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Mineralogical analysis of rock dust for remineralization of soil intended for pasture

The objective of this study was to verify the effects of rock dust on the soil of an area destined for pasture. Mineralogical analysis of the rock dust was performed using X-ray diffraction, and the major oxides and minor elements were analyzed using X-ray fluorescence. The soil samples were analyzed according to PROFERT-MG. The following were identified from the X-ray diffractogram of the total rock powder: quartz (43.66%), albite (38.10%), microcline (15.30%), and muscovite (1.80%). Regarding the major elements, SiO2 (81.92%), Al2O3 (11.04%), and Na2O (3.86%) were predominant, and an important amount of K2O (2.61%) was present. In the chemical characterization of the soil, an increase in the levels of P, K, Ca, Mg, Sb, t, V, organic matter, and organic carbon were observed with the addition of rock dust. A comparison of the chemical analysis results with the CONAMA quality reference values indicated that the rock dust sample had acceptable levels with respect to the quality reference for all analyzed heavy metals. In a comparative analysis with MAPA's Normative Instruction No. 5/2016, it was found that rock dust does not fully comply with the minimum requirements of the legislation. In full compliance with the IN from chemical analysis, it had a minimum required content of at least 1% for K2O. Preliminary studies have indicated that the application of this material as a remineralizer has potential, mainly in relation to the supply of K2O. However, physical adjustments are required in the beneficiation process to comply with the standards.

Keywords: X-ray diffraction; Potassium oxide; X-ray fluorescence; Jequitinhonha river Valley.

Análise mineralógica de pó de rocha para remineralização de solo destinado a pastagem

O objetivo deste estudo foi verificar os efeitos do pó de rocha no solo de uma área destinada a pastagem. A análise mineralógica do pó de rocha foi realizada por difração de raios X, e os óxidos maiores e elementos menores foram analisados por fluorescência de raios X. As amostras de solo foram analisadas de acordo com o PROFERT-MG. A partir do difratograma de raios X do pó de rocha total foram identificados: quartzo (43,66%), albita (38,10%), microclina (15,30%) e muscovita (1,80%). Em relação aos elementos majoritários, predominaram SiO2 (81,92%), Al2O3 (11,04%) e Na2O (3,86%), estando presente uma quantidade importante de K2O (2,61%). Na caracterização química do solo, observou-se aumento nos teores de P, K, Ca, Mg, Sb, t, V, matéria orgânica e carbono orgânico com a adição de pó de rocha. A comparação dos resultados da análise química com os valores de referência de qualidade do CONAMA indicou que a amostra de pó de rocha apresentou níveis aceitáveis em relação à referência de qualidade para todos os metais pesados analisados. Em análise comparativa com a Instrução Normativa do MAPA nº 5/2016, verificou-se que o pó de rocha não atende integralmente aos requisitos mínimos da legislação. Em total conformidade com a IN da análise química, tinha um teor mínimo exigido de pelo menos 1% de K2O. Estudos preliminares indicaram que a aplicação deste material como remineralizante tem potencial, principalmente em relação ao fornecimento de K2O. No entanto, são necessários ajustes físicos no processo de beneficiamento para atender às normas.

Palavras-chave: Difração de raios X; Óxido de potássio; fluorescência de raios-X; Vale do Rio Jequitinhonha.

Topic: **Ciências do Solo**

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INTRODUCTION

Agribusiness is characterized by a set of diverse practices linked to agriculture and is one of the pillars of the Brazilian economy. However, Brazilian soils, which are the foundation of agribusiness, in their original form, are chemically acidic and deficient in one or more nutrients essential to plants (WIETHÖLTER, 2000). Most of the time, insufficient nutrition can compromise production, or in extreme cases, lead to early death of plants. Nutritional balance is the most important factor in determining plant productivity (TOMAZ, 2015).

