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Salinity and Sodium Adsorption Ratio of Solubilized Extract from Dimension Stone Wastes Evaluated as Soil Remineralizer

Salinidade e Razão de Adsorção de Sódio do Extrato Solubilizado de Resíduos de Rochas Ornamentais Avaliados como Remineralizadores de Solo

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Abstract

In the dimension stone industry, waste comes in the form of fragments and sludge, which, when in contact with water, this waste can increase the concentration of dissolved ions due to the solubilization of some chemical species, which can become limiting to the production of crops of agricultural interest. The Sodium Adsorption Ratio (RAS) is a parameter widely used to assess the quality of irrigation water and when associated with electrical conductivity (EC), it becomes an important indicator of the risk of soil salinization. This study evaluated the effect of salinity of the solubilized extract of three types of dimension stone waste, with different particle sizes, on the soil infiltration rate. Quartz syenite, gabbro-norite and gabbro tailings were tested, collecting both coarse quarry tailings and fine tailings, originated by cutting blocks in multiwire looms. The samples were dried, homogenized and subjected to the solubility test with ultrapure water. The resulting extract was analyzed for pH, electrical conductivity, Sodium Adsorption Ratio (RAS) and other parameters, according to the NBR 10004:2004 standard. The different particle sizes of the waste studied influenced the EC of the solubilized extract, which was higher in the fine waste from multi-thread looms. However, none of the cases studied showed any degree of restriction in terms of salinity. Regarding SAR, only the two of the fine waste studied had moderate restrictions on use, while the others had severe restrictions, suggesting possible problems with soil water infiltration capacity if they are applied in excess or under a cumulative effect.

Keywords: Agrominerals. Fertilization. Rock Powder. Solubilization Test.

Resumo

Na indústria de rochas ornamentais, os resíduos gerados em forma de fragmentos e lodo, ao entrarem em contato com a água, podem aumentar a concentração de íons dissolvidos devido à solubilização de algumas substâncias químicas, o que pode afetar a produção agrícola. A Razão de Adsorção de Sódio (RAS) é um importante parâmetro utilizado para avaliar a qualidade da água de irrigação e, em conjunto com a condutividade elétrica (CE), serve como indicador do risco de salinização do solo. Este estudo avaliou o efeito da salinidade do extrato solubilizado de rejeitos de três tipos de rochas ornamentais, com diferentes granulometrias, na taxa de infiltração do solo. Foram testados rejeitos de quartzo sienito, gabro-norito e gabro, coletando tanto rejeitos grossos de pedreira quanto finos, originados pelo corte de blocos em teares multifios. As amostras foram secas, homogeneizadas e submetidas ao ensaio de solubilidade com água ultrapura. O extrato resultante foi analisado quanto ao pH, condutividade elétrica, Razão de Adsorção de Sódio (RAS) e outros parâmetros, conforme a norma NBR 10004:2004. Os resultados mostraram que a CE foi mais alta nos resíduos finos, porém, nenhum extrato apresentou restrições quanto à salinidade. Quanto à RAS, os resíduos finos apresentaram restrições moderadas, enquanto os demais mostraram restrições severas. Esses resultados indicam que, quando aplicados em excesso ou de forma cumulativa, esses resíduos podem afetar a infiltração de água no solo, o que pode prejudicar as condições agrícolas.

Palavras-chave: Agrominerais. Fertilização. Rochagem. Teste de Solubilização.

1 Introduction

Brazil is the fifth largest producer and exporter of dimension stones in the world. In the first half of 2023 alone, Brazil exported more than 549 million tons of dimension stones, and the state of Espírito Santo leads the ranking in the country (Abirochas, 2023). However, this sector contributes to environmental impacts by producing waste in the form of fragments and sludges from the processing of rocks (Lima; Rodrigues; Machado, 2023).

