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## The potential of volcanic rocks from the Serra Geral Group to soil remineralization

### *O potencial de rochas vulcânicas do Grupo Serra Geral para a remineralização de solos*

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**Abstract:** The large-scale use of chemical fertilizers generates significant negative environmental impacts. The development and improvement of techniques which promote sustainability, with alternatives that meet the nutritional needs of crops, have been of great interest to the scientific community. Soil remineralization is an agricultural practice that adds ground rocks to the soil, providing essential nutrients to the plants. Remineralizers are regulated in Brazil by Law n. 12.890/2013 and Normative Instruction n. 05/2016 of the Ministry of Agriculture, Livestock, and Supply (MAPA) establishes the minimum parameters for a rock to be used for soil remineralization. This study performed a comparative geochemical analysis between the outcropping basalts of the municipalities of Estância Velha and Campo Bom, the northeastern region of Rio Grande do Sul State, taking into account the minimum parameters established by MAPA. The analyzed lithologies have characteristics with high potential to be employed as remineralizers, such as an average K<sub>2</sub>O content of 1.82%, a base saturation ranging from 13.64% to 17.43%, and safe levels of arsenic, cadmium, mercury, and lead. Continuous research and development in this field are essential to finding innovative and sustainable solutions for agriculture.

**Keywords:** Stonemeal; Sustainability; Agriculture.

**Resumo:** O uso de fertilizantes químicos em larga escala gera significativo impacto ambiental negativo. O desenvolvimento e aperfeiçoamento de técnicas que fomentem a sustentabilidade, com alternativas que supram as necessidades nutricionais das culturas têm sido de grande interesse da comunidade científica. A remineralização do solo é uma prática agrícola que envolve a adição de rochas moídas ao solo, como forma de fornecer nutrientes essenciais às plantas. Os remineralizadores são regulamentados no Brasil pela Lei 12.890/2013 e a Instrução Normativa 05/2016 do Ministério da Agricultura, Pecuária e Abastecimento (MAPA) atribui os parâmetros mínimos para que uma rocha seja destinada à remineralização de solos. Neste estudo realizou-se análise geoquímica comparativa entre os basaltos aflorantes dos municípios de Estância Velha e Campo Bom, nordeste do estado do Rio Grande do Sul, com os parâmetros mínimos estabelecidos pelo MAPA. Constatou-se que as litologias analisadas apresentam características com elevado potencial para serem empregadas como remineralizadores, como teor médio de K<sub>2</sub>O equivalente a 1,82%; teor da soma de bases abrangendo intervalo de 13,64 a 17,43% e níveis seguros de arsênio, cádmio, mercúrio e chumbo. A pesquisa e o desenvolvimento contínuos nessa área são fundamentais para encontrar soluções inovadoras e sustentáveis para a agricultura.

**Palavras-chave:** Rochagem; Sustentabilidade; Agricultura.

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## 1. Introduction

Scientific interest in the use of remineralizers as a sustainable alternative for soil management and use has been reported (KORCHAGIN, CANER; BORTOLUZZI, 2019). This alternative fertilization technique, known as stonemeal, is based on the premise that certain crushed rocks have the potential to supply macronutrients to the soil (THEODORO; LEONARDOS, 2011). Research in this area is driven by Brazil's extensive geodiversity and its status as one of the world's largest importers of chemical fertilizers (RAMOS; MELLO; KAUTZMANN, 2014). In 2022, the import of intermediate fertilizers and NPK (nitrogen, phosphorus, and potassium) formulations reached 34.61 million tons, representing 84.25% of national consumption (ANDA, 2022). Potassium is the most imported nutrient, with approximately 95% sourced from abroad (BRASIL, 2022).

The high consumption of chemical fertilizers results from the fact that Brazilian soils are highly susceptible to gradual fertility reduction due to intense agricultural activity and the natural weathering process (THEODORO *et al.*, 2012). Compared to conventional chemical fertilizers, rock dust has a significantly lower application cost (<60%) in the long term (RAMOS *et al.*, 2022). Due to its low solubilization capacity, which reduces macronutrient leaching, stonemeal allows for an interval of four to five years between applications (THEODORO *et al.*, 2021a).