However, Brazilian agribusiness is 75% dependent on imported fertilizers (ANDA). Although soluble fertilizers release nutrients more quickly and effectively to meet the requirements of most cultivated plants with short life cycles, they can contaminate rivers and groundwater when carried by rainwater and/or irrigation (LUCHESE et al., 2001). Therefore, it is necessary to find fertilizers that contain both macro- and micronutrients, especially those that are low cost (ALOVISI et al., 2017). An alternative to reduce the use of industrial fertilizers and increase soil fertility would be the application of new technologies, such as low-cost and more sustainable rock blasting, which involves soil fertilization by the addition of rock dust. Despite being an ancient practice, the use of stones in soil fertilization still requires applied and participatory studies with farmers, especially with materials that are abundantly available locally in several regions of Brazil, such as gneiss (CARVALHO, 2012). The Jequitinhonha Valley, which has the practice of mining rooted in its history, has great potential for this purpose.

The use of this type of fertilization is essential to combine the mineralogy and geochemistry of the selected rock with the requirements of the soil and plants (SOUZA, 2014). This fertilization practice can also be perceived as a type of low-dissolution nutrient bank to which the plants resort to depending on their developmental stage (THEODORO et al., 2010).

The objective of this study was to verify whether the fertilization of the soil intended for the cultivation of forage plants in the municipality of Araçuaí (MG) can be improved with the application of rock dust.

MATERIALS AND METHODS

Location of the study area and collection of rock and soil dust

The study area is located in Vale do Jequitinhonha, in the municipality of Araçuaí, MG, (678 km from the state capital;, 16° 50' 55” S and 42° 3' 57” W), with an altitude of 315 m. The climate of the area, according to Köppen, is of the tropical type, with an average annual precipitation of 766 mm and an average temperature of, 24.2 °C. Figure 1A shows the soil collection site (highlighted in red) on the boundary line of the IFNMG (Instituto Federal do Norte de Minas Gerais), Campus Araçuaí, in which no rock dust had been applied before. The soil characteristics were determined and samples were collected from an area of, 180 m^2, in which the rock dust was applied in June, 2019 with a maximum amount of 8 tons per hectare; hence, the concentration of rock dust in the experimental area was 0.8 kg/m^2. Soil was collected at three stages: time 0 which was prior to the rock dust application, time, 1 which was after, 1 year of rock dust application, and time, 2 which was, 2 years after the incorporation of rock dust in the ground.

Samples of rock dust and waste derived from the crushing station were carried out at the Companhia Brasileira de Lítio (CBL), that has environmentally correct disposal and monitoring of its tailings, which is located 4 km from the IFNMG Araçuaí campus in the municipality of Araçuaí, MG. The samples were collected for petrographic and mineralogical analyses (Figure 1B). Figure 1C shows the points of incorporation of rock dust into the soil and soil collection, as well as the location of the rock dust collection. Figures, 1D, 1E, and, 1F indicate the rock dust that was collected at the CBL, time of the incorporation of rock dust into the soil, and soil samples collected for analysis, respectively.

Figure 1: Experiment location and materials used in it. A - shows the soil collection site (highlighted in red) on the boundary line of the IFNMG (Instituto Federal do Norte de Minas Gerais), Campus Araçuaí, in which no rock dust had been applied before.

The rock dust used in this study was the waste generated from the beneficiation process of lithiniferous pegmatite until it becomes a spodumenium concentrate; this process was performed at CBL. CBL operates its underground mine, Mina da Cachoeira, where lithiniferous pegmatite is extracted and processed to form the spodumenium concentrate, which is used for the production of lithium compounds. Extraction of the ore, which contains spodumenium, was performed using the sublevel stopping method with strict quality and safety standards, including operations using remote-controlled wheel loaders, jumbo drills, mining sequencing software, and geomechanical studies and monitoring of the openings generated during the mining. Currently, the galleries of Mina da Cachoeira are up to, 180 m in depth and 5 km in length. In this way, the beneficiation plant is fed by lithiniferous pegmatite, which undergoes crushing and granulometric classification and is processed in a medium-dense unit to obtain the spodumenium concentrate, which is the final product of the Cachoeira mine operations (CBL website).

Preparation of rock dust for mineralogical analysis by X-ray diffraction

An aliquot of approximately 5.0 g of each sample was separated by manual quartering and pulverized in a McCrone mill (agate) for, 10 min in, 10 mL of deionized water. After milling, the suspension was oven-dried at, 105 °C. After drying, the sample was recovered using a spatula, gently disaggregated by manual grinding in an agate mortar, and mounted in a backload sample holder. The sample was then transferred to the equipment to obtain the diffractogram.

