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Agronomic feasibility of using basalt powder as soil nutrient remineralizer

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Tropical agriculture is highly dependent of soluble fertilizers, what raises the cost of production. An alternative to reduce the costs inputs is the use of low-cost alternative nutrient sources, such as the basic rocks. The aim of the work was to evaluate the effect of basalt powder on the soil chemical properties and plant growth. The experiment was arranged in a 2×2×2×3+4 factorial scheme: two soils (clay soil and sandy clay loam soil); two crops (maize and soybean); two agricultural inputs (basalt rock powder and limestone); three application rates (33, 66 and 99 Mg ha⁻¹ of basalt powder or 1, 2 and 4 Mg ha⁻¹ of limestone), and four additional control treatments, with four repetitions. The use of basalt powder resulted in greater shoots growth of maize and soybean plants when compared to the limestone. Basalt powder provided a significant increase in soil pH, Ca and P concentration; however, the higher concentration of P in the soil did not result in the greater P uptake by the plants. Even without a significant increase in the Mg concentration of the soil, basalt rock powder improved the absorption of this nutrient by the maize and soybean plants.

Key words: Remineralizer, rock, soybean, maize.

INTRODUCTION

Most Brazilian tropical soils are highly weathered, acidic and have low cation exchange capacity (CEC). However, with the correction of soil acidity and fertility, the country's climatic conditions are adequate for the optimal growth and development of agricultural crops. The correction of soil fertility has been carried out with the application of soluble fertilizers for the supply of nitrogen (N), phosphorus (P) and potassium (K) or by the application of limestone for the supply of calcium (Ca) and magnesium (Mg) and correction of soil acidity.

The correction of fertility in Brazilian tropical soils depends on the application of high rates of fertilizers,

which has increased the demand for imports of mineral fertilizers. Estimates from the National Fertilizer Diffusion Agency (ANDRA, 2018), reported that there was a national production of 6.7 million tons of mineral fertilizers in 2018, while imports this year were 21.9 million tons. Therefore, more than three quarters of the fertilizers used in Brazilian agriculture are imported from other countries. This fact has been a great challenge for the national production of food, since the entire productive sector becomes dependent on the import of agricultural inputs, whose price is linked to exchange variations, as well as dependent on international trade policies.

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Table 1. Chemical composition of the rock powder used in the experiment and determined by X-ray fluorescence spectrometry LAMIR – UFPR.

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	TiO ₂	MnO	P ₂ O ₅	P.F	Sum
50.22	12.67	13.92	8.92	5.36	1.32	2.87	2.06	0.20	0.20	1.75	99.59

Table 2. Particle size analysis determined by screening of rock powder used in the experiment

Sieve mesh (mm)	4.0	2.0	1.0	0.5	0.25	0.125	0.063	0.044	<0.044
Particle retention (%)	0	0.045	17.815	18.255	13.105	10.555	8.485	3.615	28.125

This dependence on international economic policies has resulted in an expressive increase in fertilizer prices in recent years, accompanying the increase in the dollar and the devaluation of the national currency, which has raised the cost of national production. Therefore, Brazilian agriculture must seek new alternatives for the recovery of soil fertility and reduce the high dependence on fertilizer imports. Therefore, Brazilian agriculture needs to seek new alternatives for the recovery of soil fertility and reduce the high dependence on fertilizer imports.

One of the options that has been pointed out has been the use of rock powder. Silicate rocks normally contain essential nutrients for plants in quantities and availability that vary due to the mineral composition of the rocks. Therefore, these rocks have been used in agronomic studies to investigate their potential as alternative sources for the supply of nutrients to plants (Ribeiro et al., 2010). There is a wide diversity of igneous, metamorphic, or sedimentary rocks with potential for agricultural use (Brandão, 2012). These rocks have a wide range of minerals, and considerable levels of potassium (K), calcium (Ca), magnesium (Mg) and phosphorus (P), among other essential nutrients for plants. This rock powder material when applied to the soil is solubilized and promotes the availability of its nutrients to plants (Kautzmann et al., 2013; Souza et al., 2017).

Several studies have reported that the application of silicate rock powder, such as basalt, has resulted in the improvement of the chemical characteristics of fertility in various types of soil (Resende et al., 2006; Ribeiro et al., 2010; Melo et al., 2012; Silva et al., 2012; Toscani and Santos, 2017). However, the solubilization and availability of nutrients from the different rock materials should be better studied to ensure that the material produced has adequate potential for agricultural use. Thus, this study was conducted with the objective of investigating the agronomic effectiveness and the potential of using basalt rock powder as a soil remineralizer, and to evaluate changes in the chemical properties of two contrasting soils subjected to the cropping of maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merrill.].

MATERIALS AND METHODS

To determine the agronomic effectiveness of using the rock powder remineralizer, an experiment under greenhouse conditions was conducted in a 2×2×2×3+4 factorial scheme: two soils (clay soil and sandy clay loam soil); two agricultural crops (maize and soybean); two agricultural inputs [basalt rock powder (soil remineralizer) and limestone (soil corrective)]; three application rates for agricultural materials (33, 66 and 99 Mg ha⁻¹ of basalt powder or 1, 2 and 4 Mg ha⁻¹ of limestone), and four additional control treatments, and four additional control treatments, one for each soil and one for each agricultural crop, all without application of rock powder or limestone, with four repetitions. Each experimental unit consisted of a 5 L plastic pot, totaling 112 pots.

The basalt powder used as a soil remineralizer was the RENUTRI® belonging to the MINERPAL Company (Mineradora Palotina Ltda, Palotina, Paraná, Brazil). This agricultural material is provisionally registered in the Ministério da Agricultura, Pecuária e Abastecimento (MAPA) of Brazil. The limestone used contained the following characteristics: CaO = 45%, MgO = 4% and effective calcium carbonate equivalent = 72.5%. The chemical and particle size characteristics of the basalt rock powder used in this study are shown in Tables 1 and 2.

