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Zoneamento Agrogeológico como Ferramenta para o Manejo Regional da Fertilidade de Solos Agrícolas Tropicais: Potencial das Rochas Ricas em Biotita na Paraíba-Brasil

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RESUMO

O uso de pó de rocha como remineralizador de solos acelera a liberação de nutrientes das rochas e altera os índices de fertilidade do solo, adicionando macro e micronutrientes e promovendo melhorias nas propriedades físico-químicas e biológicas do solo. A produtividade do solo agrícola tropical deve-se principalmente ao uso intensivo de fontes solúveis NPK, mas essas são principalmente importadas e onerosas e sua solubilidade excessiva nem sempre é adequada em áreas tropicais devido à temperatura e chuvas intensas que podem diminuir a eficiência de uso dos nutrientes. A ineficiência de tais fontes, incentiva o Brasil a investir em fontes alternativas de nutrientes. As rochas ricas em biotita podem ser fonte alternativa regional de potássio, reduzindo a importação desse insumo agrícola. Muitos rejeitos de minas e pedreiras são produzidos na Paraíba mas o seu potencial como remineralizadores é desconhecido. O objetivo deste trabalho foi realizar um zoneamento agrogeológico da Paraíba, a fim de definir possíveis zonas de produção e consumo de rochas ricas em biotita. A metodologia baseou-se na avaliação de três planos de informação: geologia, modelo digital de elevação e uso e cobertura do solo. Os resultados mostraram que existe uma fonte considerável de potássio disponível no Estado. A área de produção de rochas ricas em biotita está mais concentrada nas mesorregiões da Mata e Agreste Paraibano, onde, coincidentemente, os solos são consideravelmente intemperizados e fracos em minerais primários. Toda a área de consumo fica a menos de 40 km das áreas de produção, tornando seu uso economicamente viável.

Palavras-chave: agromineral silicático, solo tropical, fonte de potássio.

Agrogeological Zoning as a Tool for Regional Fertility Management of Tropical Agricultural Soils: Biotite-Rich Rocks Potential in Paraíba-Brazil

ABSTRACT

The use of rock dust as soil remineralizer is a way to accelerate nutrient release from rocks, altering soil fertility indices by adding macro and micronutrients and promoting soil physicochemical properties and biological activity improvements. The productivity of tropical agricultural soil is mainly due to the intensive use of NPK soluble sources, but those are mainly imported and highly expensive, besides, its excessive solubility is not always suitable in tropical areas due to temperature and intense rains that can decrease the efficiency of nutrient use. Its use is becoming more and more inefficient, forcing Brazil to invest in alternative nutrient sources. Biotite-rich rocks, can be a regional alternative source of potassium, thereby reducing the importation of this agricultural input. A lot of mine and quarry tailings are produced in Paraíba. However, Paraíba's potential to supply rock dust is unknown. This work purpose was to perform an agrogeological zoning of Paraíba in order to define potential zones of production and consumption of biotite-rich rocks. The methodology was based on the evaluation of three information plans: geology, digital elevation model and land use and cover. The results showed that there is a considerable source of potassium available in the State. The area of biotite-rich rocks production is more concentrated in the mesoregions of Mata and Agreste Paraibano where, coincidentally, the soils are considerably weathered and poor in primary minerals. The entire consumption area is less than 40 km from the production areas, making its use economically viable.

Keywords: silicate agromineral, tropical soil, potassium sources.

Introduction

In the early days, humans depended, though indirectly, on the soil cause it sustained the eatable plants and the pastures that guided animal migration, both most important for their survival and evolution. With the agriculture advent, human dependence and its impact on the soil became more expressive and evident. History shows the close relationship between soil and the emergence of civilizations along human journey on Earth. In fact, soil has been of such importance for humans that its management has reflected throughout human history with the rise and fall of several civilizations dictating, on several occasions, their success or doom (Pérez et al., 2016).

Soil management and farming techniques have changed over the years, starting by a low productivity system or a subsistence farming that attended to a small number. It was a more intensive use of human and animal force in plantations and with no use of scientific methodologies. However, the growing human population, especially since the 19th and 20th centuries, demanded changes in agricultural practices. On one hand there was an increasing population that demanded a higher amount of food and on the other hand there were farmers who needed to meet this rising demand (Martins et al., 2017). The world responded with the “green revolution”, achieved, essentially, by the adoption of technological and scientific advances and by the expansion of the agricultural frontier (Pillon, 2017).

