https://doi.org/10.22478/ufpb.1981-1268.2021v15n4.61226

Solubilization of nutrients and amendment of soil fertility from the addition of *Eichhornia crassipes* (Mart. Solms.) in consortium with granite cutting residues

Rogerio Pires Santos[1*]

1 Federal Institute of Education, Science and Thechnology Sul Riograndense-IFSUL, Road Ana Gonçalves da Silva, 901, Camaquã, RS, Brazil, 96785-130.
*Autor para correspondência: rogeriosantos@ifsul.edu.br

Recebido em 22 de outubro de 2021.
Aceito em 23 de janeiro de 2022.
Publicado em 30 de janeiro de 2022.

Abstract - The objective of the present work was to verify the effects of the addition of mineral micro and macronutrients to the soil with the rock dusting technique regarding the physical, chemical and microbiological aspects of a haplic Planosol and its effect on the growth of Pensacola grass (*Paspalum notatum* Flüggé). The experiment was carried out in a greenhouse and consisted of 4 treatments: soil of the sample area with three doses of fine residue from marble cutting (8, 16 and 32 t ha^{-1}), combined with 8 t ha^{-1} of aquatic macrophyte (*Eichhornia crassipes* Mart. Solms.) dried in the sun for 15 days and crushed in a knife mill, plus an additional treatment, with soil from a preserved sample area used as reference, all with three replications per treatment. Physicochemical and microbiological analyzes of the soil were carried out, as well as measurements of height and dry mass of the aerial part and root system of the plants. The results indicate that the procedures with granite residues and *E. crassipes* contributed to improve the chemical conditions of the soil and provide conditions to increase the colonization rate of arbuscular mycorrhizal fungi and increase soil fertility, while the plants showed greater growth in the treatments in which higher concentrations of marble residues were added.

Key words: Stonemeal. Arbuscular mycorrhizal fungi. *Paspalum notatum.*

Solubilização de nutrientes e alteração da fertilidade do solo com adição de *Eichhornia crassipes* (Mart. Solms.) em consórcio com resíduos de corte de granito

Resumo - O objetivo do presente trabalho foi verificar os efeitos da adição de micro e macronutrientes minerais ao solo por meio da técnica de rochagem quanto aos aspectos físicos, químicos e microbiológicos de um Planossolo háplico e seu efeito no crescimento do capim Pensacola (*Paspalum notatum* Fülggé). O experimento foi conduzido em casa de vegetação e constou de 4 tratamentos: solo da área amostral com três doses de resíduo fino de corte de marmoraria (8, 16 e 32 t ha^{-1}), combinado com 8 t ha^{-1} de macrófita aquática (*Eichhornia crassipes* Mart. Solms.) seco ao sol por 15 dias e triturado em moinho de facas, mais um tratamento adicional, com solo de área amostral preservada, utilizado como referência, todos com três repetições por tratamento. Foram realizadas análises físico-químicas e microbiológicas do solo, além de medidas de altura e massa seca da parte aérea e sistema radicular das plantas. Os resultados indicam que os procedimentos com resíduos de granito e *E. crassipes* contribuíram para melhorar as condições químicas do solo, fornecer condições para elevação da taxa de colonização de fungos micorrízicos arbusculares e aumento da fertilidade do solo, enquanto as plantas apresentaram maior crescimento nos tratamentos em que foram adicionadas maiores concentrações de resíduos de marmoraria.

Palavras-chave: Stonemeal. Fungos micorrízicos arbusculares. *Paspalum notatum*.

La solubilización de nutrientes y la alteración de la fertilidad del suelo con la adición de *Eichhornia crassipes* (Mart. Solms.) Intercalado con residuos del corte de granito

Resumen - El objetivo del presente trabajo fue verificar los efectos de la adición de micro y macronutrientes minerales al suelo mediante la técnica de balanceo en los aspectos físicos, químicos y microbiológicos de un Planosol háplico y su efecto en el crecimiento del pasto Pensacola (*Paspalum notatum* Flüggé). El experimento se realizó en invernadero y constó de 4 tratamientos: suelo del área de la muestra con tres dosis de residuo fino de corte del mármol (8, 16 y 32 t ha^{-1}), combinado con 8 t ha^{-1} de macrófita acuática (*Eichhornia crassipes* Mart. Solms.) secada al sol por 15 días y triturada en molino de cuchillas, además un tratamiento adicional, con suelo de un área de muestra preservada, utilizada como referencia, todas con tres repeticiones por tratamiento. Se realizaron análisis fisicoquímicos y microbiológicos del suelo, así como mediciones de altura y masa seca de la parte aérea y sistema radicular de las plantas. Los resultados indican que los procedimientos con residuos de granito y *E. crassipes* contribuyeron a mejorar las condiciones químicas del suelo y brindar condiciones para incrementar la tasa de colonización de hongos micorrízicos arbusculares y aumentar la fertilidad del suelo, mientras que las plantas mostraron mayor crecimiento en los tratamientos en los que se añadieron mayores concentraciones de residuos de mármol.

Palabras clave: Harina de piedra. Hongos micorrízicos arbusculares. *Paspalum notatum*.

Introduction

Tropical soils have a high rate of degradability, requiring constant corrective measures to recover fertility. A technique little used in Brazil is stonemeal, which consists of using rock waste as a remineralizer.

According to Da Silveira (2021), stonemeal provides the diversification of nutrient sources, promoting new mineral supply conditions, such as the incorporation of rocks and/or minerals into the soil, being considered as a type of remineralization, where rock powder is used for to reformulate poor or leached soils, with a basic foundation in the search for a balance in fertility, in the conservation of natural resources and, consequently, in sustainable productivity.