Subsurface soil samples were collected at a depth of 0.20 to 0.50 m on two farms in the municipality of Palotina, PR, Brazil. These samples were air-dried, sieved in 4.0 mm mesh, and then placed in 5 L plastic pots. The results of physicochemical analysis are shown in Tables 3 and 4. Sowing of soybeans (cultivar BMX Potência IPRO) and maize (hybrid Supreme Viptera) was carried out on July 6, 2018, with five seeds per pot. At 20 days after sowing, seedlings were thinned to two plants per pot. The soil water content was monitored, and manual irrigation was performed daily during the experiment period. The irrigation control was carried out using the weighing method to maintain 50% of the soil porosity with water.

During the experiment, the maize plants were fertilized with 500 kg of ha⁻¹ of nitrogen. Nitrogen was the only macronutrient that was not added with the treatments, and the applied rate of this nutrient was high in order not to be a limiting nutrient for plant growth. All pots were fertilized with 50 kg ha⁻¹ of P, by adding simple superphosphate (18% P₂O₅, 16% Ca and 8% S). The application of P was carried out because this nutrient was less in the materials used. At 70 days after emergence, the plants were harvested, separated into shoots and roots, oven dried at 55°C for three days and then weighed. The roots were put in a 1.0 mm mesh sieve and washed under running tap water to remove the adhered soil. The shoot material of the plants was ground and submitted to dry digestion to determine the P concentration by colorimetry, K concentration by flame photometry and the Ca and Mg concentration by volumetry of EDTA (Pavan et al., 1992; Silva,

Table 3. Chemical properties of the soils used in the experiment.

Soil	pH	Al ³⁺	H+Al	Ca ²⁺	Mg ²⁺	K ⁺	P	OC
	CaCl ₂		-----	cmol _c dm ⁻³	-----		mg dm ⁻³	g kg ⁻¹
Clay	6.7	0	2.06	3.50	1.40	0.16	5.6	7.90
Sandy clay loam	7.0	0	1.70	2.00	1.00	0.10	6.6	6.14

OC: organic carbon.

Table 4. Particle size analysis of the soils used in the experiment

Soil	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)
CS	384	49	567
SCLS	671	12	317

CS: clayey soil, SCLS: Sandy clay loam soil.

2009). The amount of P, K, Ca and Mg accumulated in plant shoots was calculated from the dry matter produced per pot and the content of nutrient in the shoot dry matter.

At the end of the maize and soybean cropping, the soil from each pot was sampled, air-dried, ground to pass through a 2.0 mm mesh screen and chemically analyzed. Soil pH was determined potentiometrically in a 1:2.5 (soil: 0.01 mol L⁻¹ of CaCl₂) suspension using a combined calomel reference glass electrode and pH meter. Potential acidity was determined using the SMP buffer solution method, as previously described by Pavan et al. (1992). Exchangeable K and available P were extracted by the Mehlich-1 solution (0.0125 mol L⁻¹ H₂SO₄ + 0.05 mol L⁻¹ HCl) from a soil: solution ratio of 1:10, and K content was measured by a flame photometer and P content was analyzed by molybdenum blue phosphorus method using a UV-visible spectrophotometer. Calcium (Ca²⁺) and magnesium (Mg²⁺) were extracted by 1.0 mol L⁻¹ KCl solution in a soil: solution ratio of 1:10, and Ca and Mg contents were determined by atomic absorption spectrophotometry. Exchangeable Al was extracted by 1 mol L⁻¹ KCl solution and determined by titration with 0.025 mol L⁻¹ NaOH. All methods were determined as previously described by Pavan et al. (1992). The accuracy of the different methods was verified by analyzing the standard reference material. Regression analyzes were used to assess the effects of application rates of basalt rock powder or limestone on each soil and crop, and significant equations with the highest coefficients of determination (F test, *p* < 0.05) were adjusted. All analyses were performed using Sisvar[®] version 5.6 software for Windows (Statistical Analysis Software, UFLA, Lavras, MG, BRA).

RESULTS AND DISCUSSION

As the use of soil remineralizer may have effects on several chemical properties of the soil, such as pH and Ca, Mg, P and K contents (Toscani and Santos, 2017; Melo et al, 2012, Silva et al., 2012; Ribeiro et al., 2010), in this study the limestone was chosen to make the comparison between the two agricultural materials, regardless of the high pH value of the soils (Table 4) and the high base saturation of the soils that did not indicate the need liming application for maize and soybean crops

(SBCS/NEPAR, 2017).

The limestone application rates resulted in negative effects on crop growth and development, with a significant reduction in the dry matter production of the soybean shoots in both soils (Figure 1 A1) and a lower dry matter production of the maize shoots for sandy clay loam soil (Figure 1 C1). The greater cation exchange capacity (CEC) of the clayey soil (greater buffering power) promoted less effect of the limestone rates, resulting in the lesser impact of the use of this material on the growth and development of the plants. On the other hand, the lower CEC of the sandy soil (lower buffering capacity) resulted in the greater effect of limestone on the growth and development of soybean and maize plants (Figures 1 A1 and C1).

The application of basalt rock powder as a soil remineralizer had no negative effects on the shoot dry matter production of soybean and maize crops (Figures 1 B1 and D1). The shoot dry matter of soybean plants grown in the clayey soil was significantly higher with the rates of basalt powder, suggesting that, even in a short period of interaction of this material with the soil (less than 80 days), there was an improvement in characteristics of this soil, which resulted in the greater development of soybean plants (Figure 1 B1).

Resende et al. (2006) showed that the shoot dry matter production of soybean plants grown in a clayey soil was significantly higher with the application of different types of rocks, confirming the results obtained in this study. However, these authors reported that the greatest response was obtained with the millet crop grown in succession to soybean, demonstrating a residual effect of these rock materials, which was caused by the longer reaction time of the materials applied to the soil.

