academicJournals

Vol. 9(4), pp. 455-464, 23 January, 2014
DOI: 10.5897/AJAR2013.7638
ISSN 1991-637X ©2014 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Yield, nutrient uptake and potassium use efficiency in rice fertilized with crushed rocks

**Douglas Ramos Guelfi Silva[1]*, Carlos Roberto Spehar[2], Giuliano Marchi[3], Danilo de Araújo Soares[1], Eduardo Lopes Cancellier[4] and Éder de Souza Martins[5]**

[1]Departamento de Ciência do Solo, Universidade Federal de Lavras, Campus Universitário, Lavras, MG, CEP: 37200-000, Caixa-Postal: 3037, Brasil.
[2]Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, UNB, Campus Darcy Ribeiro, Brasília, DF, CEP: 70910-970, Brasil.
[3]Empresa Brasileira de Agropecuária, Embrapa Cerrados, Planaltina, DF, CEP: 73310-970, Brasil.
[5]Empresa Brasileira de Agropecuária, Embrapa Cerrados, Universidade Federal de Lavras, Campus Universitário, Lavras, MG, CEP: 37200-000, Caixa-Postal: 3037, Brasil.

Accepted 18 December, 2013

**The increasing world population has led into big food and raw material demand, with high pressure on agriculture. In Brazil, potassium fertilizers are mostly imported rising interest on rocks and mining rejects as alternative sources. The objective of this work was to evaluate the effect of crushed rocks over mineral nutrition, yield and efficiency of potash fertilization in rice. The experiment was carried out under greenhouse conditions in pots with 3.7 kg of Oxisol soil samples. The experimental design was completely randomized, in a factorial layout 4 × 6, comprising six crushed rocks used as alternative multinutrient fertilizer (breccia, biotite schist, ultramafic, Chapada byproduct, mining byproduct and phlogopite), and four doses based on potassium (0, 200, 400, 600 kg $K_2O$ $ha^{-1}$), with four replications. The concentration and accumulation of potassium, copper, zinc and nickel in rice shoot dry mass were determined. These data were used to evaluate the efficiency index of K-source rocks on fertilization. It was shown that crushed rocks promote alterations in mineral nutrition, grain yield and potassium use efficiency, remarking their potential to be used as alternative fertilizer in rice cropping systems.**

**Key words**: Alternative nutrient source, micronutrient, fertilization efficiency, plant nutrition, soil conditioner.

## INTRODUCTION

In Brazil, the first studies on materials with low nutrients dissolution kinetics were carried out in the 1970's. Since then, new technological methods have been tested in order to increase nutrient solubility from the variable content in rocks. Among these methods, crushing, thermal processes of melting, acidification and microorganisms inoculation were tested. In addition, high energy demand in processing the materials and the competition with potassium chloride. In recent times, the these rocks have been evaluated for direct use in agriculture. The methods to turn these rocks soluble have shown unfeasible due to their low nutrients release and Brazilian agricultural context has changed, as well as the consumption rates of potassium chloride (Lopes, 2005). The increase in potassium consumption by agriculture, leading to high importing dependence of K fertilizers and

*Corresponding author. E-mail: douglasguelfi@dcs.ufla.br. Tel: 553538291504. Fax: 553538291251.

**Table 1.** Total content of $K_2O$, $Na_2O$, $P_2O_5$, CaO, MgO, Cu, Zn and Ni in crushed rocks[1].

| Rock | $K_2O^{(2)}$ | $Na_2O^{(2)}$ | $P_2O_5^{(2)}$ | $CaO^{(2)}$ | $MgO^{(2)}$ | $Cu^{(3)}$ | $Zn^{(3)}$ | $Ni^{(3)}$ |
|---|---|---|---|---|---|---|---|---|
| | Percent (%) | | | | | Milligram per kilogram (mg $kg^{-1}$) | | |
| Breccia | 2.18 | 0.31 | 0.94 | 9.03 | 7.09 | 59.9 | 128.7 | 73.9 |
| Ultramafic | 3.10 | 1.71 | 1.22 | 13 | 18.50 | 87.4 | 113.1 | 651.9 |
| CBP[(4)] | 3.39 | 1.62 | 0.19 | 3.19 | 3.88 | 437.5 | 123.0 | 2.8 |
| MBP[(5)] | 11.80 | 0.72 | 0.42 | 3.58 | 0.70 | 816.8 | 28184 | 380.3 |
| Biotite Schist | 2.07 | 0.86 | 0.06 | 5.27 | 13.8 | 9.9 | 290.5 | 146.4 |
| Phlogopite | 7.71 | 0.16 | 0.2 | 0.98 | 22.89 | 9.1 | 902.7 | 1425.2 |

[(1)] Rocks crushed at 0.3 mm in this analysis; [(2)] method 4A and 4B of Acmelab (Canada) Laboratory which has as principle the sample fusion in lithium metaborate/tetraborate; [(3)] Method 3052 USEPA (1996); [(4)] Chapada byproduct; [(5)] mining byproduct.

the lack of sources to organic agriculture have risen interest on the use of crushed rocks (Bakken, 2000; Van Straaten, 2006).