The green revolution in Brazil was considered one of the periods of greatest expansion of Brazil's agricultural frontier (1960-1990), especially due to the occupation of the Brazilian Cerrado, the agricultural model was characterized by the intensification of agricultural mechanization, monoculture and the adoption of technology packages based on synthetic inputs, including limestone, soluble fertilizers (NPK) and pesticides (Pillon, 2017). From a social and capitalist point of view, the green revolution fulfilled its primary objective which was the increase of food production, transforming Brazil from an importer to an exporter of commodity. However, the negative impacts of monocultures and intensive tillage, such as, severe erosion processes and the large contingent of degraded areas, along with the use of large amount of pesticides as the only strategy for dealing with pests are very noticeable in the environmental degradation. Land-use changes resulted in a loss of

valuable habitats, land degradation, soil erosion, clean water depletion and the release of carbon into the atmosphere (FAO, 2018).

In the past three decades, the monoculture strategy coined by the green revolution, gradually gives way to integrated and rotated production (Neves et al., 2015). Such systems present less risk to changes in weather and climate, allowing a better coexistence with pests, rationalizing the use of pesticides, a higher efficiency in water and energy use and better nutrient and carbon cycling, among others.

According to Pillon (2017), for the coming years, a third wave is expected, a bio-based agriculture where there will be an increasingly clear link between food, nutrition and health. Nutrient sources present in silicate agrominerals occurring in different geological formations, many of which are still unknown, farm waste, in addition to the biological process products and co-products present in nature, whose organisms (fungi, bacteria, actinomycetes and mycorrhizae) are capable of promoting plant growth, controlling pests, enhancing nutrient uptake science, promoting biological nitrogen fixation, among other functions, will be critical to the consolidation of this “new agriculture”.

In this context, such sources could play an important role not only by nutrients that are part of its composition, but also by stimulating biological activity that its application to the soil provides (Pillon, 2017). The use of rock dust as soil remineralizer for soil fertility management falls entirely within this new agricultural vision and agroecology is an important theoretical-practical basis.

Agrogeology is an interdisciplinary science applied to the resolution of problems related to alternative sources for nutrient scarcity and soil degradation, using geological materials and knowledge of the processes that contribute to the natural and agricultural and livestock production systems recovery and/or maintenance (van Straaten, 2007).

The Ministry of Agriculture, Livestock and Supply, by means of Law 12890/2013, defines remineralizer as a material of mineral origin, which has undergone only reduction and size classification by mechanical processes and that alter soil fertility indices by adding macro and micronutrients to promote the improvement of physical or physicochemical properties or soil biological activity (BRASIL, 2013).

Remineralization is a way to mimic natural processes of weathering by physically, chemically and biologically accelerate nutrient release from rocks and new mineral formation (Haller, 2011). The term 'Rocks for Crops' was used for the first time in 2002 (van Straaten, 2002) and it is seen as an inexpensive option to contribute to soil fertility management, especially in the tropics (van Straaten, 2006, 2013, 2016).

The first version of Brazil Agrogeological Zoning, carried out jointly by the Geological Service of Brazil (SGB/CPRM - Companhia de Pesquisa de Recursos Minerais) and Brazilian Agricultural Research Corporation (EMBRAPA), was released in 2018 during the Soil Remineralizers Seminar. Among the results, the project produced a map with the crossing of information on areas of agrominerals consumption and regions with potential of production of these inputs (BRASIL, 2018).

Tropical soils are ancient and deeply weathered, unlike temperate soils formed from sediments of glacial, wind and fluvial origin, fertile soils rich in primary minerals - 2:1 clay that contribute to their high cation exchange capacity (CEC).

Most Brazilian soils are well developed, formed by advanced biogeochemical weathering stage of the source material. They are poor in nutrients (dystrophic) and organic matter, low CEC and anion exchange capacity (AEC) greater than temperate soils due to the predominance of minerals in the clay fraction such as kaolinite, oxy-hydroxide, iron oxides and aluminum hydroxide (Schwertmann and Herbillon, 1992; Buol, 2009).