Experiment conducted by Ramos et al. (2004), in Nova Prata, State of Rio Grande do Sul, Brazil, from residues of acidic volcanic rocks, demonstrated that all macronutrients and most micronutrients described in the literature were present in variable amounts in the studied sample, showing a possible potential for nutrient release to the soil and that the use of low molecular weight organic acid solutions, tested in this study, as extracting agents, proved to be efficient in providing mineral nutrients to plants, corroborating previous studies on the technique.

Similarly, Silva et al. (2008), in an experiment carried out in a degraded area arising from the construction of the Ilha Solteira Hydroelectric Power Plant, State of São Paulo, Brazil, presented considerable results, using basalt residues intercropped with residues from cattle manure or water hyacinth plants (*Eichhornia crassipes*), or sewage sludge, providing improvement in the chemical conditions of the subsoil and for the microbiological variables, concluding that the stonework made with basalt provided positive results.

Wang et al. (2000), in conducting an experiment with rice culture carried out in China, they related the growth of some plants with the supply of potassium from the application of the stonemeal technique from gneiss, concluding that the presence of potassium influenced the growth of the rice crop and that plant growth was more expressive in the portions where the finer particle size fraction was dominant, corroborating other studies in which stonemeal promoted soil rejuvenation, especially when comparing the effect to a higher proportion of silt.

Júnior et al. (2020) used rock dust as a fertilizer in southern Brazil, using the rock stone technique for soybean cultivation, and obtained harvest results above the national average.

However, due to the low levels of soluble nutrients available in rock powder, this material has been little used as a fertilizer for plants, meeting resistance from farmers who adopt conventional agriculture. The biggest disadvantage is related to the difficulty in releasing nutrients that are usually temporarily unavailable for vegetables (De Paula Medeiros, Cardoso and De Souza Vieira 2020).

However, the use of rock powder can present advantages when using these materials correctly, as it not only allows small reserves or exploration residues to be used, but also constitutes a more complete fertilization with several nutrients (Cola and Simão 2012).

An alternative to increase the availability of rock nutrients is biological solubilization. Several microorganisms manage to solubilize nutrients through the decomposition of silicate minerals (Garcia Junior 1991). Bacteria of the genus *Acidithiobacillus* are excellent sulfur oxidizers, capable of producing sulfuric acid from elemental sulfur, providing the release of insoluble phosphorus and potassium, due to the effect of low pH (Garcia Júnior 1991). Allied to this fact, the application of elemental sulfur with bacteria of the genus Acidithiobacillus to the soil provides a greater production of SO_4, which is required in large quantities by plants, and followed by the direct and indirect action of H_2SO_4 on soil pH, especially for application to high pH soils (Stamford et al. 2008).

Thus, according to Stamford et al. (2008), the sulfuric acid produced in the microbiological reaction of sulfur oxidizing bacteria can act on rocks, making nutrients available by reducing the pH.

Likewise, Ramos et al. (2014) obtained good results, concluding that there was availability of nutrients for the indicated aqueous medium and that all samples released macronutrients and micronutrients important for plant growth, in addition to the non-availability of aluminum for the aqueous medium, which is a great advantage, as aluminum is a toxic element for plants.

In the same sense, the use of plant residues, such as aquatic macrophytes, has shown good results (Arantes Pinto et al. 2020). The floating aquatic macrophyte *Eichhornia crassipes* has a wide geographic distribution, being considered a weed plant because of its excessive proliferation in various aquatic environments. This macrophyte can cause problems for multiple uses of rivers, lakes and dams, hindering navigation and water collection, impairing electricity generation, sanitation projects and compromising leisure activities (Camargo et al. 2003, Martins et al. 2003). However, due to the wide distribution and characteristic of high growth rates, added to the high capacity to accumulate nutrients, make these plants potentially attractive for the production of conditioning substrates for soils.

Aquatic macrophytes have been used successfully in the treatment of urban and aquaculture effluents (Dos Santos et al. 2020). In this sense, there is a reduced use of plant biomass produced in these treatment systems, where plants need to be removed periodically to improve nutrient removal. In this context, alternatives for using this surplus biomass can be implemented, such as in the production of paper and biogas, in animal feed and in soil fertilization (Pieterse and Murphy 1990, El-Sayed 1999), or in the treatment and removal of heavy metals in industrial effluents (Reidel et al. 2021).

Given the above, the use of waste from marble and organic waste from *Eichhornia crassipes*, in consortium, can generate a substrate rich in organic and mineral matter, composed of micro and macronutrients essential for plant nutrition.

Under appropriate conditions, the minerals disposed remain longer in the soil, and are slowly absorbed by plants, promoting water retention following the assumptions of sustainable development (Wermuth 2019).

Thus, the objective of the present work was to test the efficiency of the consortium of granite cutting residues and aquatic macrophytes as soil conditioners, and its ability to promote the elevation of fertility and colonization of arbuscular mycorrhizal fungi, increasing fertility and providing a solution sustainable use for the final destination of the waste described.

Material and methods

The experiment was carried out in a greenhouse in a commercial plant for the production of ornamental plants in Nova Petrópolis, State of Rio Grande do Sul, Brazil. Soil from a sampling area located in the municipality of Cristal, State Rio Grande do Sul, Brazil, classified according to the Brazilian Soil Classification System of the Brazilian Agricultural Research Corporation (EMBRAPA) was used as Planosol Haplic Solodic, acidic soil, with low fertility (dystrophic, saturation per bases < 50%). The experimental design was completely randomized, with three replications per treatment. Three treatments were established: sample area soil with three doses of granite cutting residue (8, 16 and 32 t ha^{-1}), combined with 8 t ha^{-1} of organic residues of water hyacinth macrophyte (*Eichhornia crassipes* (Mart .) Solms), generating 3 treatments, in addition to an additional treatment, with soil from the sample area preserved used as a control. The granite cutting waste used was collected in the city of Camaquã, State of Rio Grande do Sul, Brazil. The water hyacinth (*Eichhornia crassipes*) was collected in an artificial lake in a fish farming area in Nova Petrópolis, State of Rio Grande do Sul, Brazil. All residues were air-dried and the aquatic macrophyte residue was ground in a knife mill to have, at the end, the same diameter (0.05 mm), favoring decomposition when applied to the soil.