Preparation of rock dust for analysis of major oxides by X-ray fluorescence

An aliquot of approximately 5.0 g of each sample was separated by manual quartering and pulverized in a planetary ball mill (agate) for 40 min. After milling, the sample was oven-dried at, 105 °C for, 12 h and used to determine the loss on ignition (LOI) or gain on ignition (GOI). To determine the LOI or GOI, the samples were calcined at, 1000 °C for 5 h. An aliquot (1.0 g) of the previously calcined sample was melted with 9 g of lithium tetraborate.

Rock powder preparation for analysis of minor elements by X-ray fluorescence

An aliquot of approximately, 15.0 g of the sample was separated by manual quartering and pulverized in a planetary ball mill (agate) for 40 min. After grinding, the sample was oven-dried at, 105 °C for, 12 h and used to prepare the pressed tablet. The tablet was prepared by mixing and homogenizing in the proportion of 3.0 g of the binder to 9.0 g of previously dried sample. The sample was then pressed with a force of, 15 t.

Analysis of soil samples

The soil samples were analyzed according to PROFERT-MG as mentioned below: • pH in water (active acidity); • Organic carbon – Walkley–Black method; • Exchangeable calcium (Ca) and magnesium (Mg) – KCl, 1 mol/L and titration with EDTA; • Aluminum (exchangeable acidity)-KCl method (1 mol/L) and titration with NaOH; • H+Al (potential acidity) – Method $Ca(OAc)_2$ 0.5 mol/L; • Available phosphorus (P) – Mehlich-1 method and colorimetry; • Remaining phosphorus – P method in equilibrium and colorimetry solutions; • Available potassium (K) – Mehlich-1 method and flame photometry; • Texture (granulometry) – pipette method.

RESULTS

The results of the X-ray diffraction analysis of the rock dust sample are shown in Figure 2A, and the mineralogy modal proportion is shown in Figure 2B. Minority mineral phases present in concentrations of 0.5% or less were below the quantification limit of the technique used (< LQ). The results of chemical analyses of the major oxides and minor elements obtained by X-ray fluorescence are shown in figures, 2C and, 2D, respectively.