The presence of CaO and MgO in the chemical composition of the remineralizer (Table 1) has the ability to react and promote an increase in the pH value of the soil, a process similar to what occurs with the application

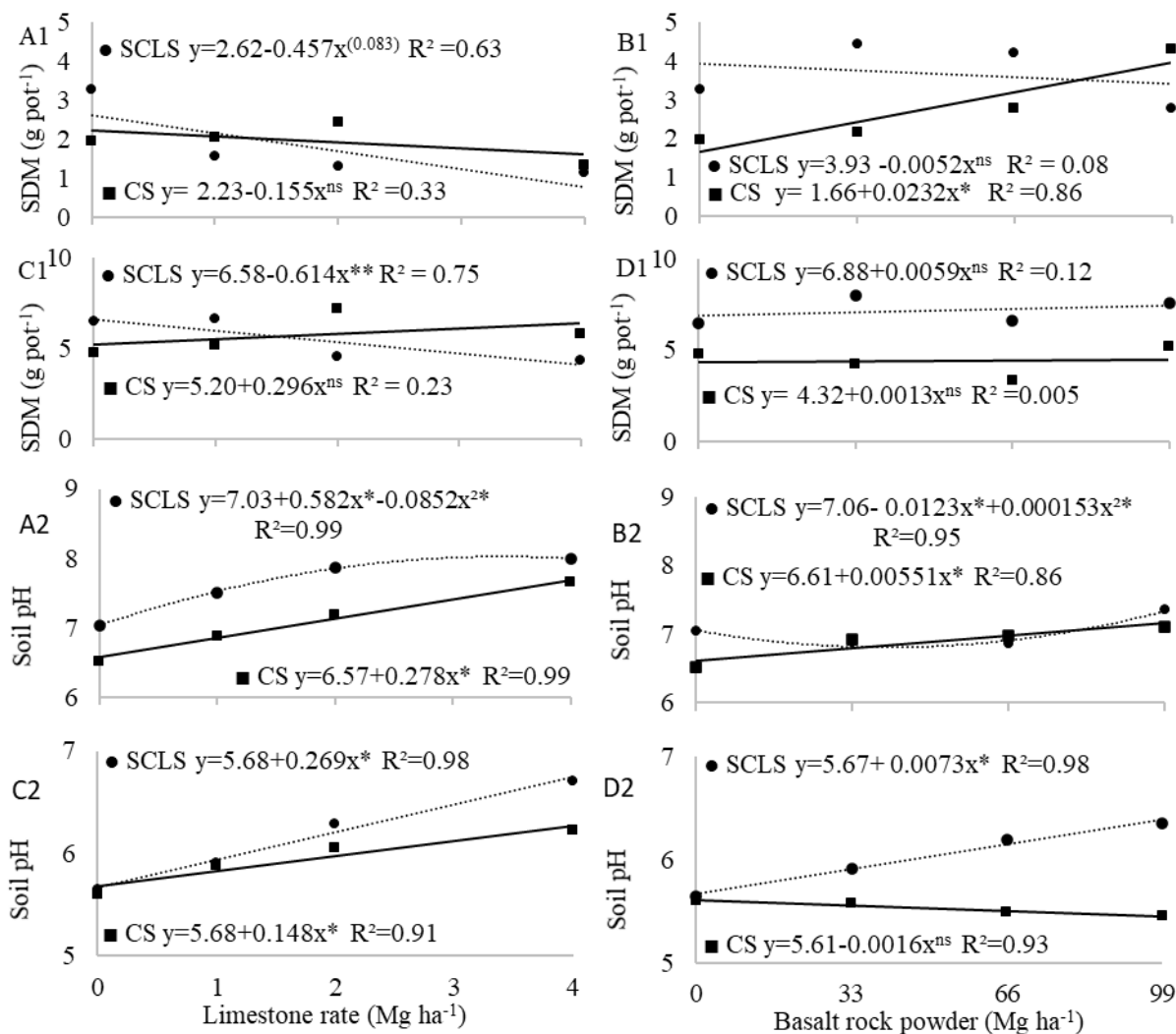


Figure 1. Shoot dry mass (SDM) of aerial part (1) and soil pH (2) as function of doses of respective materials been: A- Limestone soy; B-basalt rock powder soy; C-limestone maize; D basalt rock powder maize; in clayey soil (CS) and sandy clay loam soil (SCLS). ^{ns}: not significant. * and **: statistical significance at 1 and 5% probability, respectively.

of limestone. The comparison between the two materials indicates that limestone had the greatest potential to raise the pH value of soils (Figure 1 A2, B2, C2 and D2). However, the application of the remineralizer promoted significant effects in increasing the soil pH in most treatments, not showing significant effect only in the maize crop cultivated in the clayey soil that has a greater buffering effect (Figure 2D). The increase in pH with the use of silicate rocks has been well documented in the literature as reported in other studies (Toscani and Santos, 2017; Melo et al., 2012; Silva et al., 2012; Ribeiro et al., 2010; Resende et al., 2006). This effect occurs both due to possible calcium and magnesium oxides in the material, that will change pH and release Ca and Mg, and due to the consumption of H^+ in the reaction $KAlSi_3O_8 + H^+ \rightarrow HAlSi_3O_8 + K^+$ (Curi et al., 2005).