The plant species used as an indicator was the Pensacola grass (*Paspalum notatum* Flüggé), a grass native to South America, used as pasture and as a fixator of slopes to combat erosion on roads and engineering works. The grass was cultivated in polystyrene pots with a capacity of 3 kg of substrate in August 2016 from commercial seeds of the BR Seeds® brand, cultivar Pensacola, with a purity degree of 95.7%, germination of 71%, lot 02/2015, RENASEM SP registration 02776/2010, and irrigated to field capacity whenever necessary, under conditions of average temperature of 25 °C and relative humidity around 70%, being kept in a greenhouse in the municipality of Nova Petrópolis, State of Rio Grande do Sul, Brazil.

Plants were evaluated for growth, after 90 days of planting, by measuring height (cm) and dry matter weight of shoot and root system. Before drying, one gram of fresh root, from each repetition, was separated and preserved in 50% alcohol for future analysis. The rest of the material was placed in paper bags, taken to an oven at 60ºC for five days and weighed to check the dry mass weight of the aerial part and root system.

The substrate, without roots, was sieved and homogenized. Composite samples were prepared from simple samples collected in all experimental units (repeats) of the same treatment. Part of these samples were sent for chemical analysis, which was performed according to Tedesco, et al. (1995) at the Soil Chemistry and Fertility Laboratory at the University of Caxias do Sul-UCS.

The determination of the mineral nutrient content in the plant tissue of the *E. crassipes* sample, consid being petioles, leaflets and roots was determined from the methodology proposed by Malavolta; Vitti and Oliveira (1997), being P, K, Na, Cu, Zn, Ca, Mg, S, Fe determined by nitric-perchloric digestion, B determined by calcination and N determined by sulfuric digestion.

The analysis of marble residues was based on results obtained by different authors from the analysis of X-ray fluorescence (XRF).

For the evaluation of mycorrhizal colonization, the preserved roots were washed in running water, clarified in 10% KOH, acidified with 1% HCl, colored with fountain pen ink (Pilot, black) and white vinegar (4.2% acetic acid) (Vierheilig et al. 1998). The colonization rate was estimated by the checkered plate method (Giovanetti and Mosse, 1980). Root segments, 1 cm long, were evaluated for mycorrhizal colonization under an optical microscope. 100 segments were analyzed per plate, per repetition, per treatment. Statistical analyzes consisted of comparison of means between treatments, performed by analysis of variance ANOVA and Tukey's test at 95% significance using the statistical program ASSISTAT®.

Results and discussion

After collecting a sample of aquatic macrophyte *E. crassipes*, the sample was sent to the Soil Chemistry and Fertility Laboratory of the University of Caxias do Sul-UCS, where the concentrations of micro and macro nutrients were determined, as shown in Table 1.

Table 1. Chemical constitution of aquatic macrophyte *E. crassipes*

Macronutrients (g/kg)		Micronutrients (mg/kg)	
N	23.8	Zn	141.9
P	10.2	Cu	29.1
K	54.8	Mn	54.0
Ca	11.6	Fe	120.7
Mg	3.0	B	30.4
S	2.5		

Determination from the methodology proposed by Malavolta; Vitti and Oliveira (1997), being P, K, Na, Cu, Zn, Ca, Mg, S, Fe determined by nitric-perchloric digestion, B determined by calcination and N determined by sulfuric digestion.

The results of the leaf analysis of *E. crassipes* presented results in agreement with those found by other authors (Malavolta 1989, Henry-Silva 2001), with aquatic macrophytes being an excellent source of minerals of agricultural importance.

The high content of potassium stands out, which is a nutrient that in free form regulates and participates in many essential processes such as photosynthesis, opening and closing, of stomata, soil water absorption, enzymatic activities, starch formation and synthesis protein, in addition to contributing to the resistance to lodging of grasses.

Characterization of marble waste

The analysis of marble residues was based on results obtained by different authors from the analysis of X-ray fluorescence (XRF).

The results of the chemical characterization according to different authors can be seen in Table 2.

Table 2. Chemical characterization of granite cutting waste samples studied by different authors

Content (%)	Calmon et al. (1997)	Gonçalves (2000)	Moreira et al. (2002)
SiO_2	59.95	59.62	65.95
Fe_2O_3	6.05	9.49	7.89
Al_2O_3	10.28	12.77	12.84
CaO	6.51	4.83	3.01
MgO	3.25	1.96	1.47
K_2O	4.48	5.30	4.19
TiO_2	0.92	---	0.93
SO_3	---	0.03	---
Na_2O	3.39	2.72	2.39

Fonte: Adaptado de Moura, Gonçalves e Leite (2002).

Physicochemical and biological characterization of the produced substrate

As the dosage of granite cutting residues was increased, there was greater availability of Ca^{2+}, Mg^{2+} and K^{+} in the different treatments, with the exception of Mg for the treatment with 8 t ha^{-1} and for K for the treatment with 32 t ha^{-1}. Leaching may have contributed to the lower K content (Tables 3 and 4) due to the more clayey texture of the substrate, as described by Brito, Rolin and Pedrosa (2021), who in an experiment described an increase in K leaching in soils with higher content of clay and larger amounts of K available via fertilization. This phenomenon occurs due to the passage of K considered non-exchangeable to exchangeable, being fast with increasing residual effect, influencing leaching (Werle, Garcia and Rosolem 2008).