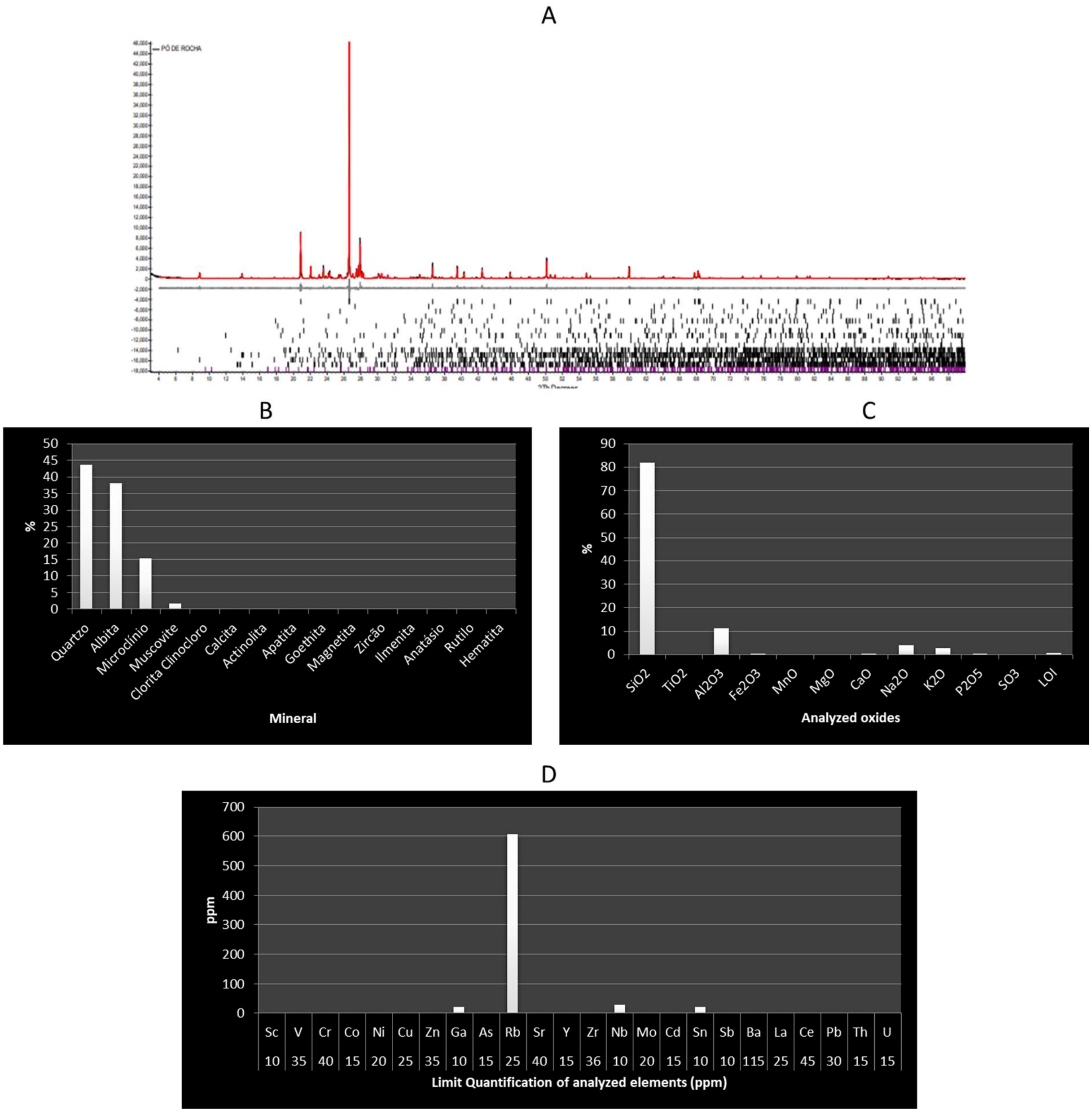

Figure 2: A) Diffractogram of the Pó de Rocha sample, with Rietveld refinement, using the Topas 4.2 program. The black dotted curve represents the measured diffractogram, and the red curve represents the calculated diffractogram. The goodness of fit parameter, in this case, was, 2.13. B) Determination of the modal proportion of the crystalline mineral phases of the rock powder sample by the Rietveld method. C) Chemical analysis of the major oxides. D) Chemical analysis of the minor elements.

In the chemical characterization of the soil, an increase in the levels of P, K, Ca, Mg, Sum of exchangeable bases (Sb), effective CTC - cation exchange capacity (t), CTC base saturation at pH 7.0 (V), organic matter, and organic carbon was observed with the addition of rock dust. Moreover, a reduction in the aluminium (Al) content of the sample was observed with the application of rock dust. As a result of this decrease in Al, the potential acidity (H^+ Al) also decreased. The other elements did not exhibit any significant changes (Figure 3).

Table 1 shows the comparison of the levels obtained by the chemical analyses of the samples collected with the reference values of quality and prevention defined by Resolution 420 of December, 28, 2009, of CONAMA; the elements whose levels are provided by law and which represent risks due to land uses are shown in Table 1. It should be noted that CONAMA Resolution 420 establishes levels of prevention and intervention, and it is necessary to present the reference levels of soil quality under study, which corresponds to establishing the local background, as determined in Resolution 460 of December 30, 2013 of the CONAMA, in which the soil quality reference values (VRQ) for naturally present chemical substances will be determined by the competent environmental agencies of the states.

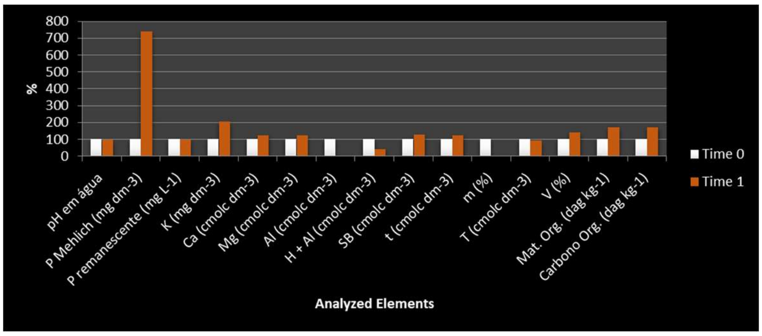

Figure 3: Soil analysis with and without rock dust incorporation.