Paraíba state displays a different scenario from Brazil, with a large part of the territory in semi-arid climate and high CEC eutrophic soils. However, the main agricultural areas occur in low to very low CEC dystrophic soils in the regions of Agreste and Mata (BRASIL, 1972; PARAÍBA, 1978; Medeiros, 2018).

The productivity of tropical agricultural soils is mainly due to the intensive use of NPK soluble sources and soil acidity control. However, although it served its purpose at first, it is becoming more and more inefficient because its: 1. Expensive, most of them are imported (83% of NPK fertilizers are imported); 2. Highly inefficient, its excessive solubility is not appropriate in tropical areas due to temperature and intense rains that quickly lixiviate the nutrients to root inaccessible depths (it is estimated an average use efficiency of 57.5% for N, 49.5% for P and 75% for total K) (ANDA, 2018). So, one can realize how important it is for Brazil to invest in alternative nutrient

sources through the definition, identification and mapping of domestic agricultural inputs.

Biotite is a mineral from the silicate family of the phyllosilicate group, rich in potassium, magnesium and iron (Fanning et al., 1989). They are commonly found as macrocrystalline, sand or silt size particles in granites, schists, phyllites, gneisses and fine-grained clastic sedimentary rocks (Thompson e Ukrainczyk, 2002).

Biotite can be altered in the soil by weathering transformation in the soil by physical, chemical and biological weathering into illite, vermiculite, smectite or kaolinite. The presence of biotite in the soil is environmentally significant as source of K for plant nutrition (Thompson e Ukrainczyk, 2002), because the weathering process makes part of the chemical elements available to plants and microorganisms.

Physical weathering is done during rock processing to obtain the main mining activity products. Most of the tailing or by-products remain as rock dust. Depending on the time of exposition on the soil surface, biogeochemical weathering occurs in certain degree and has a significant role in altering minerals. Rock dust in Brazil can be sold as a soil remineralizer as long as it meets the specifications of granulometry, total major element oxides, nutrients and potential toxic elements (BRASIL, 2013, 2016).

Biotite schist is a metamorphic rock formed by regional metamorphism, consisting of more than 5% of biotite (Mason, 1990) and composed of phyllosilicates minerals rich in potassium and magnesium (Cola e Simão, 2012; Aguiar et al., 2012). Biotite schist has already shown performance comparable to potassium chloride (KCl) (Castro et al., 2006). Thus, biotite schist, like others biotite-rich rocks, can be a regional alternative source of potassium, thereby reducing the importation of this agricultural input.

Precambrian rocks occur in about 80% of Paraíba total area and are part of the Paleo-, Meso- and Neoproterozoic evolution of the Borborema Province. Paraíba mineral scenario is today quite diverse and with potential for new inputs discovery. Like many other northeastern states, Paraíba stands out for its non-metallic substances production, also called industrial rocks and minerals and it represents more than 82% of the total volumetric production. Paraíba have a prominent national position in ornamental granite and vermiculite (Santos et al., 2002). So, a lot of mine and quarry tailings are produced in the state and are not being exploited by the miners and may even cause negative impacts on the environment. Thus, the use of by-products from biotite-rich rocks

mining as a soil remineralizer can solve problems in the mining and agribusiness sectors: it would give tailings a purpose, solving an environmental problem and adding income to the miner, while contributing to sustainable soil fertility management. However, Paraíba state potential to supply regional agrominerals is still unknown, as well as the capability of each tailing for soil remineralization.

This work purpose is to perform an agrogeological zoning of Paraíba state in order to define potential zones of production and consumption of biotite-rich rocks.

Material and methods

Study area

Paraíba is located east of the Northeast of Brazil (6,05-8,32 S; 34,78-38,77 W) and its territorial area is 56 469,778 km², being one of the smallest states in the country (Figure 1).

Paraíba's relief is diverse, ranging from coastal plains to backwoods depressions. On the coast there is the Coastal Plain, in its center there is Borborema Plateau, a transition region between the coast and the backlands, with altitude between three hundred and eight hundred meters. Finally, in the backlands, there is the Sertaneja Depression,

from the municipality of Patos to the Serra da Viração. More than half of the state's territory is dominated by very old and hardy rocks formed during the Precambrian period over 2.5 billion years ago (Santos et al., 2002).