The amendment of Law No. 6,894/1980 (BRASIL, 1980), commonly known as the "Fertilizer Law," to Law No. 12,890/2013, which included remineralizers in the category of agricultural inputs, was a milestone for the dissemination of this technique in Brazil. The Normative Instruction No. 5, of March 10, 2016, by the Ministry of Agriculture, Livestock, and Supply (MAPA), established the specifications and minimum parameters for a lithology to be commercialized as a soil remineralizer. Among these parameters, the following stand out:

- I. The sum of bases (CaO + MgO + K<sub>2</sub>O) must be equal to or greater than 9%;
- II. The potassium oxide (K<sub>2</sub>O) content must be equal to or greater than 1%;
- III. Free SiO<sub>2</sub> (quartz) present in the product must not exceed 25%;
- IV. Potentially toxic elements must have concentrations lower than 15 ppm of arsenic (As), 10 ppm of cadmium (Cd), 0.1 ppm of mercury (Hg), and 200 ppm of lead (Pb).

Basic rocks with aphanitic texture, such as basalts, are more suitable for this use. This is due to their geochemical and mineralogical characteristics associated with a higher susceptibility to chemical weathering, which facilitates the release of macronutrients (DANIELL; TONDER, 2023).

In the state of Rio Grande do Sul (RS), the most significant outcrops of volcanic rocks belong to the Serra Geral Group (GSG), which covers 917,000 km<sup>2</sup> in the southeastern region of South America (HARTMANN, 2014). The predominant volcanic rocks are basalts, basaltic andesites, and andesites. The GSG is notable for its concentrations of amethyst and agate geode deposits, as well as its metallogenic potential for gold deposits (HARTMANN, 2014). Ramos, Mello, and Kautzmann (2014), Ramos *et al.* (2017), and Korchagin, Caner, and Bortoluzzi (2019) reported that the rock dust from the GSG basalts, outcropping in the region of Ametista do Sul and Nova Prata in northern Rio Grande do Sul (RS), can serve as a source of macro and micronutrients for the soil.

In the northeastern part of RS, the municipalities of Estância Velha and Campo Bom are located within the GSG and have significant mining activities (HARTMANN, 2014). Therefore, this study aims to analyze the K<sub>2</sub>O content and the sum of bases (SB) of the lithologies outcropping in these municipalities to determine if these parameters comply with the specifications established by MAPA's Normative Instruction No. 5, for potential use of these lithologies as alternative fertilizers.

## 2. Methodology

The lithologies targeted in this study are exploited and commercialized by the mining companies Indústria e Comércio de Pedras Ltda. (INCOPEL) and AGCM Construtora e Mineradora Ltda., which are located approximately 50 km from Porto Alegre (RS) in the municipalities of Estância Velha and Campo Bom, respectively. The location map of the study area (Figure 1) was created using the open-source software QGIS version 3.20.2. The cartographic work adopted the Coordinate Reference System (CRS) and the Geodetic Reference System for the Americas (SIRGAS 2000).