Table 1: Comparison of the chemical analyses of the rock dust sample and reference values for prevention and land uses according to CONAMA Resolution No. 420.

Element	**Land uses – VQR**		**Contents of the rock dust sample**
	Prevention	**Agricultural Intervention**	
Pb	72	180	< LQ
Ni	30	70	< LQ
Co	25	35	< LQ
Cu	60	200	< LQ
Zn	300	450	< LQ
As	15	35	< LQ
Cr	75	150	< LQ
Ba	150	300	< LQ

<LQ = proportion below the quantifiable threshold.

A comparison of the results of chemical analysis with the CONAMA quality reference values indicates that the rock dust sample has acceptable levels according to the quality reference for all analyzed heavy metals, within the parameters established for agricultural prevention and intervention (Table 1). In this study, a comparative analysis was performed between the attributes required by IN 05/2016 - MAPA and those found in the analyzed rock dust (Table 2).

Table 2: Comparative analysis between the attributes required by IN 05/2016 - MAPA and those found in the analyzed rock dust.

Evaluated parameters		**MAPA requirements**	**Analyzed rock dust**
Granulometry		Filler, dust or crumbly	Crumbly or higher
Sum of bases		= ou >9%	2.76
Potassium content (K_2O)		= ou >1%	2.61
Hydrogen potential (pH)		As stated by the registrant	-
Free SiO2		25%	81,92
Potentially toxic elements	As	15 ppm	<LQ
	Cd	10 ppm	<LQ
	Hg	0.1 ppm	-
	Pb	200 ppm	<LQ

<LQ = proportion below the quantifiable threshold.

DISCUSSION

The previously reported pegmatites are coarse-grained igneous rocks generated by the crystallization of post-magmatic liquids, forming tabular bodies that can have large dimensions. Mineralogically, lithiniferous pegmatites are composed of quartz, feldspar, and mica, with spodumene and other lithium minerals as accessory minerals (BRAGA et al., 2008). The analyzed rock dust corresponded to the finest tailings from the transformation of lithiniferous pegmatite into spodumene concentrate.

In this study, the mineral phases and clay minerals present in the rock dust were identified by X-ray diffractometry analysis. The following were identified upon the interpretation of the X-ray diffractogram of the total rock powder: quartz (43.66%), albite (38.10%), microcline (15.30%), and muscovite (1.80%). The other minerals were below the quantifiable limits. Generally, pegmatites are composed of 60–70% feldspar, 25–30% quartz, 5–10% muscovite, and, 1–2% other minerals (OBA et al., 2006). In a study performed with lithiniferous pegmatite from the region of Araçuaí, MG, the main mineral phases present in the pegmatite sample were identified to be spodumene (46.20%), quartz (32.10%), albite (13.40%), mica (7.40%), and chlorite (0.90%) (ELIOTÉRIO et al., 2019). As expected, these minerals were the most abundant in lithiniferous pegmatites from the region studied, in this case, the northeast of Minas Gerais (ROMEIRO et al., 2005).

In present study, the major elements and trace elements of the rock dust were analyzed using X-ray fluorescence. Regarding the major elements, SiO_2 (81.92%), Al_2O_3 (11.04%), and Na_2O (3.86%) were predominant, and an important amount of K_2O (2.61%) was present. These elements are important constituents of feldspar group of minerals. It can be seen that the feldspar present in the pegmatite from the region of Araçuaí, MG, is a sodium (Na) feldspar, because the content of Na_2O is higher than that of K_2O. Albite contributes to the Na content, and microcline and muscovite contribute to the K content. Fe_2O_3, CaO, and P_2O_5 were found in low amounts (0.20, 0.15, and 0.22%, respectively). The other elements were below quantifiable limits.