Table 3. Physical and chemical soil parameters for a control sample and different treatments with granite cutting residues and *E. crassipes* aquatic macrophyte and base saturation evolution

Treatment	(Cmol$_c$/dm^3)						Saturation (%)			(% m/v)	
	pH	Ca	Mg	Al	H+Al	CEC	Al	Bases	Indice SMP	OM	Clay
Control	5.2	3.2	2.2	1.3	9.7	6.9	18.8	36.8	5.3	1.9	47
8 t ha^{-1}	5.3	3.6	1.4	0.5	6.9	6.0	0.5	44.5	5.6	2.1	39
16 t ha^{-1}	5.6	4.0	2.2	0.3	5.5	7.0	0.3	55.1	5.8	2.2	39
32 t ha^{-1}	5.7	4.3	2.3	0.2	4.9	7.3	0.2	59.0	5.9	2.2	41

Determination of pH in water in a 1:1 ratio; Touchable Ca, Mg, Al and Mn extracted with 1 mol/L KCl. SMP index estimated by the TSM solution. Clay determined by the hydrometer method. OM by wet digestion with dichromate, according to the methodology proposed by Tedesco et al. (1995).

Table 4 shows the chemical parameters for the control sample and different treatments with granite cutting waste and *E. crassipes* aquatic macrophyte.

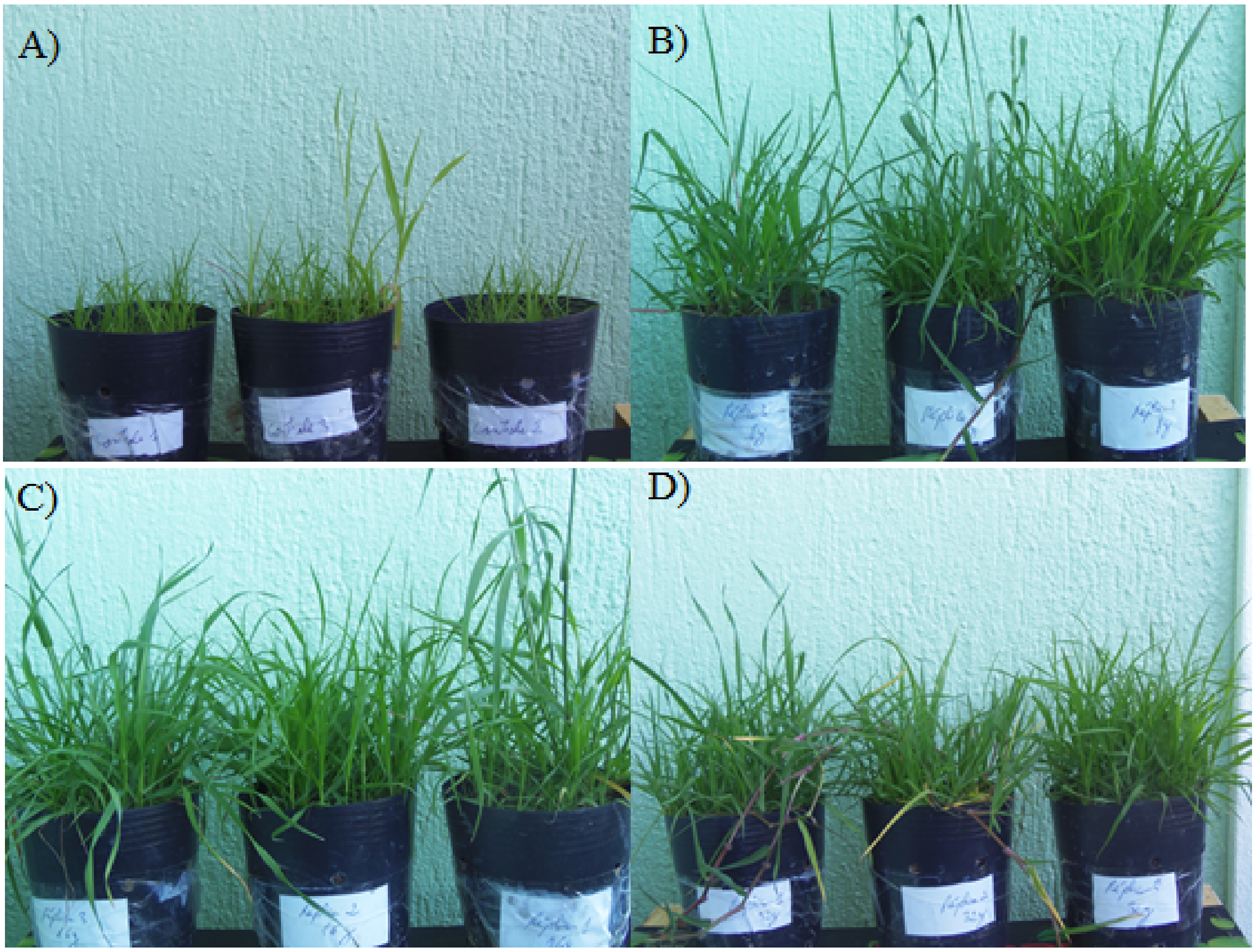
Table 4. Soil chemical parameters for control sample and different treatments with granite cutting residues and *E. crassipes* aquatic macrophyte considering base saturation

Tratament	(mg/dm^3)		(Cmol$_c$/dm^3)		(mg/dm^3)					
	S	P	K	CEC pH 7	K	Cu	Zn	B	Mn	Na
Control	2.3	1.9	0.235	15.3	92	1.4	1.0	0.4	27.1	36.0
8 t ha^{-1}	12.1	11.8	0.512	12.4	200.0	2.2	3.2	0.4	26.0	<15.0
16 t ha^{-1}	12.3	18.0	0.527	12.2	206.0	3.7	3.7	0.4	28.0	<15.0
32 t ha^{-1}	13.1	20.6	0.486	12.0	190.0	5.6	4.9	0.5	31.0	<15.0

S-SO^4 extracted with $Ca(H_2PO_4)2$ 500 mg/L of P. P, K and Na extracted by the Mehlich-1 method. Zn and Cu extracted with Mehlich-1 and B extracted with hot water according to the methodology proposed by Tedesco et al. (1995).