Due to its proximity to the Equator Line, Paraíba has a warm climate, with high temperatures throughout the year, and varied according to the local relief. According to Alvares et al. (2013), by Köppen classification there is three main climate classes: humid tropical savanna with rain concentrated on summer and winter drought (Aw), located in the westernmost area of the state; steppe or semiarid climate, with precipitation ranges between 250 and 500 mm/year (BSH) in its center, over Borborema Plateau; and humid tropical with rain concentrated in winter (As), located by the coast.

In the mesoregion of Mata the most representative soil types are Acrisols, Arenosols, Podzols and Ferralsols, dystrophic soils, with low to very low CEC and sandy to sandy clay loam texture (BRASIL, 1972; PARAIBA, 1978; Medeiros, 2018), with sugarcane monoculture. The Agreste mesoregion has greater soil diversity, but the main agricultural areas are the Acrisols and Ferralsols (BRASIL, 1972; PARAIBA, 1978; Medeiros, 2018), with sugarcane, pasture, banana and horticulture crops.

Figure 1. Paraíba and its mesoregions location. Source: first author.

Methodology

The methodology was based on the agrogeological zoning methodological proposal of

Oliveira et al. (2019). It is based on the evaluation of three information plans: source material

(geology), digital elevation model (MDE - slope) and land use and cover.

Regarding the geology plan, data were obtained from the database of CPRM called Geoscience System of the Geological Survey of Brazil (GEOSGB). The mapping available is on a scale of 1:500,000 and was carried out through an agreement signed between the State Government and CPRM, within the Basic Geological Surveys of Brazil Program (PLGB), which contains the geological and mineral resources maps of the State (Santos et al., 2002). Biotite schist and the rocks rich in biotite has been associated with the geological units in which it is inserted. Biotite is a mineral rich in potassium and magnesium with the ideal formula $K_{0.9}Mg_{1.9}Fe_{1.1}Al_{1.0}Na_{0.1}Si_3O_{10}(OH)_2$ (Sverdrup et al., 2019). It occurs in igneous and metamorphic rocks associated with several geological units in Paraíba.

The location zones of the biotite-rich rocks have been designated as the production zone and its exploitation is viable according to the other factors under consideration: slope and land use and cover. For the source material theme, the production zones were considered to be very high potential and the areas outside the production zones as unable to explore.

Regarding the slope plane, it was obtained from the Digital Elevation Model (DEM) of the 1-second Arc product (spatial resolution 30 m) from the Radar Shuttle Topography Mission (SRTM), products 09S38W_1arc_v3, 09S37W_1arc_v3, 08S39W_1arc_v3, 08S38W_1arc_v3, 08S37W_1arc_v3, 08S36W_1arc_v3, 08S35W_1arc_v3, 07S39W_1arc_v3, 07S38W_1arc_v3, 07S37W_1arc_v3, 07S36W_1arc_v3, 07S35W_1arc_v3 available at <https://earthexplorer.usgs.gov/> (Farr et al., 2007). These 12 products correspond to scenes that cover the entire state. Some of these products (08S37W_1arc_v3, 07S37W_1arc_v3 e 07S38W_1arc_v3) had null values, uncorrected errors in the DEMs provided by USGS, so it was necessary to complete these pixels. In order to obtain the DEM from the total area of Paraíba, it

was necessary to mosaic the products mentioned above (including the corrected ones) and then cut it according to the geopolitical limit of the State.

Finally, the land use and cover plan was generated from MAPBIOMAS data, a multi-institutional initiative involving universities, non-governmental organizations and technology companies that came together to contribute to the understanding of territorial transformations based on the annual mapping of land use and cover. The data were obtained by using spectral images of the Landsat 8 satellite OLI sensor, with 30 m resolution. For this research we used the 2017 land use and cover map. Table 1 represents the land use and cover classes according to MAPBIOMAS and its respective potential classification.

To calculate the agrogeological potential of production zones, the matrix information plans were joined using map algebra and geoprocessing software to sum up the classifications and divide them into unable potential (0), low potential (1 to 3) medium potential (4 to 6), high potential (7 to 9) and very high potential (10 to 12). Areas that received a zero score were considered unsuitable for future exploration generating unfitted areas regardless the other parameters results.