Dimension stone processing waste (DSPW) consists basically of rock dust and water, if it comes from multi-thread looms, plus grit and hydrated lime, if it comes from multi-blade looms. It has a water content of around 40 %, alkaline pH, and is mostly disposed in basins adjacent to developments or in industrial landfills (Freitas; Raymundo; De Jesus, 2012; Neves *et al.*, 2019). Normative Instruction 11/2016 of the State Institute for the Environment and Water Resources (IEMA) (Espírito Santo, 2018) establishes minimum procedures for the storage of this waste to avoid the transfer of possible pollutants to the soil.

In Brazil, waste classification studies follow the Brazilian standard NBR 10004:2004 of the National Standards Organization (ABNT), which classifies waste according to its potential risk to public health and the environment (ABNT, 2004a). Based on an analysis of environmental risk parameters, the regulation classifies waste as hazardous or non-hazardous and, in the case of non-hazardous waste, as inert or non-inert.

Since its chemical composition is like that of processed rocks, studies have been conducted to incorporate dimension stone waste in several products, thus aligning the sector with one of the principles of Law 12,305 of August 2, 2010 (Brasil, 2010), which establishes the National Solid Waste Policy. Among the principles highlighted in Article 6 of this law, Item VIII provides for the recognition of reusable and recyclable solid waste as an economic asset with social value.

Studies have been performed on the use of DSPW as a raw material for building, as the production of ecological bricks (Barros *et al.*, 2020); in the ceramics industry (Gadioli *et al.*, 2019); the cosmetics industry (Puget; Nunes; Tomas, 2020); the paper industry (Ribeiro; Caranassios; Morani, 2014); the polymer industry (Chagas *et al.*, 2021); the glass industry (Gevu *et al.*, 2024); and construction of solar panels (De Andrade *et al.*, 2024).

In agriculture, the use of rock powder for mineral enrichment of soils has been growing given its economic, environmental, and productive advantages compared with conventional fertilization. This is due to its nutrient-rich composition, which tends to improve the physical and chemical properties of the soil (Swoboda Caranassios; Morani, 2022).

Some authors highlighted a considerable release of potassium from rock powder (Bertossi *et al.*, 2012; Camara; Dos Santos; Da Silveira, 2023; Duarte *et al.*, 2021), or improvements in agronomic characteristics (Aguilera *et al.*, 2022; Bono; Assis, 2023; Santos; Carvalho; Camara, 2021), showing potential for use in soil fertilization. However, a series of factors associated with its physical, chemical, and mineralogical nature, its interaction with soil components, and the adoption of an appropriate agricultural system deserve attention (Martins *et al.*, 2014).

When in contact with water, this waste can increase the concentration of dissolved salts due to the solubilization of some chemical species. Depending on the physicochemical characteristics of the water that percolates through the soil, factors such as the concentration of soluble salts or salinity can limit the production of crops (Silva *et al.*, 2011). In fact, along with the release of beneficial elements such as calcium (Ca), magnesium (Mg), and potassium (K), DSPW can also provide sodium (Na) (Duarte *et al.*, 2021), which at certain levels can cause soil salinization.

The sodium adsorption ratio (SAR), estimated from Ca, Mg, and Na contents, can assess the risk of soil salinization due to the application of saline water and solutions. When associated with electrical conductivity (EC), the SAR becomes an important soil water infiltration rate indicator (Ayers; Westcot, 1985).

The environmental impact of dimension stone waste industry, especially about soil quality and agricultural production, as it can release salts that increase the concentration of dissolved ions in the soil, increasing the risk of salinization and compromising its fertility, which negatively affects the growth and development of crops. In addition, the presence of sodium in high concentrations can alter the structure of the soil, reducing water infiltration and increasing compaction, which makes it difficult for plants to absorb water and favors erosion processes.