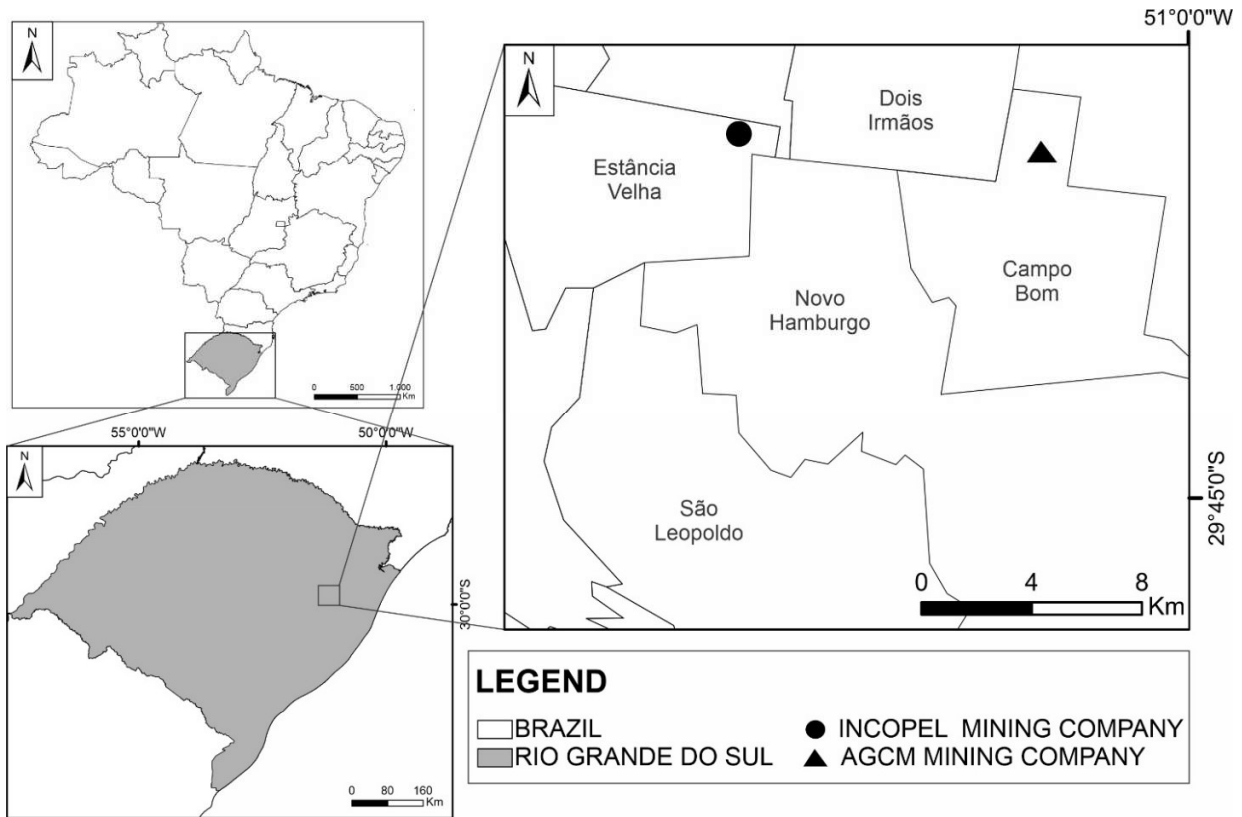


Figure 1 – Location of the study area at the national, state, and municipal levels, with emphasis on sampling points  
Source: Authors (2023).

Geochemical analyses were derived from the research of Hartmann, Baggio, and Duarte (2012), conducted by Acme Analytical Laboratories in Vancouver (Canada). These analyses are therefore characterized as secondary data analysis. The authors employed inductively coupled plasma optical emission spectrometry (ICP-OES) for detecting oxide contents and inductively coupled plasma mass spectrometry (ICP-MS) for detecting potentially toxic elements. The database used in this study comprises eight chemical analyses: three from the lithologies of Estância Velha (EV01, EV02, and EV03) and five from the lithologies of Campo Bom (CB01, CB02, CB03, CB04, and CB05). The geochemical data were interpreted using diagrams created with the open-source software Geochemical Data Toolkit version 6.0 (JANOULEK; FARROW; ERBAN, 2006).

### 3. Results and Discussion

According to the classification diagrams proposed by Middlemost (1994), the analyzed lithologies are andesitic basalts, with  $\text{SiO}_2$  ranging from 51.52% to 55.74%, and a standard deviation of 1.69%, and alkalis ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ) ranging from 3.25% to 5.38%, with a standard deviation of 0.22% (Figure 2).