The treatments under maize cultivation resulted in the

acidification of the two soils when compared to the initial pH value of the soils, which may be associated with a high rate of nitrogen fertilizer application in this crop. The pH of the clayey soil was reduced from 6.7 to 5.6 and the pH of the sandy soils decreased from 7.0 to 5.6 (Table 3 and Figure 1 B2 and D2). This acidification caused by the application of high N rates in the maize crop resulted in the lack of response from the application of basalt rock powder in the pH value of the clayey soil (Figure 1 D2). Both the application of basalt powder and limestone resulted in a significant increase in the Ca^{2+} content of the soils (Figure 2 A1, B1, C1 and D1). The initial Ca^{2+} content of the soil was considered high and medium, respectively, for the clayey soil and sandy clay loam soil (SBCE/NEPAR, 2017) (Table 3). This increase in the Ca^{2+} content of soils with the application of limestone was expected, since 80 days after the application of the lime

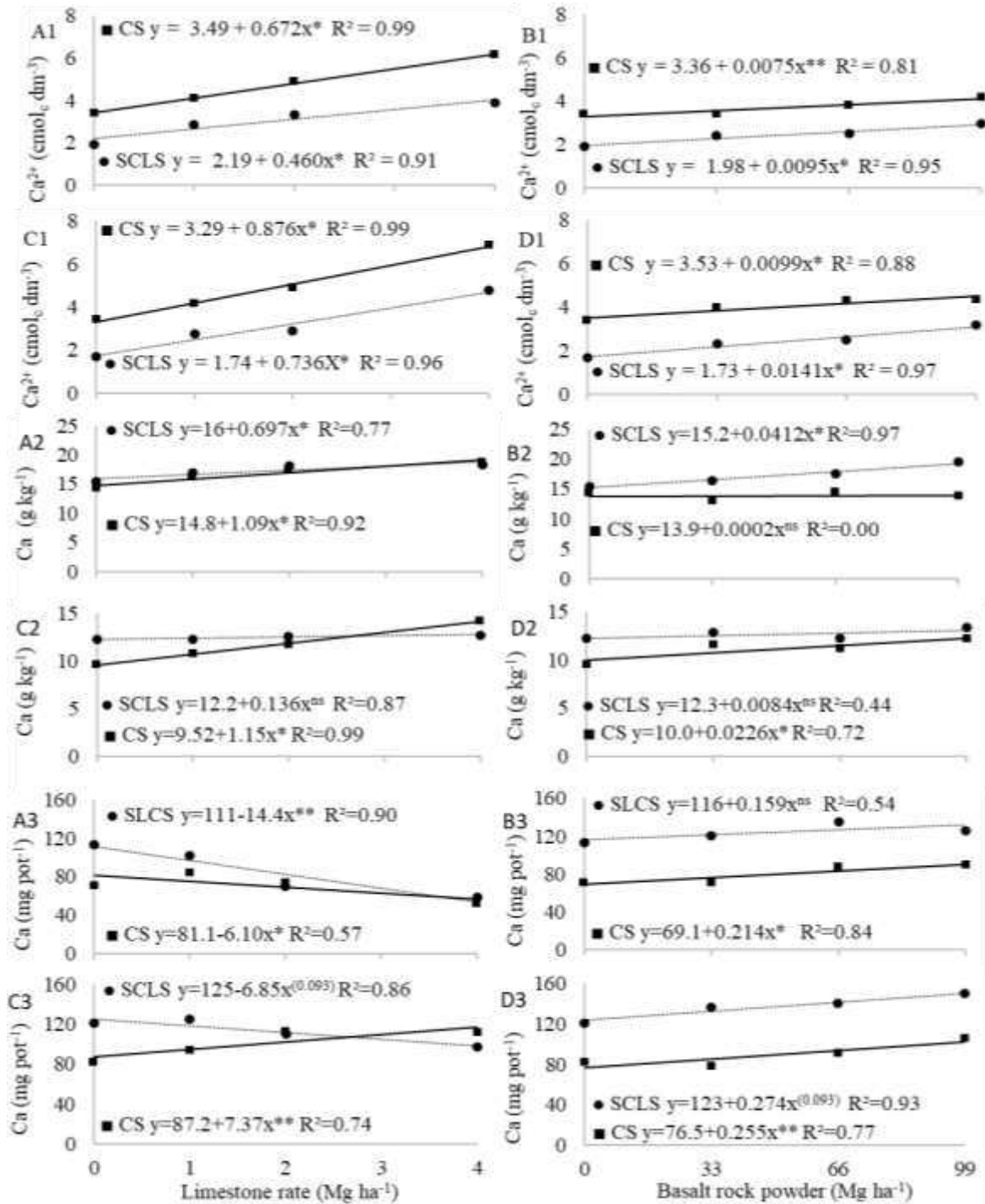


Figure 2. Calcium content in soil (1), concentration in shoots (2) and accumulation in shoots (3) as function of doses of respective materials been: A-Limestone soy; B-basalt rock powder soy; C-limestone maize; D basalt rock powder maize; in clayey soil (CS) and sandy clay loam soil (SCLS). ^{ns}: not significant. * and **: statistical significance at 1 and 5% probability, respectively.

this material could have released most of the available calcium. The levels of Ca^{2+} in the soils were elevated to levels considered high for sandy clay loam soil and very high level for clayey soil (SBCS/NEPAR, 2017) (Figure 2

A1 and C1).

In turn, the basalt rock powder has a slower reaction, with less effect in the short term, but a greater release of Ca is expected in the medium and long term. However,

even in the short term, the application of basalt powder was sufficient to raise the Ca^{2+} content of the sandy clay loam soil to levels considered high (SBSCS/NEPAR, 2017) (Figure 2B1 and D1). The remineralizer was applied at high rates 30 times higher than the application of lime due to the fact that the material has a slow solubilization time and a lower concentration of calcium and magnesium oxides (Table 1). The increase in Ca^{2+} contents with the application of rock powder confirms the results of the literature, which report that calcium is potentially released by these rock materials (Resende et al., 2006; Ribeiro et al., 2010; Melo et al., 2012; Silva et al., 2012).

The increase in the Ca^{2+} content of the soils resulted in an increase in the Ca concentration in the plant shoots in most treatments with application of limestone (Figure 2 A2 and C2). Only the Ca concentration in the maize plants grown in the sandy clay loam soil did not increase significantly with the increase in calcium rates. The use of remineralizer resulted in a significant increase in Ca concentration in soybean plants grown in sandy clay loam soil and in maize plants in clayey soil (Figure 2 B2 and D2). The Ca concentration of the plants was within the range considered adequate for soybean crop (that is, 4.0 to 20.0 g kg⁻¹) and higher than the value considered adequate for maize crop (that is, 2.5 to 8.0 g kg⁻¹) (Silva, 2009). Therefore, the lack of response in some situations may be due to the adequate nutritional status in Ca of the plants.