The greater input of nutrients favored the growth of grasses, as shown in Figures 1A, 1B, 1C and 1D, where it is possible to visualize the development stages of grasses during the experiment for the different treatments and control.

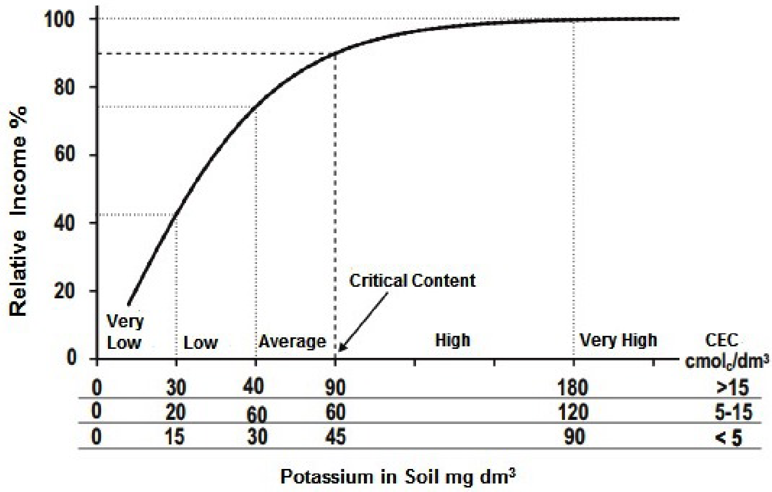
Figure 1. Final growth stage of sample units with grass planting *Paspalum notatum* in a greenhouse. Treatments (granite cutting residue at different dosages intercropped with 8 t ha^{-1} of *E. Crassipes*): 1A: control; 1B: 8 t ha^{-1}; 1 C: 16t ha^{-1}; 1D: 32t ha^{-1}.



The increase in the potassium content stands out, which reached an expressive 4.12 t ha^{-1}, and in the same direction the phosphorus content of 0.412 t ha^{-1}, which is respectively equivalent to 4.96 t ha^{-1} of K_2O and 0.944 t ha^{-1} of P_2O_5 which according to the Brazilian Society of Soil Science (SBCS, 2004) can be considered as high content, with 100% yield for crops, in soils from the states of RS and SC, Brazil as seen in Figure 2.

Potassium chloride imports in Brazil in 2018 totaled 6.3 million tons of K_2O concentrate, an increase of 8.7% compared to 2017. The value of imports reached the amount of US$ 3.1 billion. Potassium chloride exports reached US$ 3 million, showing a deficit balance of around US$ 3.1 billion (MME, 2019), which demonstrates the importance of seeking alternative sources of more accessible sources to obtain potash for agriculture and restoration of degraded soils.

Figure 2. Potassium content evaluation graph in soils in RS and SC. Source: SBCS (2004).



Regarding organic matter (OM), the addition of aquatic macrophyte residue provided a small improvement in its content (from 1.9% to 2.2%). The addition of OM provides better conditions for the development of microbial life in the soil. If there are favorable conditions for the survival of bacteria and fungi, humic acids are formed. These acids play an important role in the formation of clumps and macropores responsible for making the soil porous and facilitating the entry of air and water.

Organic matter is not essentially a fertilizer in organic form, but a biophysical soil conditioner that restores its porosity. Thus, as it has a low density in relation to minerals, it reduces the apparent density of the soil.

When organic matter is humified, it will bring more benefits, increasing the soil's cation exchange capacity (Table 4) and its buffering power. Among the various types of organic substances, only humus can influence the chemical properties of the soil, although plant residues, during their decomposition, have a greater influence on soil physics. Thus, the effect of organic matter depends on proper management, being necessary that it be applied superficially and not in depth.

However, the addition of macrophytes provided the addition of micronutrients and macronutrients important for plant development, due to adsorption of these from the aquatic environment and fixation in its leaf tissue, contributing to the elevation of fertility and the growth and production of plant biomass of *Paspalum notatum*.

The macronutrients N, P, K, Ca, Mg and S are known as the main nutrients and are absorbed by plants in greater proportion than the micronutrients B, Zn, Cu, Fe, Mo, Cl and Mn, which are known as trace elements. Both are constituents of the minerals that give rise to the soil, and of the organic matter of the substrate where the plants grow, which are also found dissolved in the soil solution. However, one or more nutrients may be absent from the soil or in a form that the roots cannot absorb. To make them available, the soil must be properly managed. However, when nutrients are absent it is necessary to replace them (Dos Santos et al. 2021).

Thus, the ion exchange capacity of soils (CEC) represents the graduation of the release capacity of several nutrients, favoring the maintenance of fertility for a long period and reducing or avoiding the occurrence of toxic effects from the application of fertilizers.