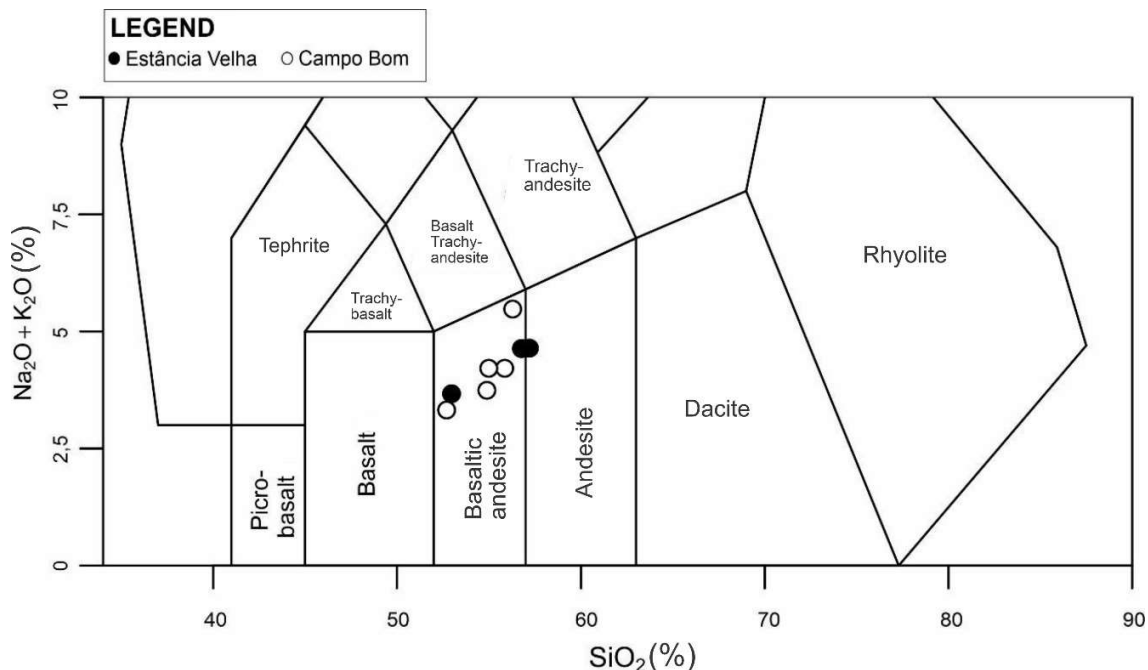


Figure 2 – Geochemical classification diagram.  
 Source: Modified from Middlemost (1994).

The average contents of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, essential macronutrients for soils, are 0.22% and 1.79%, respectively. The SB ranges from 13.64% to 17.43%, which is in accordance with MAPA's Normative Instruction No. 5. Regarding potentially toxic elements, their concentrations are below the maximum parameters established by MAPA's Normative Instruction No. 5. The average Pb content is 3.62 ppm, while the contents of As, Cd, and Hg are below the detection limit of the analytical technique employed (Table 1):

Table 1 – Geochemical analysis of the andesitic basalts from the municipalities of Estância Velha and Campo Bom.

	Estância Velha			Campo Bom				
	EV01	EV02	EV03	CB01	CB02	CB03	CB04	CB05
	%							
SiO <sub>2</sub>	55.74	55.34	52.27	55.24	55.27	52.28	53.87	51.52
TiO <sub>2</sub>	1.26	1.26	1.3	1.13	1.33	1.31	1.13	1.19
Al <sub>2</sub> O <sub>3</sub>	14.25	14.32	15.29	14.51	14.22	14.61	14.73	14.78
Fe <sub>2</sub> O <sub>3</sub>	9.83	9.78	11.78	10.44	10.14	10.07	10.47	10.43
MgO	4.15	4.59	4.98	4.59	4.44	4.46	4.81	6.56
MnO	0.13	0.14	0.17	0.15	0.16	0.18	0.15	0.16
CaO	7.29	7.29	9.13	8.48	6.95	8.51	8.49	9.69
Na <sub>2</sub> O	2.33	2.34	2.24	2.36	2.74	2.32	2.43	2.07

<b>K<sub>2</sub>O</b>	2.20	2.18	1.39	1.81	2.64	1.25	1.07	1.18
<b>P<sub>2</sub>O<sub>5</sub></b>	0.26	0.25	0.15	0.17	0.28	0.27	0.17	0.18
<b>Cr<sub>2</sub>O<sub>3</sub></b>	0.005	0.01	0.011	0.007	0.005	0.005	0.006	0.022
<b>SB (K<sub>2</sub>O+MgO+CaO)</b>	13.64	14.06	15.50	14.88	14.03	14.22	15.00	17.43
ppm								
<b>As</b>	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<b>Cd</b>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<b>Hg</b>	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<b>Pb</b>	3.50	3.00	2.00	2.90	3.40	9.70	2.40	2.10

*Source: Modified from Hartmann, Baggio, and Duarte (2012).*

The lithologies within the GSG exhibit a wide geochemical diversity. In the mining district of Ametista do Sul, located in the northern part of Rio Grande do Sul, and in the gemological district of Los Catalanes in Artigas, Uruguay, the extracted basalts are considered byproducts of amethyst mining and are included in waste piles (CHIGLINO *et al.*, 2022). The generation of waste piles represents one of the significant issues related to mining, as these consist of lithologies associated with mineral deposits or ornamental rocks but are not economically viable. According to Markoski (2006), the accumulation of mining waste can lead to the siltation of drainage systems due to improper disposal.