Unlike Oliveira et al. (2019) who stipulated buffers of 50 km, 100 km, 200 km and 300 km from the location of the biotite-rich rocks to determine a viable minimum or maximum radius for potential agromineral consumption, in this paper we opted to calculate the Euclidean distances between production zones and consumption zones. The consumption zones are the agricultural areas of the state. Euclidean distance or Euclidean metric is the "ordinary" straight-line distance between two points in Euclidean space, allowing to determine the real distance between the biotite-rich rocks source and the cultivated territory where they will be consumed.

Considering the three information plans, the areas were classified as shown in Table 2.

Table 1. Land use and cover classes according to MAPBIOMAS and its respective potential classification.

Land use and cover	Description	Classification

Forest formation	Large trees with predominance of continuous canopy, occurring mainly near the drainage (riparian forests) and on the humid slopes south of hills.	0
Savanic formation	Vegetation type with predominance of semi-continuous canopy species. Formation of a continuous herbaceous stratum in association with a discontinuous shrub-tree stratum. Secondary vegetation in various regeneration stages.	0
Grassland formation	Vegetation types with predominance of herbaceous to shrubby species.	2
Other non-forest natural formation	Natural areas with other types of vegetation excluding forest.	0
Pasture	Pasture areas, natural or planted, linked to agricultural activity. Sometimes it has exposed soil in overgrazing areas. Areas with herbaceous species and shrubs, almost always grasses with forage value.	2
Annual and perennial agriculture	Areas predominantly occupied with annual crops and in some regions (especially the Northeast) with the presence of perennial crops.	1
Mosaic of agriculture or pasture	Mix of crops and pasture. Areas where scale does not allow differentiation between the two.	1
Urban area	Urban area and other intensively used areas, structured by buildings and road system.	0
Rocky outcrop	Naturally exposed rocks on land surface without ground cover, often with the partial presence of rupicolous vegetation and high slope.	3
Mining	Areas referring to large mineral extraction, with clear exposure of the soil by the action of heavy machinery.	4
Water	Watercourses and canals (rivers, streams, canals and other linear water bodies), naturally enclosed, non-moving water bodies (natural lakes) and artificial reservoirs.	0
Other non-vegetated areas	Non-permeable surface areas (infrastructure, urban sprawl or mining) not mapped in their classes.	3
Non-observed	Non-classified areas.	0

Table 2. Agrogeological potential classification.

GEOLOGY	POTENTIAL	CLASSIFICATION
Biotite-rich rocks production zone	Very high	4
Outside production zone	Unable	0
SLOPE		
Flat (0 - 3%)	Unable	0
Soft wavy (3-8%)	Unable	0
Wavy (8-20%)	High	3
Strongly wavy (20-45%)	High	3
Hilly (45-75%)	Very high	4
Steep (>75%)	Very high	4
LAND USE AND COVER		
Natural and urban areas	Unable	0
Agricultural and forestry	Low	1
Pasture and grasslands	Average	2
Bare soil and non-vegetated	High	3
Mining area	Very high	4

Results and discussion

Weathering and soil properties

The humid and hot climates of the Agreste and Mata mesoregions make the biogeochemical weathering intense. Hydrolysis is the most important chemical weathering reaction for altering minerals in the silicate family (Murphy and Helgeson, 1987; Sverdrup et al., 2019).

The main mechanism of biogeochemical evolution is hydrolysis and in some areas of the mesoregion of Mata, acidolysis is the most intense mechanism of mineral weathering.

The alteration of silicates by hydrolysis occurs in conjunction with various soil formation processes in the two mesoregions. While acidolysis is a mechanism of biogeochemical evolution that is directly related to podzolization and Podzol formation and formation of extremely acidic and very dystrophic soils.

The abundance of divalent Fe in biotite contributes to instability in the oxidizing environment (Thompson and Ukrainczyk, 2002), equal to that of most soils in these mesoregions.

The most representative soil classes in the Forest are Acrisols, Arenosols, Podzols and Ferralsols (Medeiros, 2018). They are very deep soils, strongly leached (dystrophic) and with low to very low CPB (Table 3).

Agreste presents a greater diversity of soils with a higher occurrence of eutrophic soils and with medium to high CEC such as Luvisols, Solonetz, Planossolos, Regosols and Vertisols, but most Acrisols and Ferralsols are dystrophic and with low to very low CEC (Table 3).