Crushed rocks can be considered multinutrient fertilizers carrying silicate minerals containing other macro and micronutrients in variable concentrations. Among these, the main are phosphorus, calcium and magnesium (Wilpert and Lukes, 2003; Ribeiro et al., 2010). In addition to the supply of macronutrients, some crushed rocks promote changes in soil characteristics such as acidity due to variable Relative Neutralization Value (RNV). Crushed rocks must be applied in high amounts to supply macronutrients. Because of their variable composition, they also end up taking micronutrients to soil, which become available along crop seasons (Amaral-Sobrinho, 1992). Consequently, they may be found on parts of cultivated plants in areas where they were applied as alternative fertilizers.

Thus, it is necessary to know the potential of nutrient release, uptake and accumulation in plants. This study was carried out aiming to evaluate the effect of crushed rocks utilized as multinutrient fertilizer~~, selected among many promising materials,~~ in terms of potassium supply and efficiency to rice crop nutrition.

## MATERIALS AND METHODS

A greenhouse experiment was carried out at the Soil Science Department of “Universidade Federal de Lavras”, Lavras, MG, Brazil, from November 2010 to April 2011. Samples of a sandy clay loam Oxisoil were collected in Itutinga, MG, under natural savannah vegetation, 0 to 20 cm from the surface. Soil was air dried, sieved with a 4-mm-mesh, homogenized and placed in 3.7 kg cultivation pots. Concomitantly, soil samples were collected for chemical and physical characterization, as follows: K = 22 mg $dm^{-3}$, S = 5.4 mg $dm^{-3}$, P $_{(Mehlich1)}$ = 0.9 mg $dm^{-3}$, Ca = 0.1 $cmol_c$ $dm^{-3}$, Mg = 0.1 $cmol_c$ $dm^{-3}$, Al = 0.1 $cmol_c$ $dm^{-3}$, H + Al = 1.7 $cmol_c$ $dm^{-3}$, SB = 0.3 $cmol_c$ $dm^{-3}$, t = 0.4 $cmol_c$ $dm^{-3}$, T = 2.0 $cmol_c$ $dm^{-3}$, Fe = 27.4 mg $dm^{-3}$, Zn = 0.5 mg $dm^{-3}$, Cu = 0.7 mg $dm^{-3}$, B = 0.0 mg $dm^{-3}$, Mn = 0.4 mg $dm^{-3}$, sand = 600 g $kg^{-1}$, silt = 170 g $kg^{-1}$ and clay = 230 g $kg^{-1}$. The experimental design was a completely randomized in 4 × 6 factorial scheme with six crushed rocks utilized as alternative multinutrient fertilizer (breccia, biotite schist, ultramafic, mining byproducts, Chapada byproduct and phlogopite), and four doses based on potassium supply (0, 200, 400 and 600 kg $K_2O$ $ha^{-1}$), with four replications (Table 1).