As for Mg, the lower concentration observed in relation to the control (Table 3) can be determined by the greater absorption by plants or due to the dilution of the soil used as a control and inoculum of microorganisms in all treatments, which may have contributed to a lower concentration , as the availability of the nutrient via macrophyte is estimated to have resulted in a similar contribution in all treatments, given the dosage used in each treatment, the opposite being the dosage in relation to granite cutting residues, which may have contributed to greater availability in other treatments.

However, regarding the Mg, in the treatment with 8 t ha^{-1}, it can determine the reduction of the effective CEC of the treatment in relation to the control, however the root, leaf and dry mass growth was considerably superior, as well as the indicator sum of bases, which determines soil fertility.

In this sense, it can be said that as the dosage of granite cutting residues was increased, most of the soil CEC was occupied by essential cations such as Ca^{2+}, Mg^{2+} and K^{+}, and it can be said that this is a substrate with good conditions for plant nutrition in opposition to a large part of the CEC occupied by potentially toxic cations such as H^{+} and Al^{3+}, in the control sample, which can be considered as an indicator of a soil poor in nutrients.

The results for H^{+} and Al^{3+} were positive in relation to the control, in all treatments, with the neutralization of Al^{3+} toxic to plants, which corroborates the results obtained by Pavinato and Rosolem (2008), since in soils that receive residues of plant origin normally, Ca and Mg increase in solution when the pH is less than 6.0. Thus, it can be stated that there was probably complexation with organic anions, making Al non-toxic to plants (Pavinato and Rosolem 2008), which can reduce the acid effect of Al from acidic volcanic rocks.

Thus, according to Da Silva Freire et al. (2021), soils with a low CEC value indicate that there is a small capacity to retain exchangeable cations; in this case, large amounts of fertilizers and liming should not be done at once, but in installments to avoid greater losses due to leaching.

In the same sense, pH indicates the amount of hydrogen ions (H^{+}) that exist in the soil. Thus, a soil is acidic when it has many H+ ions and few calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}) ions adsorbed on its colloidal exchange complex.

The pH provides an indication of the general chemical condition of the soil. Soils with high acidity usually present: base poverty (mainly calcium and magnesium); high content of toxic aluminum; excess manganese; high phosphorus fixation in soil colloids and deficiency of some micronutrients. Soil pH is the indicator of a biological-physical-chemical situation and as such it would be misleading to consider only its direct chemical effects on the roots (Da Silva Freire et al. 2021).

The direct effect of soil acidity on plant growth and development manifests itself through the toxicity of aluminum (Al) and/or manganese (Mn), constituting one of the serious problems of tropical soils. In excessively acidic soils, plant development is hampered by the unavailability of essential nutrients, such as phosphorus, zinc and iron, which, in general, are complexed with organic substances or other mineral elements (Habte 1995). Under these conditions, the growth of roots and shoots is reduced and the high amount of exchangeable Al in the soil acts on the root system of the plants, modifying their anatomy, suggesting that the concentration of this element limits the ability of the roots to absorb many of the others nutrients (Ribeiro 2020). Root cells affected by Al may undergo cytological changes, causing growth arrest, as this mineral interferes in the cell division process, mainly in DNA replication (Minocha et al. 1992).

However, to correctly assess aluminum toxicity, the Al saturation (m%) must be calculated, which in the different treatments showed a significant improvement, proving the reduction in the toxic potential of Al (Table 3).

Table 5 shows the results of average leaf and root growth for different treatments and control.

Table 5. Average leaf and root growth in different treatments. Average of 3 repetitions

Treatment	Average leaf growth (cm)	Average root growth (cm)
Control	10.00 c	3.33 b
8 t ha^{-1}	20.30 ab	15.00 a
16t ha^{-1}	23.30 a	16.00 a
32t ha^{-1}	17.67 b	15.33 a
F	47.733	94.73
CV%	7.17	8.70

F = Test statistics F. CV% = Coefficient of variation in % . Significant at the 5% probability level (.01 =< p < .05). The means followed by the same letter do not differ statistically from each other. Tukey's Test was applied at the level of 5% probability.

Regarding the weight of dry matter (Table 6) there is an increase directly proportional to the dosage of granite cutting residues in the different treatments compared to the control.

Table 6. Dry matter mass (g) in different treatments and control

Treatment	Mass (g)
Control	1.82 b
8 t ha^{-1}	4.96 a
16 t ha^{-1}	5.48 a
32 t ha^{-1}	6.46 a
F	13.19
CV%	20.44

F = Test statistics F. CV% = Coefficient of variation in % . Significant at the 5% probability level (.01 =< p < .05). The means followed by the same letter do not differ statistically from each other. Tukey's Test was applied at the level of 5% probability.

Regarding the micro and macronutrients present, there was a significant relationship with the granite cutting residue, as the dosage of aquatic macrophyte residues was the same (8 t ha^{-1}) in all treatments, thus increasing the availability of these elements it is not only due to the availability of macrophytes, despite the relatively short time, there was evidence of chemical and biological solubilization of the granite cutting residue, which provided the plants with higher levels of nutrients, favoring root and leaf growth and dry matter weight in in relation to control.

Another important indicator of the improvement of the produced substrate is the base saturation, which was higher in all treatments, even rising to 59% in the treatment with 32 t ha^{-1} of granite cutting residues, changing the dystrophic soil classification for Eutrophic (Table 3).

In the same sense, the analysis of the AMF colonization rate was shown to be significant and directly proportional to the increase in the dosage of granite cutting residues, being fundamental in the absorption of nutrients (Table 7). Arbuscular mycorrhizal fungi (AMF) are microorganisms that form mutualistic symbiotrophic associations with plant roots, which normally occur in nature.