Table 3. Chemical properties of Agreste and Mata soils

Ferralsols ¹ (<i>Latossolos</i>) ²					Soil fertility class
Horizon*	Mg	K Cmolc.kg ⁻¹	CEC	V %	
A	0.34	0.06	6.46	22	dystrophic
Bo	0.23	0.05	3.45	23	
Acrisols ¹ (<i>Argissolos</i>) ²					
A	0.57	0.11	5.96	33	
Bt	1.03	0.08	4.86	35	
Podzols ¹ (<i>Espodossolos</i>) ²					
A	0.08	0.03	2.45	16	eutrophic
Bm or s	0.05	0.08	10.05	4	
Arenosols ¹ (<i>Neossolo Quartzarênicos</i>) ²					
A	0.14	0.03	2.00	56	eutrophic
C	0.10	0.05	1.36	49	

1 = (IUSS / WRB, 2015); 2 = (EMBRAPA, 2018); * = Average of the values of the profiles of the Agreste and Mata mesoregions of the soil surveys Brasil (1972) and Paraíba (1978).

According to Hazelton and Murphy (2016), the contents of Mg, K, CEC and base saturation (V%) in Ferrasols, Podzols and Arenosols are low to very low. Arenosols have base saturation $\geq 50\%$ (Table 3), because these soils occur in the mesoregion of Mata very close to the coast, influenced by atmospheric depositions. However, they are sandy soils with a very low CEC (2.0 cmolc/kg) which gives them fertility similar to Ferralsols and Podzols.

Acrisols have moderate Mg, moderate to high K exchangeable, low to very low CEC and low V%. The levels of moderate K and Mg are associated with some Acrisols of the Agreste mesoregion formed from parent material biotite-

hornblende migmatite and biotite gneiss (BRASIL, 1972; Paraíba, 1978).

Most of the soils in the mesoregion of Mata have parent material, sandstones and conglomerates with intercalations of siltites and claystones from the Barreiras group with low potential for nutrient supply. It is in these areas where there is the most intensive agriculture in Paraíba and which demands the greatest fertilizers inputs.

These soils have properties with double aptitude for the use of remineralizers as a source of K and Mg: 1) Content of these elements low to very low, which demands continuous fertilization; 2) Reaction of soils from strongly to extremely acidic

that intensifies the alteration of biotite and release of these elements.

The more acidic the reaction of the soil solution, the greater the ability to release these chemical elements from the mineral and the greater the bioavailability for plants and microorganisms (Ramos et al., 2015; Dalmora et al., 2019).

In Podzols, the pedogenetic podzolization process with the action of several low molecular weight organic acids with easy H^+ dissociation from phenolic and carboxylic groups, can intensify the alteration of remineralizers of rocks rich in biotite. In relation to the other Acrisols, Ferralsols and Arenosols soils, the chemical weathering of minerals will be by hydrolysis.

Since 2019, some sugar cane producers in the municipalities of Alhandra and Jucurutu in the mesoregion of Mata began to apply by-products

from the mining of pegmatites (feldspar) and shale biotite (biotite) in Acrisol and Podzol, but without previous studies to evaluate the potential of these materials as soil remineralizers.

Geological units

Biotite is present in several geological units from Proterozoic. 1. Neoproterozoic: Indiscriminate granitoid, Caralina-Surubim, Jucurutu and Seridó formation rich in metamorphic rocks composed of garnet-biotite schist; 2. Paleo/mesoproterozoico: Serra de São José Group, Serra do Deserto granite Group, Recanto-Riacho do Forno metagranitoid, Poço da Cruz magmatic Group and Serrinha-Pedro Velho complex, all rich in biotite schist, biotite gneiss and granite (Figure 2).

Figure 2. Paraíba geological units with biotite-rich rocks. Source: first author.

About 18,5% of Paraíba territory has biotite resource and so can be explored as a potassium source. Serrinha-Pedro Velho complex is the most representative geological unit

composed of biotite schist, biotite-gneiss, biotite-hornblende and migmatite.

The areas of flat to soft wavy slope occupy 54% of the production area and are unsuitable for biotite-rich rocks exploration. The areas of wavy to

strongly wavy slope occupy 44.22% of the production area and 1.78% is hilly to steep,

showing a high to very high potential for biotite-rich rocks exploration (Figure 3).

Figure 3. Paraíba slope with emphasis on the biotite-rich rocks production zone. Source: first author.