Based on this, this study investigates how different types of dimension stone waste, considering their variations in granulometry and chemical composition, impact the salinity and infiltration capacity of the soil. The objective is to better understand the environmental risks associated with the disposal of this waste and its possible consequences for agricultural and environmental sustainability. In addition, other parameters considered pollutants are evaluated, whose levels in the solubilized extract are used by ABNT to classify waste as inert or non-inert.

2 Material and Methods

Samples of Brazilian dimension stones that potentially had a high K_2O content and a low SiO_2 content, which are fundamental for the use of a material as a soil remineralizer, were selected. Dimension stone companies willing to support alternatives for disposing of the waste produced were sought to define the samples to be analyzed.

Three types of dimension stones were selected: a quartz syenite, whose commercial name is Ocre Itabira (OI); a gabbro-norite, with the commercial name Preto São Benedito (PSB); and a gabbro, known in the market as Preto São Gabriel (PSG). For each type, coarse quarry waste, identified by the acronyms OIP, PSBP, and PSGP, and fine waste produced by sawing blocks on multi-thread looms, identified by the acronyms OIM, PSBM, and PSGM, were collected.

Laboratory analyses were performed at the Ornamental Stone Laboratory (LABRO) of the Espírito Santo Regional Center (NRES), part of the Center of Mineral Technology (CETEM). Coarse quarry waste samples were comminuted in a Marconi MA 4080 jaw crusher and then sieved in a Mineralmaq vibratory sieve shaker with a 28-mesh screen (0.6 mm). The fraction that passed through the sieve was stored in plastic bags and the retained fraction was taken to a MR 200 SR 1881 roller mill for grinding and then sieved. The fraction retained on the sieve was grounded in a MA 700-disc mill and mixed with the fraction passing through for subsequent homogenization and quartering, according to the adapted procedure from (Góes Luz; Possa, 2010).

Samples of multi-thread waste were collected in the form of sludge. They were then left to stand until all the soldiers present in the effluent had decanted. Later, the supernatant liquid was removed, and the solid phase was placed in stainless steel trays, dried in an oven at 100 °C for 48 hours, and disaggregated on a 28-mesh sieve (0.6 mm) for subsequent homogenization and quartering, according to the adapted procedure from (Góes; Luz; Possa, 2010).

In the homogenization and quartering stage, the samples were arranged in conical piles and then, using a shovel, small portions were removed from around the pile, evenly distributing the sample on a smooth, previously cleaned surface, thus creating a longitudinal pile. The ends of the pile were cut, and the leftovers were redistributed evenly into the pile. Using a stainless-steel blade, the pile was divided into equal fractions, which were removed and packed in bags in sufficient quantities to perform the tests described below. This entire procedure was adapted from (Góes; Luz; Possa, 2010).

The waste solubilization test was performed following the methodology established in NBR 10006:2004 (ABNT, 2004b). Samples were dried in an oven for 24 hours at 42 °C. For each sample, 250 g were placed in a 2 L beaker, together with 1 L of ultrapure water, and the mixture was stirred using a Fisatom 715 vertical agitator for five minutes. The beaker was then covered with PVC film and left to stand for seven days. At the end of this time, the solution was filtered using a filtration kit with a membrane with a pore size of 0.45 µm and a diameter of 47 mm.

The pH and EC of the extracts were obtained using an AKSO AK88 multiparameter equipment. The extracts were acidified with about 1 mL of ultrapure HNO_3, stored in plastic bottles in a refrigerator. This test was performed in duplicate. The extracts were prepared at LABRO and then sent to the Mineral Analysis Laboratory of CETEM in Rio de Janeiro for analysis of the parameters described in Annex G of NBR 10004:2004 (ABNT, 2004a).

The parameters were analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES; Ultima 2 spectrometer, Horiba Jobin Yvon), which is a highly sensitive technique that can analyze a wide range of concentrations.