Korchagin, Caner, and Bortoluzzi (2019) and Chiglino *et al.* (2022) reported on the agronomic applicability of the dust from the basalts extracted in Ametista do Sul and Artigas. A geochemical comparison was made between the outcropping basalts in these regions and the andesitic basalts from Estância Velha and Campo Bom (Table 2). This comparison highlighted the geochemical compatibility between the sum of bases (SB) content of the andesitic basalts and those from Ametista do Sul (Figure 3).

*Table 2 – Geochemical comparison between the outcropping lithologies in Artigas, Ametista do Sul, Estância Velha, and Campo Bom.*

<b>Lithology</b>	<b>Municipality</b>	<b>Average Content (%)</b>			
		<b>MgO</b>	<b>CaO</b>	<b>K<sub>2</sub>O</b>	<b>K<sub>2</sub>O+MgO+CaO</b>
Basalt	Artigas	2.72	5.06	1.24	9.02
Basalt	Ametista do Sul	5.46	7.80	1.79	15.05
Andesitic Basalt	Estância Velha	4.57	7.90	1.92	14.40
Andesitic Basalt	Campo Bom	4.97	8.42	1.72	15.11

*Source: Modified from Hartmann, Baggio, and Duarte (2012), Korchagin, Caner, and Bortoluzzi (2019), and Chiglino et al. (2022).*