Feldspar is the most important mineral group in the world and constitutes approximately 60% of the Earth's crust. It can be found in almost all eruptive and metamorphic rocks, as well as in some sedimentary rocks (VIDYADHAR et al., 2006). They belong to the group of aluminum silicates with K, Na, Ca, and barium (Ba). The main minerals are orthoclase/microclinium ($K_2O.Al_2O_3.6SiO_2$), albite ($Na_2O.Al_2O_3.6SiO_2$), and anorthite ($CaO.Al_2O_3.2SiO_2$) (MORAES et al., 1997).

The presence of K_2O in the analyzed rock powder is a relevant feature because the high external dependence of this element requires a coordinated action to seek alternative sources of K. Additionally, potassium sulfate (K_2SO_4), double potassium magnesium sulfate ($K_2SO_4.MgSO_4$), and potassium nitrate (KNO_3) are also used as sources of K. Together, they are the most important sources of K for fertilizers, with K_2SO_4 being the second most used (POTAFOS, 1996). However, there are restrictions on the use of these fertilizers in conventional and organic agriculture (COSTA et al., 1997; MALAVOLTA et al., 2000).

Primary mineral reserves with relatively high levels of K are found in almost all regions of the country (TÁVORA, 1982; NASCIMENTO et al., 2004). However, most minerals with K in their structure are insoluble or poorly soluble, with some difficulty in obtaining the element, which occurs, for example, with silicates. These minerals are formed by tetrahedral SiO_4 groups linked by cations (NASCIMENTO et al., 2004). According to Oliveira et al. (2001), potassium-rich silicates, such as potassium feldspar, muscovite, and leucite, are not important sources of this nutrient because they are not soluble in water, and their structures are difficult to break by artificial means. However, in most cases, the agronomic efficiency of rocks depends on their origin and composition, soil factors, incubation time, chemical or thermal treatment, and the crops used.

Unsatisfactory results with the use of rocks as a source of nutrients are often related to a lack of knowledge of the mineralogical characteristics of the material used. Some of the cited studies used basalt, feldspar, muscovite, and zeolites but with very low solubility. Mineralogy, an indicator of the solubility potential of minerals and their ability to release K, is an extremely important factor in selecting rocks for direct application to the soil (NASCIMENTO et al., 2004).

Alkaline feldspars (orthoclase and microcline) and feldspathoids (anhydrous silicates similar to feldspars, but with less silica; for example, uncommonly occurring leucite) are considered potential sources of K for the manufacturing of fertilizers, either in the form of salts or thermophosphates, or for direct application to the soil. Among the silicate minerals, mica has great potential for K extraction because of its considerable K_2O content and abundance. However, for its use as a slow-release fertilizer, it should be applied directly to the soil to be really effective, and studies on the chemical characteristics of soils and kinetics of migration of ions are necessary because these characteristics vary with the type of soil and climatic conditions of the regions (NASCIMENTO et al., 2004).

There are several abundant silicate rocks in Brazil, which can be used as a source of K in its powder form. In some cases, in addition to K, rocks, such as ultramafic, micaschist, and alkaline ultramafic rocks, can provide other nutrients and have an alkalizing effect, acting as soil conditioners (LEAL et al., 2010), and they probably have low K content.

According to Resende et al. (2006), geochemical characterization, definition of processing methods, and systematic agronomic evaluation of these rocks may result in the identification of effective alternative sources of K supply, thus forming a new group of alternative agricultural inputs.

With regard to trace elements, gallium (21 ppm), rubidium (608 ppm), niobium (28 ppm), and tin (21 ppm) were detected. The other trace elements were below quantifiable limits. Regarding compliance with IN 05/2016 and considering the most restrictive criterion of the maximum limits of toxic heavy metals present in fertilizers, it was observed that the values found for potentially toxic elements in the rock dust used in this study were very low compared to the limits established by current legislation.

Usually, Al is a conservative and not a very mobile element, and in this case, it probably got diluted due to the addition of rock dust. This decrease in Al concentration may be interesting because excess Al in soil is harmful to plants (BARBOSA, 2017). It is known that Ca and Mg have greater mobility than Al; thus, it can be seen that there was a response according to the natural influences of the soil and rock dust.