To estimate the SAR, an aliquot of the solubilized extract of each waste was separated and sent to the Laboratory of Chemical and Environmental Analyses (LAQUAM) of the Department of Plant Production of the Federal University of Espírito Santo (UFES), Campus Alegre, and the methodology used to analyze the Na, Ca and Mg parameters followed the same procedure adopted by (Silva, 2009). The Na concentration was measured using a Digimed DM-62 flame photometer, while the Ca and Mg parameters were analyzed using a GBC SavantAA atomic absorption spectrophotometer.

The SAR was estimated using Equation 1 and the results, associated with the EC values, were classified according to the classification proposed by (Ayers; Westcot, 1985) (Table 1).

$$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}} \qquad \textit{Equation 1}$$

Where: Ca, Mg, and Na correspond to the concentration of these elements in mEq L^{-1} in the solubilized extract.

Table 1 - Guidelines for interpreting percolating water quality based on the SAR (mEq L^{-1}) and EC (dS m^{-1}).

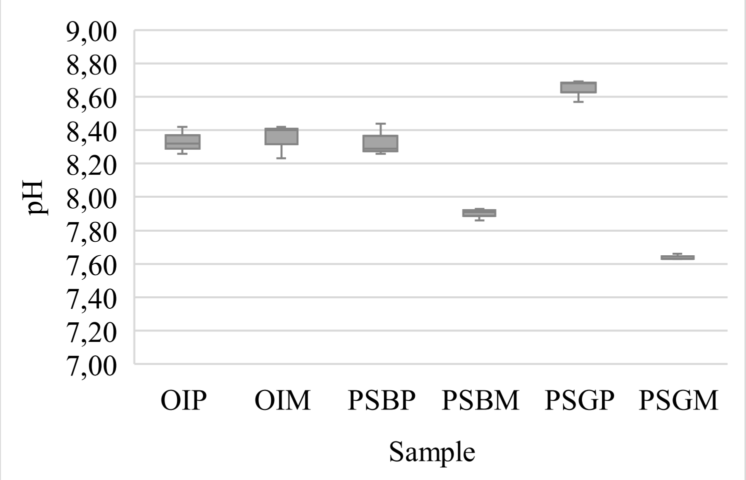
Infiltration			Degree of restriction of use		
			None	**Moderate**	**Severe**
SAR 0 - 3	and	EC	> 0.7	0.7 – 0.2	< 0.2
SAR 3 - 6	and	EC	> 1.2	1.2 – 0.3	< 0.3
SAR 6 - 12	and	EC	> 1.9	1.9 – 0.5	< 0.5
SAR 12 - 20	and	EC	> 2.9	2.9 – 1.3	< 1.3
SAR 20 - 40	and	EC	> 5.0	5.0 – 2.9	< 2.9
Salinity					
EC			< 0.7	0.7 – 3.0	> 3.0

Source: Ayers and Westcot (1985).

3 Results and Discussion

Figure 1 shows the pH values of solubilized extracts of waste studied. ABNT considers pH as one of the parameters that classify waste as hazardous, indicating corrosiveness if the value is equal to or less than 2 or equal to or greater than 12.5. The waste analyzed in this study is considered non-corrosive and therefore non-hazardous in relation to this parameter, as all the measured values were within the pH range of 2 to 12.5 (Figure 1).

Figure 1 - Distribution of the pH values of the solubilized extracts of the waste studied



Source: research data.

When studying the sludge used to saw blocks on a conventional loom, Freitas Raymundo and De Jesus (2012) found pH values above 12.5, leading them to consider DSPW to be dangerous. In fact, the pH of the waste produced when using conventional looms tends to be higher due to the lime used in the sawdust pulp. On the other hand, Neves *et al.* (2018) stated that the pH of the sludge and its waste tends to decrease over time because of interactions with atmospheric CO_2, and the extraction of the liquid phase of the effluent by a filter press or drying bed reduces the pH of the effluent. This was also observed by Neves *et al.* (2013), who studied the pH of processing sludge at different stages of the process and in waste deposits of different ages. In percolation experiments in soil columns, Bertossi *et al.* (2012) found an increase in soil pH with the application of 20 % and 40 % of dimension stone waste. However, no pH values showed dangerousness to the environment. Some authors observed a significant increase in soil pH and Ca and Mg content after the introduction of ground rock waste, showing that the application of these materials is viable both in the use of rock powder and in liming, i.e., mineral enrichment and soil pH correction (Souza *et al.*, 2017; Raymundo *et al.*, 2013).