Agrogeological Zoning

As showed in Figure 4, biotite-rich rocks production zone is used and covered by natural areas which include forest and savanic formation and other non-forest natural formations. All those and as well as non-observed areas, water and urban areas were classified as unable to explore biotite-rich rocks, which represents 48.96% of the production zone. Agriculture zones which included annual and perennial agriculture as well as mosaic of agriculture or pasture received a potential score of 1 (low potential) and represent 16.34% of

biotite-rich rocks production zone. Pasture (29.15%) and grasslands (5.39%) were classified as average potential for biotite-rich rocks exploration. Only 0.15% of the production zone were classified as high potential for biotite-rich rocks exploration and correspond to other non-vegetated areas and rocky outcrop. Finally, very high potential for biotite-rich rocks exploration was only found in mining areas in less than 0.01% of the production zone.

Figure 4. Paraíba land use and cover. Source: first author.

Figure 5 shows the agrogeological potential of biotite-rich rocks in the state of Paraíba. The result of the evaluated overlapping information plans showed that the production zone has two types of potential: high and very high. Both represented an area of about 1900 km², only 18.3% of the production zone. The remainder of the production area was considered unsuitable for exploration. The areas with undulating to strong undulating slope and mountainous and steep, as well as the pasture zones were the main responsible for the high potential classification of the production zone. Very high potential areas represent only 0.7%.

The highest concentration of high potential for biotite-rich rocks is in east of the state, at the Agreste region where there are several mineral exploration, such as gneiss and granite for

ornamental and construction purposes (Santos et al., 2002).

This arrangement is favorable to the state since the most weathered soils that would benefit most from input of primary minerals through soil remineralizers applications are precisely in this more coastal region that includes the Mata and Agreste Paraibano mesoregions. In contrast, most of the soils in the semi-arid region of the state (further inland) are shallow, but with low degree of pedogenetic development and a good amount of primary minerals (e.g. biotite), and in this case soil fertility would not benefit as much from biotite remineralizers. Soil limitations in Paraíba semi-arid region can be attended by other agrogeological technologies related to water-accumulating substances, since water is the major constraint on agricultural productivity in these regions.

Figure 5. Agrogeological potential for biotite-rich rocks in Paraíba-Brazil and mineral occurrences according to Santos et al. (2002). Source: first author.

There are areas of consumption, that is, areas of perennial and annual agriculture, distributed throughout all the state, with sugarcane being more concentrated in eastern Paraíba in the Mata and Agreste Paraibano mesoregions and all are within a maximum distance of 40 km in relation to the production zones (Figure 6). According to Oliveira et al. (2019), consumption zones must be located no further than 300 km from production zones to remain economically viable. Unlike synthetic and rapid assimilation inputs, remineralizers require tons of material applied per hectare. Beyond 300 km, the freight would become too costly and economically unviable.

So, the entire consumption area in Paraíba is at an economically viable distance. Result identical to that obtained by the Agrogeological Zoning of Brazil produced by EMBRAPA and CPRM that showed that practically 100% of the cultivated regions of the country are close to areas with potential for the supply of agrominerals as a source of potassium, calcium and magnesium (BRASIL, 2018).

Figure 6. Euclidean distance from biotite-rich rocks production zone. Source: first author.

Conclusions

Biotite-rich rocks zoning of Paraíba allows us to state that there is a source of potassium available in the State. The area of biotite-rich rocks production is more concentrated in the mesoregions of Mata and Agreste Paraibano where coincidentally the soils would benefit most from remineralizing technique.

Soils in these mesoregions are well developed and strongly leached and although rich in iron and aluminum oxides, enabling good AEC, they are poor in primary minerals and CEC is mainly performed by organic matter.

Remineralizing with biotite-rich rocks would enable: 1. a sustainable management of agricultural soils fertility in these regions; 2. the reduction of dependence on potassium imports; 3. to solve environmental problems coming from mining tailings accumulation; 4. an extra source of income for the miner.

The source material, the high slope and the pasture areas were the factors that most contributed to the high and very high potential for biotite-rich rocks production. The large land occupation with smooth relief and with natural areas resulted that

82% of the production area was unsuitable for biotite-rich rocks exploration.

The entire consumption area of Paraíba is less than 40 km from the production areas, making its use economically viable.

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