Table 7. Percentage rate of AMF colonization

Treatment	AMF colonization rate in percentage (%)
Control	15.66 d
8 t ha^{-1}	36.30 c
16t ha^{-1}	78.30 b
32t ha^{-1}	91.00 a
F	2490
CV%	22.1

F = Test statistics F. CV% = Coefficient of variation in % . Significant at the 5% probability level (.01 =< p < .05). The means followed by the same letter do not differ statistically from each other. Tukey's Test was applied at the level of 5% probability.

One of the advantages of mycorrhizal colonization is due to the increased absorption of nutrients by plants, especially of elements with low mobility in the soil, such as phosphorus (P), leading to greater plant growth and productivity (De Souza Pereira, Giongo and De Aguiar Lima 2021). The high efficiency of hyphae in P absorption is due to its smaller diameter, larger hypha-soil contact surface and also its capacity to store polyphosphates in vacuoles (Marschener 1997).

The results obtained corroborate Murcia et al. (2007). The authors used construction and demolition waste in intercropping with waste marble and sewage sludge in soils degraded by mining in Spain, reporting an increase in colonization by fungi and bacteria in the soil under study.

For E Vila et al. (2021) the current knowledge of the AMF allows for broad generalizations about their ecological characteristics, but the ways in which mycorrhizae affect plant species and the dynamics of communities, and their large-scale use in agricultural production and environmental conservation they are big challenges, and discussion is imperative in any study that addresses agricultural biotechnology.

Thus, although the study was preliminary, not having identified the AMFs, or deepening the ecological investigation about their contribution to plant growth, the high colonization rate brought evidence of a positive and environmentally safe contribution to the use of associated waste.

Conclusions

The consortium of granite cutting residues with aquatic macrophytes residues composed by *E. crassipes* provided significant improvements in the growth of *P. notatum* grass and in the substrate produced, considering the chemical and biological variables.

There was an increase in the colonization rate of arbuscular mycorrhizal fungi and in the content of mineral nutrients in the soil. Granite cutting residue in particular in the dosage of 32 t. ha^{-1} intercropped with 8t ha^{-1} of *E. crassipes* showed better results with the contribution of 4.12 t ha^{-1} of potassium and 0.412 t ha^{-1} of phosphorus, which are equivalent to 4.96 t respectively ha^{-1} of K_2O and 0.944 t ha^{-1} of P_2O_5, increasing base saturation, promoting the classification of the soil as eutrophic (base saturation >50%).

Future studies should contemplate the use of different species of macrophytes, in addition to macrophytes after the composting process, in order to speed up the process of nutrient release.

The use of granite cutting waste in a consortium with aquatic macrophytes provided an environmentally viable solution for the final disposal of waste from different stages and production cycles, favoring the closure of the waste cycle and providing a sustainable alternative for the recovery of degraded soils.

Participação dos autores: RPS - execução da pesquisa, interpretação dos resultados, redação e revisão do texto.

Aprovação ética: o estudo não demandou nenhuma licença ou autorização.

Disponibilidade dos dados: os dados não estarão disponíveis em bases ou repositores.

Fomento: não houve financiamento ao projeto.

Conflitos de interesses: o autor declara não haver conflitos de interesse.

References

Arantes Pinto M. et al. 2020. Utilização da técnica de vermicompostagem para reutilização de resíduos orgânicos e de macrófitas aquáticas. In: Colloquium Exactarum.

Brito FL, Rolim MM, Pedrosa EMR. 2021. Teores de potássio e sódio no lixiviado e em solos após a aplicação de vinhaça. Revista Brasileira de Engenharia Agrícola e Ambiental (9): 52-56. https://doi.org/10.1590/1807-1929/agriambi.v9nsupp52-56.

Camargo AFM, Henry-Silva GG, Pezzato MM. 2003. Crescimento e produção primária de macrófitas aquáticas em zonas litorâneas. In: Henry R. (Ed.) Ecótonos nas interfaces dos ecossistemas aquáticos. São Carlos: Fundibio/Rima, p. 213-232.

Cola GPA, Simão JBP. 2012. Rochagem como forma alternativa de suplementação de potássio na agricultura agroecológica. Revista Verde 7 (4): 15-27.

Da Silva Freire G. et al. 2021. Atributos edáficos e vegetação em áreas de nascentes da Sub-Bacia Hidrográfica do Rio Piauitinga, Sergipe. Magistra 31: 661-674.

Da Silveira CM. et al. 2021. Produtividade do amendoim sob efeito residual da rochagem em área de reforma de canavial. South American Sciences 2 (edesp 1): 21127-21127.

De Paula Medeiros F, Cardoso IM, De Souza Vieira MS. 2021. Experimentação participativa com pó de rocha. Cadernos de Agroecologia 15 (1).

De Souza Pereira V, Giongo V, De Aguiar Lima RLF. 2021. Micorrizas Arbusculares como Indicador Biológico para Seleção de Modelos de Agroecossistemas Multifuncionais. Revista Brasileira de Geografia Física (14) 05: 3108-3124.

Dos Santos F D. et al. 2021. Fatores que afetam a disponibilidade de micronutrientes no solo. Tecno-Lógica 25(2): 272-278. https://doi.org/10.17058/tecnolog.v25i2.15552

Dos Santos GB. et al. 2020. Bioquimica ambiental: as macrófitas aquáticas como fitorremediadoras e bioindicadoras de poluentes. Revista Macambira 4 (2): 042004-042004.

E Vila VV. et al. 2021. Microbiota do solo na tolerância de doenças em plantas: Uma revisão. Research, Society and Development 10 (8): 25910817161-25910817161. DOI: http://dx.doi.org/10.33448/rsd-v10i8.17161

El-Sayed AFM. 1999. Alternative dietary protein sources for farmed tilapia, *Oreochromis spp*. Aquaculture 179: 149-168.