In the environment, pH directly influences the solubilization of chemical elements, which can release chemical species or immobilize them. The study by Freitas, Raymundo and De Jesus (2012) shows that the increase in pH causes the solubilization of some chemical species present in waste, such as Al and Cr. Therefore, monitoring the pH of the effluent is important, as several studies point to values close to the corrosivity limits. Braga *et al.* (2010) highlights the need for care in handling, packaging, and transporting the waste produced in the dimension stone processing plant and the water used in the production process.

Regarding other parameters considered by NBR 10004:2004 (ABNT, 2004a) for waste classification, Braga *et al.* (2010) consider the DSPW as non-hazardous, since they are not flammable, reactive, toxic, or pathogenic, their origin is known, and due to the metal content extracted in the leaching test. These authors also performed the solubilization test, classifying this waste as non-inert, but analyzing materials from other lithological types.

Our study analyzed waste in relation to the solubilization test (Table 2), to assess the availability of certain components to the environment. All coarse quarry waste (OIP, PSBP, and PSGP) and the multi-thread waste OIM had Al contents above the maximum permitted value (MPV) for the material to be considered inert. Similarly, the Ba content was above the MPV in the OIP, OIM, and PSBP extracts, and the Fe content was above the MPV only in OIP. The results for the other parameters were always below the MPVs. Thus, we classified the materials studied here as Class II – Non-inert, except for PSBM and PSGM, which belonged to Class II – Inert.

Table 2 - Concentration of components (mg L^{-1}) in the solubilized extracts, highlighting in bold the results above the maximum permissible value (MPV) for inert waste according to NBR 10004:2004 (ABNT, 2004a)

Sample	Al	As	Ag	Ba	Cd	Cu	Cr	Fe	Hg	Mn	Na	Pb	Se	Zn	Cl^-	SO_4^{-2}
OIP	0,82	< 0,01	< 0,006	0,71	< 0,003	< 0,02	< 0,002	0,32	< 0,02	0,05	4,23	< 0,01	< 0,01	0,090	< 0,5	5,2
OIM	1,53	< 0,01	< 0,006	0,89	< 0,003	< 0,02	< 0,002	0,16	< 0,02	0,03	8,00	< 0,01	< 0,01	< 0,003	12,5	36,5
PSBP	0,36	< 0,01	< 0,006	1,07	< 0,003	< 0,02	< 0,002	0,27	< 0,02	0,03	4,73	< 0,01	< 0,01	< 0,003	11,5	5,1
PSBM	< 0,04	< 0,01	< 0,006	0,36	< 0,003	< 0,02	< 0,002	0,06	< 0,02	0,03	9,20	< 0,01	< 0,01	< 0,003	56,5	145,0
PSGP	0,27	< 0,01	< 0,006	< 0,02	< 0,003	< 0,02	< 0,002	0,16	< 0,02	0,09	3,70	< 0,01	< 0,01	0,050	< 0,5	19,0
PSGM	0,10	< 0,01	< 0,006	0,33	< 0,003	< 0,02	< 0,002	0,06	< 0,02	0,04	35,10	< 0,01	< 0,01	0,090	56,5	176,0
MPV	0,2	0,01	0,05	0,7	0,005	2,0	0,05	0,3	0,001	0,1	200,0	0,01	0,01	5,0	250,0	250,0

Source: research data.

