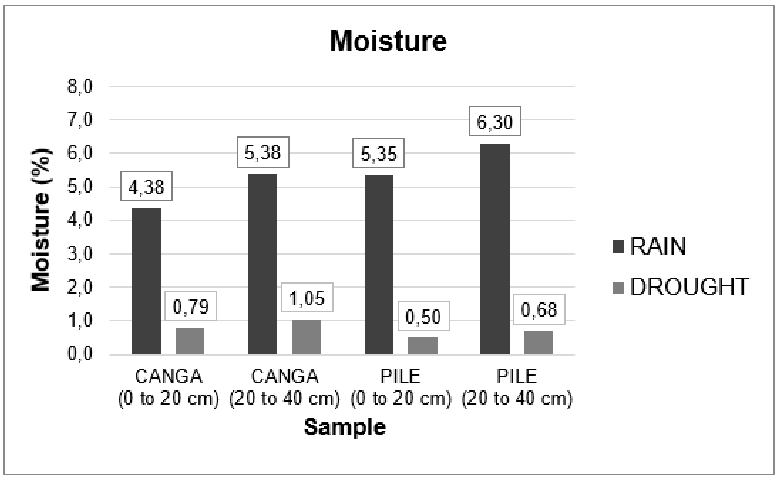
Moisture

It can be observed (**Figure 3**) that during the rainy season there is a greater amount of water in the samples compared to the dry season, which was expected. This suggests that both studied areas may not have good soil water retention capacity. As Scaloppi (1978) demonstrates, soil moisture is essential for plant metabolism and consequent growth. The availability of water to make up for what is lost through evapotranspiration is essential for the correct development of these individuals. This situation can be an obstacle to the recovery of degraded areas in these locations, since during the dry season there is little water available for the development of vegetation cover. Despite this, the region's natural plants have several forms of adaptation to this condition, as presented by Duringan *et al*. (2018). Trichomes, presented by *B. dracunculifolia* and other plants, facilitate the capture of water from the atmosphere. Furthermore, the water distribution system in these plants also has adaptations so that water is carried from the leaves to the rest of the plant, unlike what normally happens when water is brought from the roots.

Figure 3. Moisture of the analyzed samples in the dry and humid seasons of the year



CHEMICAL CHARACTERIZATION

pH in dissolution

All analyzed points obtained pH between 6 and 7 (**Figure 4**), which can be characterized as neutral soil. Thus, the similarity between the analyzed environments is evident, since the samples collected in the waste rock pile had pH values very close to those found for the *canga* samples, which may favor the use of native plants from the *canga* environment in the environmental recovery of the waste rock pile. Furthermore, pH directly influences plant development by determining the availability of nutrients and the health of soil biota (Camargos, 2005). In neutral soils, the decomposition of organic matter and nitrogen fixation by microorganisms tends to be favored, according to Dionísio (1996). In this aspect, the pile has considerable similarities to the *canga* environment, showing conditions of being a good substrate for the development of natural plants in the study region, such as *B. dracunculifolia*.

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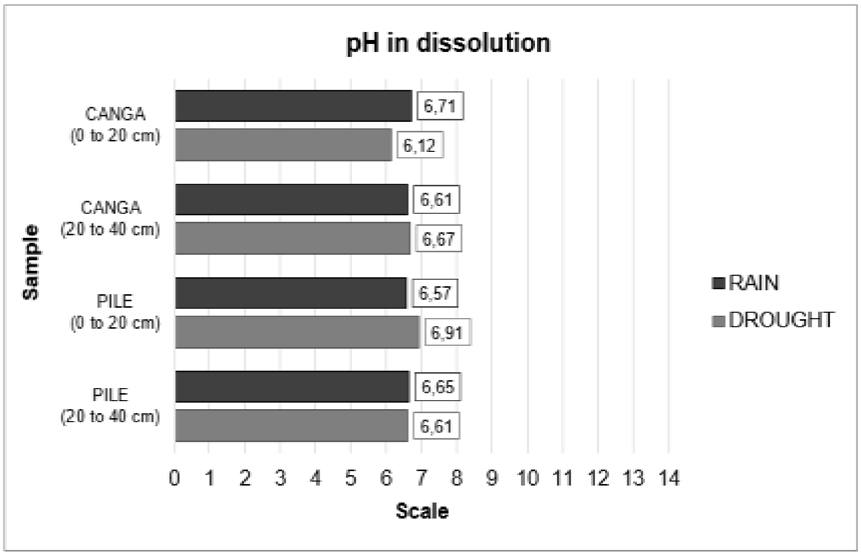
Figure 4. pH in dissolution of the analyzed samples in the dry and humid seasons of the year