The increase in the Ca content of the soils and the higher Ca concentration in the plants with the applied lime rates did not promote greater Ca accumulation in the plants (Figure 2 A3 and C3). In most treatments with limestone application, there was a reduction in the accumulation of this nutrient by the plants, except for the maize crop in the clayey soil (Figure 2 C3). Thus, the increase in Ca concentration in plants can be related to a concentration effect on leaf tissues caused by the lower growth of plants (Figure 2 A2, C2, Figure 1 A1 and C1) and not by the greater availability of this nutrient in the soil.

In turn, the use of remineralizer that had no negative effect on the development of maize and soybean plants (Figure 1 B1 and D1), and the positive effects on soil Ca contents and in some cases on the concentration of this nutrient in plants (Figure 2 B2 and D2) resulted in the highest Ca accumulation in soybean plants grown in sandy clay loam soil (Figure 2 B3 and D3). The initial Mg content in the soils was at levels considered high and medium for the clayey and sandy clay loam soils, respectively (SBSCS/NEPAR, 2017) (Table 3).

Unlike the effect reported for Ca^{2+} content that the application of basalt rock powder or limestone resulted in greater availability of Ca in soils in a short term, the Mg^{2+} contents in soils were little changed by the application of rock powder and limestone (Figure 3 A1, B1, C1 and D1). Only for the soybean cropping in the sandy clay loam soil

there were significant effects, in which the application of limestone rates resulted in a reduction in the Mg^{2+} contents of the soil (Figure 3 A1). This fact may be related to the significant increase in the Ca^{2+} content of the soil that resulted in the loss of Mg^{2+} in the system, and an increase in the nutrient contents when the remineralizer is applied (Figure 3 B1).

Contrary results have been reported in some studies, in which the application of rock powder has resulted in increases in the Mg^{2+} content of soils (Resende et al., 2006; Melo et al., 2012). However, Ribeiro et al. (2010) also did not report increases in Mg^{2+} contents of the soils after the application of various types of rock materials, thus showing that the application of rock powder may or may not have a significant effect on the Mg^{2+} content of the soil. There is preference in the release of the elements present in the rock materials to the soil, occurring in the following decreasing order: $\text{CaO} > \text{MgO} \gg \text{Al}(\text{OH})_3 > \text{Fe}(\text{OH})_3 > \text{SiO}_2$, this associated with the formation of secondary minerals causes the rate of release of nutrients from rock materials is not linear (Oelkers, 2001). As the Mg^{2+} content of the soils was considered adequate, the concentration of this nutrient in the shoots of plants was also considered adequate for the soybean crop (3.0 to 10.0 g kg⁻¹) (Figures 3 A2 and B2), and above the appropriate range for the maize crop (1.5 to 5.0 g kg⁻¹) (Figures 3 C2 and D2) (Silva, 2016).

Even with the low effects reported in the Mg^{2+} content in the soil, the Mg concentration in the soybean and maize plants increased with the application of rock powder and limestone, except for the clayey soil with the application of limestone (Figure 3 C2). A similar result was reported with the cultivation of soybean in the sandy clay loam soil, in which there was a reduction in soil contents and the plant had an increase in the concentration of this nutrient (Figures 3 A1 and A2).

In contrast to the use of limestone, the application of remineralizer promoted a significant increase in the production of shoot dry, in the concentration and accumulation of Mg in soybean plants in the clayey soil (Figure 1 B1, Figure 2 B2 and B3). In the other treatments, there were no significant effects in some cases and a greater tendency to increase the Mg accumulation in the maize crop in the sandy clay loam soil (Figures 3 B3 and D3).

The soils initially had low P contents (SBSCS/NEPAR, 2017) (Table 3). Thus, all treatments with application of remineralizer resulted in significant increases in the contents of available P of the soils (Figures 4 B1 and D1). These results can be explained by some factors, among which we can mention the increase in pH that favored the availability of soil P due to the decrease in P fixation by the oxides existing in these soils; however, this increase in pH promoted by the application of limestone did not have the same effect (Figures 4 A1 and C1). The increase in soil phosphorus content may also be associated with the fact that the application of silicon