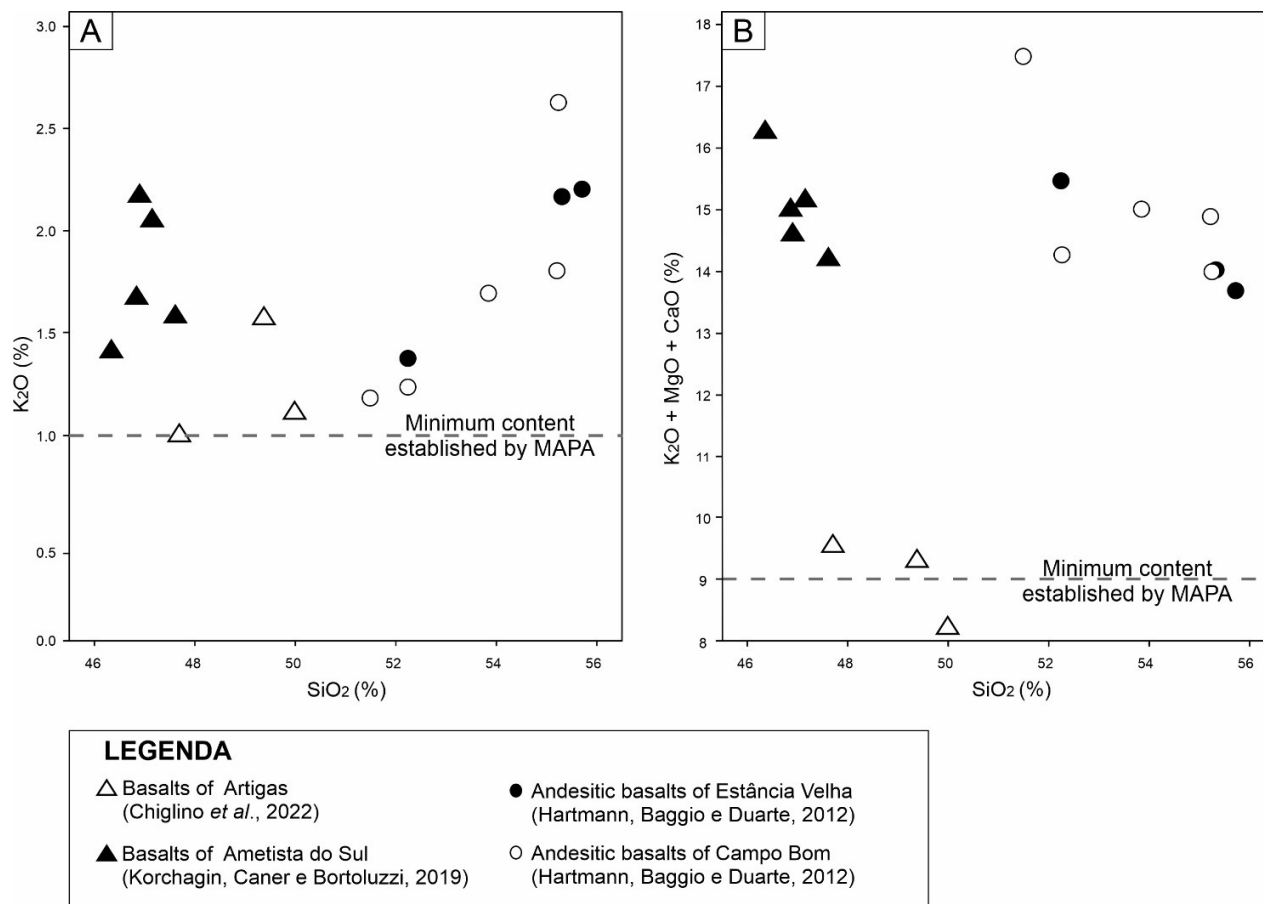


Figura 3 – Correlação entre teores geoquímicos das litologias aflorantes em Artigas, Ametista do Sul, Estância Velha e Campo Bom, utilizando a  $\text{SiO}_2$  como índice de diferenciação, enfatizando o parâmetro mínimo estabelecido pelo MAPA. A)  $\text{K}_2\text{O}$ ; B)  $\text{K}_2\text{O} + \text{MgO} + \text{CaO}$ .

Fonte: Autores (2023).

The results of this study indicate the geochemical viability of the andesitic basalts of the GSG outcropping in the Campo Bom and Estância Velha region for soil remineralization. Hartmann and Duarte (2020) obtained similar results for an andesitic basalt sample from the Sinimbu region (RS), approximately 145 km from Estância Velha, which showed 1.83%  $\text{K}_2\text{O}$ ; 7.67%  $\text{CaO}$ , and 3.99%  $\text{MgO}$ , favorable levels for soil remineralization. Similarly, Burbano (2020) and Theodoro *et al.* (2021b) found that the basaltic lithologies of the GSG have potential for use as agricultural inputs due to their high levels of  $\text{MgO}$  and  $\text{CaO}$ , combined with low quartz content, which facilitates the weathering process and the release of nutrients.

Although the use of rock dust for soil remineralization is a relatively old technique, it has gained popularity in tropical countries over the past decade, such as Brazil, Angola, South Africa, and Cameroon (THEODORO *et al.*, 2012). This trend is attributed to the combination of geological, climatic, and socio-environmental conditions conducive to remineralization, including the vast geodiversity found in these countries, high rates of weathering, and the limited access of smallholder farmers to conventional fertilizers (THEODORO; LEONARDOS, 2011). Additionally, most chemical fertilizers are imported from China, Russia, the United States, Morocco, Canada, and Belarus and are subject to external policies and fluctuations in foreign currency exchange rates (BRASIL, 2022). The agricultural experiment conducted by Theodoro *et al.* (2012) implementing soil remineralization techniques on small farms in Brazil, Angola, South Africa, and Cameroon indicated an increase in soil pH and an average productivity increase of 30% for cassava and 20% for corn and beans.

#### 4. Final considerations

The results of this study are promising for the use of outcropping volcanic lithologies in the municipalities of Estância Velha and Campo Bom, in the northeastern part of RS, as potential soil remineralizers. To this end, complementary studies such as mineralogical characterization (to determine the index of free SiO<sub>2</sub>) and leaching tests (to assess the effectiveness and agronomic applicability of andesitic basalt dust) are recommended. This information is essential for the commercialization of these lithologies as agricultural inputs and for the consequent adoption of practices that promote the sustainability of the sector.

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