In all waste classified as Class II – Non-inert, Al was above the MPV for inert waste according to NBR 10004:2004 (Table 2). For Braga *et al.* (2010), the presence of Al in concentrations above the MPV is related to the composition of the processed rocks, since this element is present in rock-forming minerals such as feldspars and micas. The Al concentration is higher when comparing the extract of multi-thread waste and the extract of coarse quarry waste from OI, showing an increase in the solubility of the elements that constitute the rocks as the particle size of the waste decreases. However, this behavior is the opposite in the other lithological types studied, which showed differences in mineralogical composition. While OI is a quartz syenite, with an abundance of Al-rich minerals, PSB and PSG are respectively a gabbro-norite and a gabbro, which are Al-poor mafic rocks. Moreover, the solubility of Al is regulated by pH and can produce undesirable chemical species at pH greater than 6 in the form of hydroxy complexes (Freitas; Raymundo; De Jesus, 2012). However, Al tends to be immobilized in the form of insoluble oxyhydroxides at pH values below 9.5 to 9.0 and dissolved at pH values below 4.0, creating a solution of complex ions (Neves; Raymundo, 2022).

Like Al, Fe also tends to produce insoluble oxides and hydroxides when the pH of the medium is close to neutrality (Neves; Raymundo, 2022). In the extracts analyzed, we identified excess Fe values only in the OIP waste. Braga *et al.* (2010) found high Fe values in samples from the settling tank and from multi-blade looms, attributing this increase to the wear of the steel shot and blades. In plants, Fe is a micronutrient that plays a role in several physiological processes but, in excess, can affect cell balance, reducing photosynthetic rate and respiration, and significantly increasing levels of reactive oxygen species, which can lead to cell death (Tavares *et al.*, 2020). However, in healthy soils, both Fe and Al are less available when the soil pH is adequate and are only soluble in very specific situations.

The OIP, OIM, and PSBP samples had Ba values above the limit recommended by the standard to inert waste. In rocks, Ba is present in minerals such as carbonates, sulfates, and silicates, as an isomorphic substitute for elements such as Ca and K (Biondi *et al.*, 2011). The Resolution 420/2009 of the National Environment Council (Brasil, 2009), which establishes criteria for soil quality in terms of the presence of chemical substances in contaminated areas, defines guideline values for assessing soil contamination by Ba, ranging from 150 mg Kg^{-1} to 700 mg Kg^{-1}, depending on the characteristics of the soil (whether agricultural, residential, or industrial). No study identifies the levels of Ba contamination from ornamental rocks; therefore, an in-depth assessment of the mobility and bioavailability of this metal is necessary to verify the potential risk of using this waste in agricultural activities.

Similarly to EC, the levels of sulfate (SO_4^{-2}), chloride (Cl^-), and Na in the waste produced by multi-thread looms were higher compared with coarse quarry wastes. The levels of Cl^- and SO_4^{-2} are probably due to the reuse of water in the processing, which incorporates polishing inputs such as sulfate-based flocculants. These inputs tend to concentrate as water is reused. However, in the waste analyzed in this study, these parameters always remain below the MPV for inert waste.

The initial condition for using a material as a soil mineral enrichment agent is that it can release components in the environment. Thus, the fact that the waste studied here is non-inert shows that it can provide macro and micronutrients and correct the pH of acidic soils. However, analyzing whether the desirable components are accompanied by the risk of releasing undesirable constituents, such as Na and other metals that can increase the salinity of the medium, is necessary. Bertossi *et al.* (2011), when studying the influence of marble sawdust waste on soil hydraulic conductivity and water quality, observed that the addition of 20 % and 40 % waste to the soil increased the EC of the water percolating through this material, indicating a risk of soil salinization. Similarly, Duarte *et al.* (2021) observed the concomitant release of K and Na from the processing waste of different types of dimension stone using Mehlich-1 solution and 2 % citric acid.