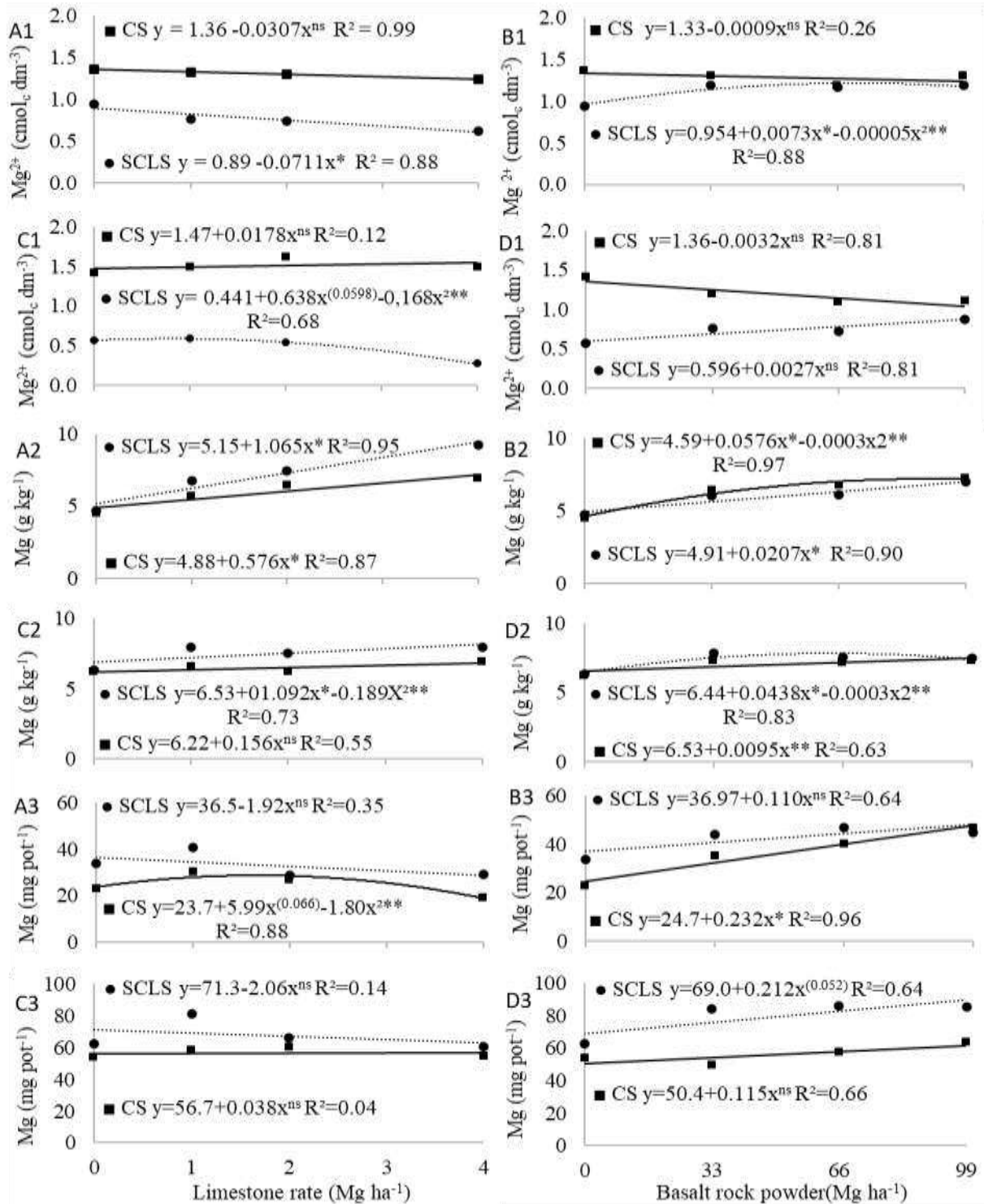


Figure 3. Magnesium content in soil (1), concentration in shoots (2) and accumulation in shoots (3) as function of doses of respective materials been: A-Limestone soy; B-basalt rock powder soy; C-limestone maize; D basalt rock powder maize; in clayey soil (CS) and sandy clay loam soil (SCLS). ^{ns}: not significant. * and **: statistical significance at 1 and 5% probability, respectively.

oxide has promoted competition with the phosphate adsorption sites (Alleoni et al., 2019), in addition to the

availability of phosphate by remineralizer that even in low concentration in the applied material (Table 1), can be