Embrapa-Empresa Brasileira de Pesquisa Agropecuária. 2006. Sistema brasileiro de classificação de solos. 2 ed. Rio de Janeiro: Embrapa solos.

Garcia Júnior O. 1991. Isolation and characterization of *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* from mineral mines. Rev. Bras. Microbiol. 20: 1-6.

Giovanetti M, Mosse B. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. New Phytol. (84):489-500.

Habte M. 1995. Soil acidity as a constraint to the application of vesicular-arbuscular mycorrhizal technology. In: Varma A.; Hock B. (Ed.). Mycorrhiza - structure, function, molecular biology and biotechnology, Berlin: Heidelberg: Spring-Verlag. p.593-605.

Henry-Silva GG. 2001. Utilização de macrófitas aquáticas flutuantes (*Eichhornia crassipes, Pistia stratiotes* e *Salvinia molesta*) no tratamento de efluentes de piscicultura e possibilidades de aproveitamento da biomassa vegetal. Jaboticabal: Universidade Estadual Paulista. 79 fl. Dissertação de Mestrado em Aqüicultura em Águas Continentais.

Júnior JJA. et al. 2020. Análise das variáveis tecnologicas na cultura da soja (glycine max) com utilização de remineralizador de solo como fertilizante. Brazilian Journal of Development 6 (8): 56835-56847. https://doi.org/10.34117/bjdv6n8-190

Malavolta E. et al. 1989. Sobre a composição mineral do aguapé (*Eichhornia crassipes)* An.Esalq, Piracicaba, 46 (parte 1): 155-162.

Marschener H.1997. Mineral Nutrition of Higther Plants. Hohenheim: Institute of Plant Nutrition University of Hohenheim.

Martins D. et al. 2003. Caracterização química das plantas aquáticas coletadas no reservatório de Salto Grande (Americana-SP). Planta Daninha 21:21-25. https://doi.org/10.1590/S0100-83582003000400004

Minocha R. et al. 1992. Effects of aluminum on DNA synthesis, cellular polyamine, polyamine biosynthetic enzymes and inorganic ions in cell suspension cultures of a woody plant. Catharauthus roseus. Plant Physiol 85:417-424.

MME - Ministério de minas e energia. 2019. Anuário Mineral 2019. Secretaria de Geologia, Mineração e Transformação Mineral: Brasília.

Moura WA, Gonçalves JP, Leite RS. 2002. Utilização do resíduo de corte de mármore e granito em argamassas de revestimento e confecção de lajotas para piso. Feira de Santana: Sitientibus 26.

Murcia FJ. et al. 2007. Assessment of mining soil improvement after construction and demolition wastes amendment additions evaluated by microbiological analysis. Global Nest Journal 9 (3):224-228. https://doi.org/10.30955/gnj.000455

Pavinato PS, Rosolem CA. 2008. Disponibilidade de nutrientes no solo: decomposição e liberação de compostos orgânicos de resíduos vegetais. Rev. Bras. Ciênc. Solo [online] 32 (3): 911-920. Disponible on: http://www.scielo.br/pdf/rbcs/v32n3/a01v32n3.pdf . Last acess on: 15 out.2015.

Pieterse AH, Murphy K. 1990. Aquatic weeds and management of nuisance aquatic vegetation. New York: Oxford University Press. 593 p.

Ramos CG. et al. 2014. A preliminary study of acid volcanic rocks for stonemeal application. Environmental Nanotechnology, Monitoring & Management: 30–35. https://doi.org/10.1016/j.enmm.2014.03.002

Reidel A. et al. 2021. Utilização de efluente de frigorífico, tratado com macrófita aquática, no cultivo de tilápia do Nilo. Revista Brasileira de Engenharia Agrícola e Ambiental 9: 181-185. https://doi.org/10.1590/1807-1929/agriambi.v9nsupp181-185

Ribeiro VC. 2020. Efeito do alumínio sobre a endoglucanase e xiloglucanase da raiz de cebola (*Allium cepa*). Disponible on: http://repositorio.unitau.br/jspui/handle/20.500.11874/4440.

SBCS-Sociedade Brasileira de Ciência do Solo. 2004. Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina. Comissão de Química e Fertilidade do Solo. 10. ed.: Porto Alegre.

Silva EA. et al. 2008. Efeitos da rochagem e de resíduos orgânicos sobre aspectos químicos e microbiológicos de um solo exposto e sobre o crescimento de *Astronium fraxinifolium* Schott. R. Árvore 32 (2): 323-333. https://doi.org/10.1590/S0100-67622008000200015

Silva FAS, Azevedo CAV. 2002. Versão do programa computacional Assistat para o sistema operacional Windows. Revista Brasileira de Produtos Agroindustriais, Campina Grande 4 (1):71-78.

Vierheilig H, Coughlan AP, Wyss U, Piché Y. 1998. Inky and vinegar, a simple staining technique for arbuscular-mycorrize fungi. Apllied and envinronmental microbiology 64:5004-5007.

Wang J. et al. 2000. Release of potassium from K-bearing minerals: Effect of plant roots under P deficiency. Nutrient Cycling in Agroecosystems 56: 45–52. https://doi.org/10.1023/A:1009894427550

Werle R, Garcia RA, Rosolem C.A. 2008. Lixiviação de potássio em função da textura e da disponibilidade do nutriente no solo. Revista Brasileira de Ciência do Solo 32: 2297-2305.

Wermuth C. 2019. Efeito da aplicação de resíduo ruminal bovino com cinzas na fertilidade do solo. Available in: http://repositorio.fama-ro.com.br/bitstream/123456789/110/1/TCC%20C%C3%A1ssio_Final_V%2002%20EPF%2006122019%20FINAL.pdf. Last accessed on January 21, 2022.