Table 1 (Ayers; Westcot, 1985) shows that the association between the SAR values and water EC suggests possible salinization problems and influence on soil infiltration capacity, since one of the negative effects of a saline solution on the soil is changes in its structure and consequent compaction. These parameters are commonly used to assess the quality of irrigation water, but in this study, we adopted the point of view of possible effects caused by a solution that will be extracted from dimension stone wastes applied *in natura* to the soil, simulating an overdose or cumulative effects, given the low solubility of silicate minerals.

Table 3 shows the Ca, Mg, and Na concentrations in mEq/L and the EC and SAR values of the solubilized extracts of the waste studied. Regarding infiltration, PSBM and PSGM showed moderate restriction to use, while the other samples showed severe restriction, warning of possible problems with soil infiltration capacity. On the other hand, EC did not show any degree of restriction to salinity in any of the materials studied. The finer residues (OIM, PSBM, and PSGM) had higher EC, showing that reducing the particle size of waste favors the release of rock constituents in the solubilized extract. According to Corwin and Yemoto (2020), factors such as mineralogical composition and the presence of soluble salts can also influence the EC.

Table 3 - Parameters analyzed in the solubilized extract to interpret the quality of percolating water based on SAR and EC

Sample	**Concentration (mEq L^{-1})**			**SAR**	**EC (dS m^{-1})**	**Restriction to Use**	
	Ca	**Mg**	**Na**			**Infiltration**	**Salinity**
OIP	0.11	0.01	0.13	0.55	0.06	Severe	None
OIM	0.09	0.02	0.87	3.67	0.16	Severe	None
PSBP	0.06	0.14	0.14	0.45	0.09	Severe	None
PSBM	0.13	0.12	1.43	4.05	0.47	Moderate	None
PSGP	0.14	0.06	0.15	0.48	0.11	Severe	None
PSGM	0.24	0.05	2.62	6.88	0.51	Moderate	None

Source: research data.

Multi-thread waste released higher amounts of Na in the solubilized extract compared with coarse quarry wastes, showing that the smaller the particle size, the higher the concentration of soluble Na in the soil solution. According to Dalmora *et a.* (2020), in studies on the dissolution kinetics of multinutrients from silicate rocks, the dissolution rate of cations increases the smaller the particle size. Moreover, Braga *et al.* (2010) found Na values above the MPV in samples of waste from polishing stored at the bottom of horizontal sedimentation tanks, due to the influence of inputs used. Since the water used in the process is recirculated, the concentrations of components such as Na, Cl^-, and SO_4^{-2} tend to increase in waste.

Bertossi *et al.* (2011) observed that the SAR values decreased as the concentration of rock waste in the soil increased, from moderate with 20 % of waste incorporated into the soil to none with 40 % of waste, showing that the addition of waste to the soil brought benefits to the quality of percolating water. However, the authors highlight the importance of paying attention to the dosage of the waste to be applied, since the SAR values obtained in the study are inversely proportional to the EC value, which may suggest high salinity, causing damage to soils with poor drainage.

4 Conclusion

Regardless of the source, the dimension stone waste analyzed in this study belongs to Class II (non-hazardous) in terms of corrosiveness, highlighting its low risk to the soil. Wastes from the sawing of mafic rocks on a multi-thread loom (PSBM and PSGM) are classified as Class II – Inert, which suggests less interference in the physical-chemical parameters of the soil, while the rest is Class II – Non-inert, due to its Al, Ba, and/or Fe content, indicating the need for care in the management of soils for agricultural purposes.

The solubilized extract of the inert waste (PSBM and PSGM) has a moderate degree of restriction in terms of SAR, while the others present a severe degree of restriction, indicating a possible negative influence on the infiltration capacity of soils, if applied in natura, in excess or because of a cumulative effect. These findings suggest that specific management practices, such as controlled application and continuous monitoring of soil properties, may be essential to minimize the risks of compaction and reduce infiltration. However, none of the samples showed any restrictions for application to soils in terms of salinization risk.

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