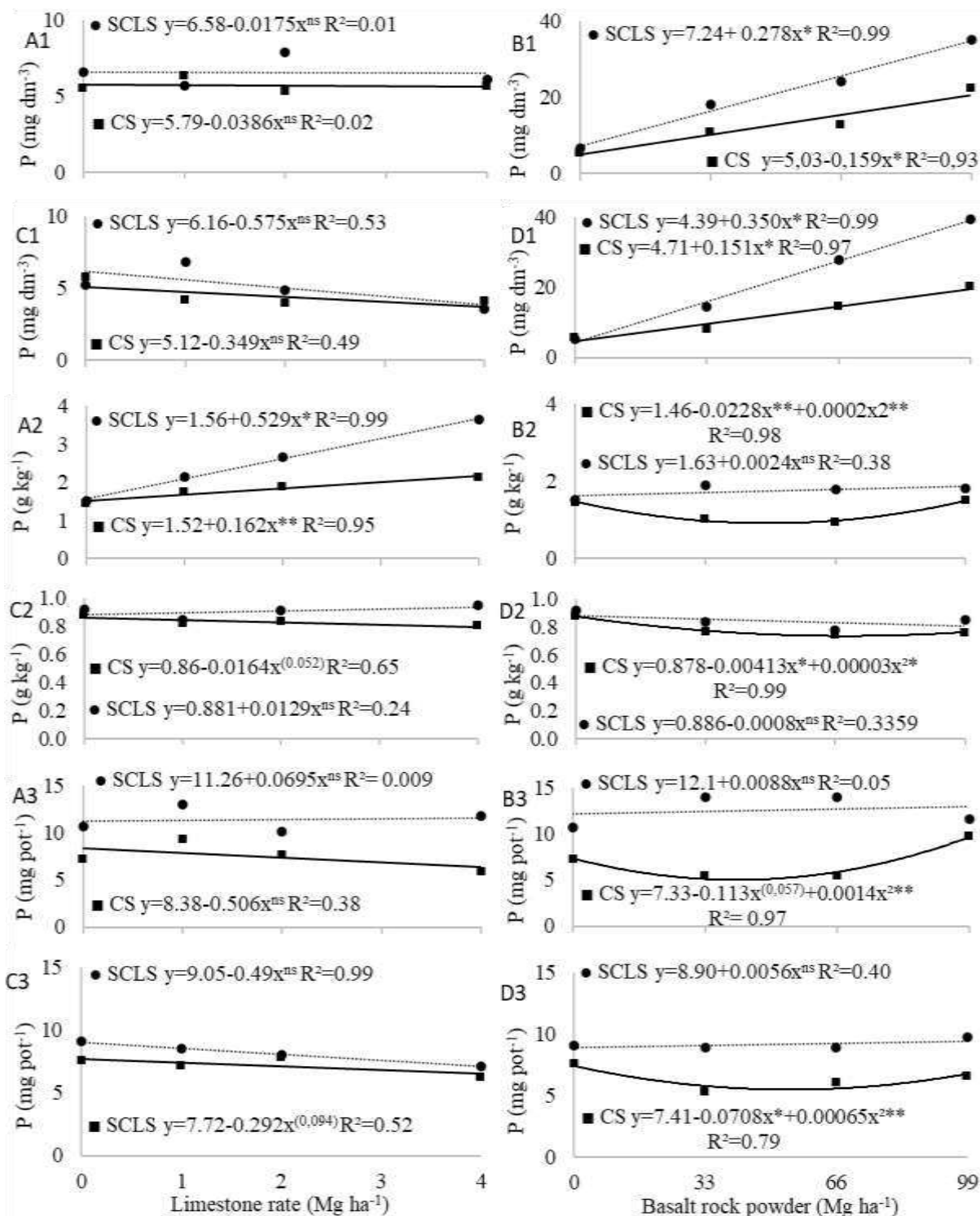


Figure 4. Phosphorus content in soil (1), concentration in shoots (2) and accumulation in shoots (3) as function of doses of respective materials been: A-Limestone soy; B-basalt rock powder soy; C-limestone maize; D basalt rock powder maize; in clayey soil (CS) and sandy clay loam soil (SCLS). ^{ns}: not significant. * and **: statistical significance at 1 and 5% probability, respectively.

significant due to high rates applied to the soil.

The levels of P available in soils, considered initially

low, at the end of the experiment can be considered extremely high with the application of the highest rates of

soil remineralizer. Similar results have been reported by other authors, who showed that there was an increase in soil P content with the application of rock powder both when extracted by Mehlich I (Ribeiro et al., 2010), and by ion exchange resin (Resende et al., 2006).

The low initial levels of P in the soils resulted in plants with a low concentration of this nutrient in the shoots, the appropriate P concentration range for maize and soybean plants should be 2 to 4 g kg⁻¹ and 2.5 to 5 g kg⁻¹, respectively (Silva, 2009). Only with the application of limestone in the soybean crop, at the rates of 2 and 4 Mg ha⁻¹, that the concentration of P in the plants was considered adequate (Figure 4 A2). However, this fact was not due to the increase in the availability of soil P in these treatments, but due to the reduction in plant growth (Figure 1A), which resulted in the effect of concentration of this nutrient in the shoot dry matter of the plants. This fact can be confirmed by the absence of a significant effect on the accumulation of P in the plant shoots (Figure 4 A3).

A similar effect occurred in the clayey soil cultivated with soybeans, in which there was a significant increase in the P concentration of the plants (Figure 4 A2), caused mainly by the reduction of shoot dry matter production (Figure 1 A1), which can be confirmed by the lack of difference in the accumulation of P in the plants (Figure 4 A3). In these cases, the P concentration in the shoots was below the range considered adequate for soybean crop. The application of remineralizer, even increasing the P content of the soils (Figure 4 B1 and D1), did not result in an increase in the concentration of this nutrient in the plants. In sandy clay loam soil, the concentration and accumulation of P by plants were not significantly influenced by the application of remineralizer rates. For the clayey soil there was a reduction in the concentration and accumulation of P by the soybean and maize crops with the application of the lowest applied rates; however, the application of the highest rate of remineralizer again had a positive response in the concentration and accumulation of P in the plants (Figures 4 B2, D2, B3 and D3). The lack of relationship between the availability of P from the soil and the amount of nutrient extracted by the crops may be related to the period of release of P from rock powder material. The slower release of P by the remineralizer may have started making this nutrient available after the period of greatest accumulation of this nutrient in plants. The lower concentrations of P in the plants observed in this study may be due to the fact that the P content of the entire shoot of the plants was analyzed, while the reference concentration values used refer only to the P content of the leaves of the plants.

In the sandy soil there was no significant variation in the levels of exchangeable K, which remained as the values initially classified as low level (Table 3 and Figure 5 A1, B1, C1 and D1) (SBCS/NEPAR, 2017). In the clayey soil, the initial exchangeable K content was considered to be medium (Table 3), and the application

of rock powder or limestone was not sufficient to promote an increase in soil K contents to the upper level of fertility (Figure 5 A1, B1, C1 and D1) (SBCS/NEPAR, 2017). In this soil, the application of limestone resulted in a small significant increase when cultivated with soybean, and a small reduction in K contents when subjected to maize cropping, and in this case, the K content of the soil was reduced from the medium level to the low level with the application of 4 Mg kg⁻¹ (Figure 5 A1 and C1). The application of remineralizer in the clayey soil, initially promoted significant reductions in the availability of K in the soil, the K levels were reduced from the medium level to the low level when cultivated with corn (Figure 5 B1 and D1).

The reduction or increase in K content in the soil may be associated with the absorption and extraction of this nutrient by the crops. However, the concentration of K in the shoot of plants only increased significantly in cases where there was no significant difference in the K content of the soil with the application of limestone (Figures 5 A1, C1, A2 and C2), and the accumulation of K had no significant effect with the rates applied (Figure 5 C3) or there was a reduction in the amount accumulated in the plants (Figure 5 A3).

The low availability of K in the soil promoted plants with low concentration of this nutrient in the shoots, regardless of the application of rock powder or limestone, the K concentrations in the plants were below 17 g kg⁻¹, which would be the minimum content for adequate nutrition of K from soybean and maize plants (Silva, 2009). The only case that the accumulation of K by the crop justifies the reduction of the K content in the soil is with the application of remineralizer in the maize crop for clayey soil, in which there was a quadratic response to the application of rock powder rates to the soil (Figure 5 D1). These results can be justified by the tendency of the increase of K in the maize plants (Figure 5 D2) to have resulted in the significant increase in the amount of K accumulated in the plants (Figure 5 D3).