The increased Ca in the soil may have originated from a trace mineral that was not detected in the rock dust sample. According to Goldich's (1938) mineral alteration sequence, calcium plagioclase and augite have low resistance to weathering; that is, they release their cations easily into the environment. According to Gupta (1991), the best method for determining the extent of accumulation or scarcity of a given metal in the soil is by the analysis of trace element concentrations. The trace elements that were present in high concentrations were Sb and t, clearly demonstrating their association with the addition of rock dust.

Interestingly, a significant increase was found in the levels of P (more than seven times) and K (double) in the sample with the application of rock dust. The increased K levels were probably due to albite, which, in addition to being present in its composition, also reduces the leaching losses of exchangeable cations, mainly K^+. With the addition of rock dust, these nutrients are gradually released, thus reducing leaching losses and favoring long-term fertilization of tropical soils (BRITO et al., 2019)

Phosphorus exhibited an exuberant increase in relation to the standard of the samples without the addition of rock dust, even though the amount of P_2O_5 in the rock dust was only 0.22%. Indeed, the behavior of P in soils depends on several factors, such as soil P content, soil texture, P saturation (clay or sandy), location of the agricultural plot in relation to the drainage network, agricultural practices, and climatic conditions (SANTOS et al., 2008).

Escosteguy et al. (1998) reported high P content in basalt doses; however, they attributed this effect to the Mehlich-1 method extractor because acid extractors can dissolve certain minerals present in low amounts (traces) in rock dust, but are rich in P. In this study, a greater release of P was observed for P-Mehlich-1 than for P-resin, which corroborates the possibility attributed to the results of the above mentioned authors. Oliveira (2012) concluded that several minerals, including trace minerals, can be reactive in the presence of water. This reactivity may be related to the acidic pH of the soil, which contributed to the release of this nutrient. Another reason for the release of large amount of P into the soil could be related to the amount of silicon released by the rock. According to Brait (2008), silicon can cause P desorption in the soil and promote competition for the same binding sites, thereby improving P availability to plants.

Soil carbon can exist in inorganic (carbonate and bicarbonate) and organic forms. Soil organic carbon (organic matter, OM) is composed of microorganisms, stabilized humus, and plant and animal residues in various stages of decomposition. Rocking increased the OM content. In comparison with the pH of water, which indicates active acidity, there was no change upon the addition of rock powder.

The soil sorptive complex, which is the ability to exchange cations and anions and reflects the behavior of clays and OM that are adsorbed on them, showed interference in the elements Al, Ca, and Mg, and there was no increase in the potential acidity attributes (H^+Al), aluminum saturation (m), and CTC. In this system, the addition of rock powder had not yet occurred because of its low solubility. However, regarding V% (base saturation) in relation to the total number of cations in the complex and K^+ (basic cations on the surface of minerals), they showed that there was a significant tendency to increase when rock dust was added.

There was no change in the pH due to the application of rock dust; however, the OM content increased. The increase in OM was due to the deposition of organic residues, mainly of plant origin. During photosynthesis, plants use the CO_2 present in the atmosphere and fix it to accumulate biomass. Part of the carbon fixed by the plants is released into the soil via root exudates, and the remaining is incorporated by addition of the plant tissues after senescence. This is one of the main indicators of soil fertility, as it is related to other factors such as water retention, CTC, pH, and microbial action (GIONGO et al., 2011).

The Brazilian legislation for the use of rock dust or remineralizers began with the enactment of Law, 12,890 of December, 2013. This law amended Law 6,894 of, 1980, which regulates inputs that could be used in Brazilian agriculture. Law, 12,890 established the concept of remineralizer as: “material of mineral origin that has undergone only reduction and size classification by mechanical processes and that alters soil fertility rates through the addition of macro and micronutrients to plants, as well as promotes the improvement of physical or physical-chemical properties or biological activity of the soil” (BRASIL, 2013). Thus, the remineralizers could be commercialized and inspected by federal agencies. This law was regulated by IN 53/2013, establishing criteria for research, labeling, inspection, and other attributes of agricultural inputs in general.