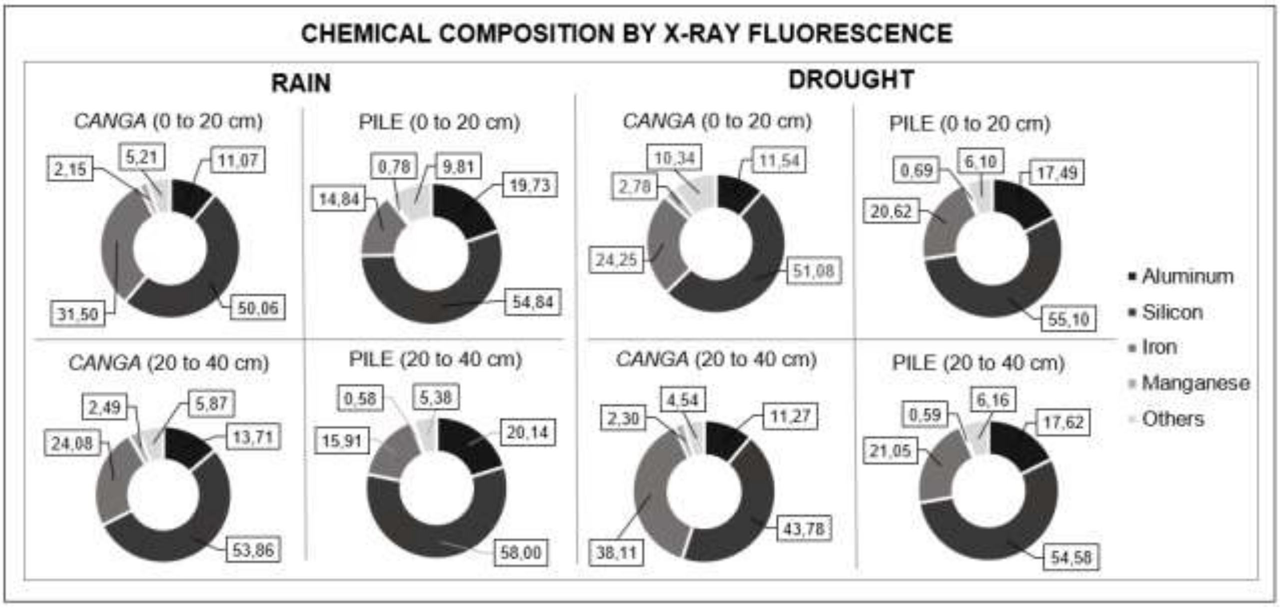


X-Ray Fluorescence

It is noted that the chemical composition of the *canga* and the waste rock pile are similar (**Figure 5**), with the main constituents of the samples being iron, silicon, aluminum and manganese oxides. The *canga* has a higher proportion of iron oxides than the waste rock pile, while the proportion of silicon oxides increases in the pile compared to the *canga*. These results were already expected, since these oxides are common in the Iron Quadrangle region, as explained by Castro *et al*. (2020) and coincide with the specific mass results, in which the *canga* had higher values than the waste rock pile. Furthermore, the points collected did not have significant concentrations of oxides composed of potentially toxic elements, which is an advantage for the population to use the plants that are part of environmental recovery projects.

In short, the *canga* environments and the waste rock pile analyzed had significant similarities. These similarities are an advantage for the process of recovering degraded areas with the use of plants native from *canga* environments such as *B*. *dracunculifolia*, as these plants already have adaptations to the conditions of these environments. The development of trichomes to obtain water from the atmosphere and the resistance of the roots to penetrate the compact substrate of these environments bring advantages to the development of vegetation cover when compared to other plants not native from the region. The selectivity of absorption and distribution of substances from the soil, such as potentially toxic elements, also facilitates the survival of these individuals in environments as adverse as the *canga*. Furthermore, the large number of interactions with insects, mainly with *A. mellifera*, that *B dracunculifolia* develops, also brings an advantage for its use in recovery processes of areas degraded by mining. The possibility of developing bee pastures in degraded areas reconciles environmental recovery with the socioeconomic diversification of the community affected by the mineral extraction process.

Figure 5. Chemical composition by X-ray Fluorescence of the analyzed samples in the dry and humid seasons of the year



CONCLUSIONS

Based on the studies conducted in this research, it can be concluded that the *canga* and waste rock pile environments have similarities that bring advantages to the environmental recovery process using plants native from the region. *B. dracunculifolia* is a good option to be used in this type of project, not only because it has advantageous adaptations for the development of vegetation cover, such as selectivity in absorbing substances from the soil, trichomes for capturing water and resistant roots for penetration into the compact substrate. This plant also develops interactions with a series of insects, such as *A. mellifera*, enabling the diverse use of recovery areas as bee pasture. By aligning environmental recovery with the socioeconomic aspects of the affected communities, the implementation of local beekeeping arrangements brings the possibility of diversifying work and, consequently, the income of the populations affected by mining, leveraging an improvement in the quality of life and a reduction in mining dependence.

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