The lower concentration of K in shoot of the plants is justified by the addition of Ca to the soil with the application of both agricultural materials. Marschner (2012) describe the reduction in the development of plants due to the imbalance of nutrients, mainly Mg and K. Medeiros et al. (2008) reported this antagonistic effect with the linear reduction in the K concentration in the shoot of the plants when there was an increase in the Ca:Mg ratio of the applied soil acidity correctives. Some studies have also not reported a significant increase in the K content of the soil with the application of remineralizer from basaltic rock (Toscani and Campos, 2017). However, other studies have shown an increase in the availability of K in the soil caused by the application of silicate rock powder, in relatively short periods of interaction of the remineralizer with the soil (Ribeiro et al., 2010; Silva et al., 2012).

However, Silva et al. (2012) describe that the K

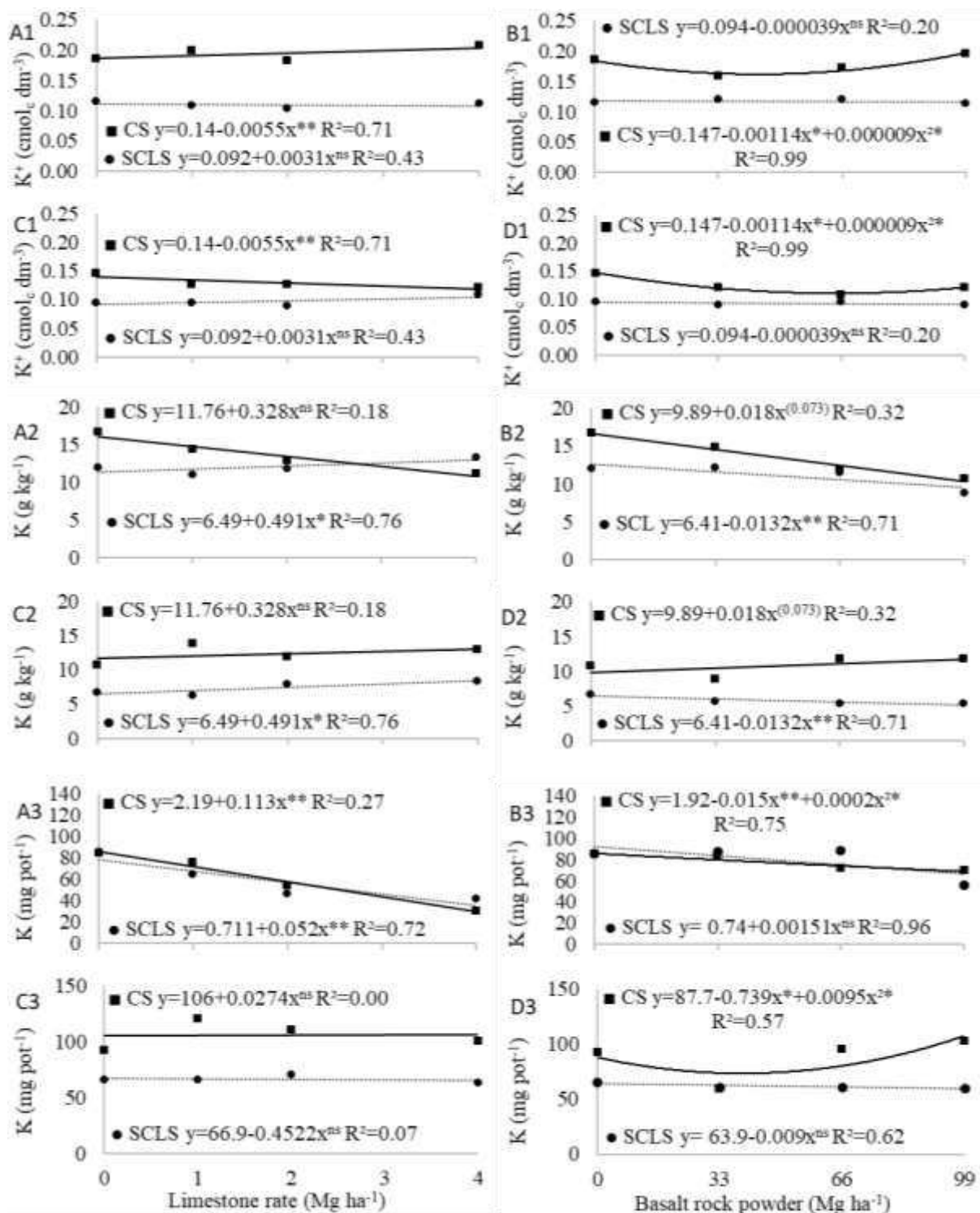


Figure 5. Potassium content in soil (1), concentration in shoots (2) and accumulation in shoots (3) as function of doses of respective materials been: A-Limestone soy; B-basalt rock powder soy; C-limestone maize; D basalt rock powder maize; in clayey soil (CS) and sandy clay loam soil (SCLS). ^{ns}: not significant. * and **: statistical significance at 1 and 5% probability, respectively.

released by feldspars that occur in silicate rocks, may not be readily exchangeable due to its strong bonds with the

SiO₄⁻ and AlO₄⁻ tetrahedrons, which have negative charges available for K bonding in their structure

minerals. Thus, according to Curi et al. (2005), the final release of K to the soil depends on moderately acidic pH conditions for the $\text{KAlSi}_3\text{O}_8 + \text{H}^+ \rightarrow \text{HAlSi}_3\text{O}_8 + \text{K}^+$ reaction to occur; however, as the application of remineralizer promoted a significant increase in soil pH (Figures 1 B2 and D2), there was a significant reduction in the availability of K in the remineralizer (Table 1).

Conclusion

The application of basalt rock powder (Renutri[®]) was efficient to improve some of the chemical characteristics of soil fertility, especially of pH, Ca and P concentration. The application of basalt rock powder had less negative effect on the growth of soybean and maize plants when compared to the application of limestone. The magnesium availability of soils was not altered by the application of basalt powder rates, but the use of this soil remineralizer increased the concentration and accumulation of this nutrient in the soybean and maize plants. The phosphorus availability of soils increased with the application of basalt powder rates, but the use of this soil remineralizer did not result in greater absorption of this nutrient by soybean and maize plants.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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