IN 05/2016 and IN 06/2016 of March, 2016 were applied to regulate the prerequisites for a remineralizer to be legally marketed. In Chapter 4, IN 05/2016 establishes the minimum requirements for registration of remineralizers. Item I of that chapter refers to the granulometry of the material in view of its different behavior regarding agricultural use for different particle sizes. According to Batista (2013), it is classified as a filler (pass sieve 0.3 mm), powder (pass sieve, 2 mm), and mash (pass sieve 4.8 mm). In addition, regarding the physical nature of the remineralizers, the following are the same IN states that the rock dust must have as a minimum requirement—V –, 100% of the particles passing through the, 2.0 mm sieve in weight/weight (ABNT nº, 10); VI – at least 70% of the particles passing by weight/weight in the 0.84 mm sieve (ABNT nº, 20); VII – at least 50% of the particles passing by weight/weight in the 0.3 mm sieve (ABNT nº 50). Article, 2 specifies the elements that cannot be present in excess in the remineralizer and determines its maximum values for SiO_2 and potentially toxic elements present in the product. MAPA IN 06/2016 establishes all the concepts of remineralizer production, storage, labeling, and sampling. It also determines that research on each remineralizer, as a unique product, should be conducted to evaluate its agronomic efficiency, and the experiments should be performed in the field or in a greenhouse. Also, they must be conducted in regions that are representative of the cultivation of the crop, which will be recommended in the national territory at two locations with different soil and climate conditions for two crops, or at four locations with different soil and climate conditions for one crop. This information clarifies that the material does not meet the minimum requirements for the physical specifications according to Annex I Normative Instruction No. 5/2016 of MAPA, and therefore requires physical adjustments for the use in question.

According to MAPA's Normative Instruction No. 5/2016, the sum of the bases (CaO, MgO, and K_2O) must be greater than 9%. The results presented here indicate that the sum of the bases is, 2.76%, which is far below the minimum required limit. In full compliance with the IN from the chemical analysis, it has the minimum required content of at least, 1% for K_2O, and levels of potentially toxic elements—arsenic, cadmium, mercury, and lead—were not determined from the technique used.

The determination of the agronomic efficiency index and the quantification of the residual effect of K and other nutrients present in the selected rocks are prerequisites for the correct dimensioning of the fertilization recommendations with the rocks, aiming at the recovery and maintenance of soil fertility and nutritional balance in the different production systems. Therefore, this type of evaluation should be conducted under the most varied experimental conditions in no-tillage, crop-livestock, fruit, and forestry systems while considering conventional and organic production modalities. Organic production systems form a promising market niche because they allow for great added value in the commercialization of products, thereby enabling agricultural exploitation even on a small scale. One of the basic principles of organic agriculture is the replacement of high-solubility synthetic fertilizers with other inputs that have nutrient release rates adjusted according to crop demand over time. It is desirable for these alternative inputs to be close to the growing regions, which would reduce transport costs and increase the sustainability of agricultural production (NEVES et al., 2004).

In organic systems, the application of potassium chloride is prohibited and that of potassium sulfate is accepted with restrictions; therefore, K supply is critical for organic production in tropical soils. In such cases, the possibility of using rocks as sources of K is of strategic importance because the demand for nutrients would be easily met by the direct application of these rocks to the soil as part of the management of cover crops, or in composting processes for the production of organic fertilizers enriched in K.

CONCLUSIONS

Based on the results obtained, it is still not possible to state that the use of lithiniferous pegmatite residues from the region of Araçuaí, MG, as soil remineralizers can promote the use of a material currently considered as tailings, and even boost the emergence of a new regional consumer market for this material. There are inconsistencies, such as the sum of bases and the SiO_2 content, which need to be remedied by conducting further research using the material. In addition, it was observed that the granulometry of the particles was not in accordance with that proposed by the standard; hence, the material has inappropriate granulometry for use as a remineralizer. To improve this distribution, comminutions can be performed using other equipment, such as a high-pressure roller crusher or high-frequency screens, for better classification of the material.

This study despite being preliminary, indicates that the application of this material as a remineralizer has potential, mainly in relation to the supply of K_2O. However, physical adjustments are required in the beneficiation process to comply with the standards. This material, if used, would greatly contribute to the establishment of a new market that would be helpful for the sustainability of mining activities in the Jequitinhonha river Valley region.

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