Most rocks were sampled in various mining sites, where they are usually discarded. Understanding their potential for agricultural use is advantageous, decreasing the environmental impact of mining waste to turn them into farming input. A brief description of each rock and respective mining site is presented as follows: Volcanic alkaline breccia, found in Santo Antônio da Barra, Goiás, Brazil was formed in volcanic conduits, being composed by feldspathoids, zeolites and volcanic glass. Alkaline-ultramafic is a mining byproduct from Lages, Santa Catarina, Brazil. The original rock is formed by igneous intrusion, composed by ferromagnesian minerals (olivine, pyroxene and phlogopite), plagioclase and carbonates. It occurs in an old mining place to produce building materials. Biotite Schist, named here as Chapada byproduct from Chapada, Novo Horizonte, Goiás, Brazil was formed by hydrothermal process, altering granitic rocks and generating copper and gold ore. It is composed by biotite, muscovite, having as accessories quartz and carbonates. This material was obtained from flotation and crushing process, not submitted to chemical transformation. Biotite schist, a byproduct of emerald ore from Itabira, Minas Gerais, Brazil, is formed by hydrothermal processes of granite fluid passage over ultramafic rocks that formed emerald. Composed by biotite and quartz, this material is accumulates as waste in mining sites.
Phlogopite schist, called phlogopite (phlogopitite, emerald mining by product from Campo Formoso, Bahia, Brazil). Rock formed from hydrothermal processes of fluids passage of granitic composition over ultramafic rocks that formed emerald; composed by phlogopite and serpentine. This material is an accumulated waste in emerald mining sites. Mining byproduct, manganese ore waste found in Belo Horizonte, MG, Brazil, originated from metallurgical process of manganese extraction. In processing, the potassium is separated from ore and concentrated on wastes. A more detailed characterization of these materials, including X-ray diffractometry, photomicrography, and effects over soil chemical attributes are available at Silva et al. (2012). The total amount of rocks, in t $ha^{-1}$, corresponding to doses of 200, 400 and 600 kg $ha^{-1}$ $K_2O$ equivalent, were respectively: Breccia 13.64, 27.28 and 40.92; ultramafic 9.59, 19.18 and 28.77; Chapada byproduct 8.77, 17.54 and 26.31; mining byproduct 2.52, 5.04 and 7.56; biotite schist 14.36, 28.72 and 43.08; and phlogopite 3.86, 7.72 and 11.58. The rocks were used in their original granulometry (Table 2), as they are likely to be applied in soils, without additional energetic costs on crushing. In addition to potassium, the sources utilized in this study are also micronutrient suppliers such as nickel, copper and zinc which were added to soil in variable amounts, according to treatments of $K_2O$ doses (Table 3).

**Table 2.** Proportion of granulometric fractions of crushed rocks.

| Rock | Proportion of rock particles by size | | | | |
|---|---|---|---|---|---|
| | 1 mm | 0.42 mm | 0.250 mm | 0.125 mm | < 0.125 mm |
| | Percent (%) | | | | |
| Biotite Schist | 9.88 | 30.14 | 25.02 | 23.36 | 11.60 |
| Phlogopite | 11.55 | 27.43 | 35.76 | 13.62 | 11.64 |
| CBP (1) | 21.13 | 23.75 | 13.85 | 22.64 | 18.63 |
| Breccia | 32.85 | 31.69 | 9.28 | 22.01 | 4.17 |
| Ultramafic | 22.14 | 20.84 | 14.29 | 22.29 | 20.44 |
| MBP (2) | 26.58 | 28.34 | 8.60 | 32.42 | 4.06 |

(1) Chapada byproduct; (2) mining byproduct.

**Table 3.** Total amount of rocks and micronutrients (mg pot$^{-1}$) added by treatments.

| Rock | 200 kg de $K_2O$ ha$^{-1}$ | | | | 400 kg de $K_2O$ ha$^{-1}$ | | | | 600 kg de $K_2O$ ha$^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dose | Ni | Cu | Zn | Dose | Ni | Cu | Zn | Dose | Ni | Cu | Zn |
| | g pot$^{-1}$ | mg pot$^{-1}$ | | | g pot$^{-1}$ | mg pot$^{-1}$ | | | g pot$^{-1}$ | mg pot$^{-1}$ | | |
| Breccia | 20.5 | 1.51 | 1.22 | 2.6 | 40.9 | 3.02 | 2.44 | 5.3 | 61.4 | 4.53 | 3.66 | 7.9 |
| Ultramafic | 14.4 | 9.37 | 1.26 | 1.6 | 28.8 | 18.7 | 2.52 | 3.3 | 43.2 | 28.11 | 3.78 | 4.9 |
| CBP(1) | 13.2 | 0.04 | 5.75 | 1.6 | 26.3 | 0.08 | 11.5 | 3.2 | 39.5 | 0.12 | 17.25 | 4.8 |
| MBP(2) | 3.8 | 1.44 | 3.09 | 107 | 7.6 | 2.88 | 6.18 | 213 | 11.3 | 4.32 | 9.27 | 320 |
| Biotite Schist | 24.5 | 3.59 | 0.24 | 7.1 | 43.1 | 7.18 | 0.48 | 14.3 | 64.6 | 10.77 | 0.72 | 21.4 |
| Phlogopite | 5.8 | 8.24 | 0.005 | 5.2 | 11.6 | 16.48 | 0.01 | 10.4 | 17.3 | 24.72 | 0.015 | 15.7 |

(1) Chapada byproduct; (2) mining byproduct.

**Table 4.** Rock pH[1], soluble CaO and MgO, calcium carbonate equivalent (CCE), fineness (F), calcium, magnesium and relative neutralization value (RNV)[2].

| Rock | pH ($H_2O$) | CaO | MgO | CCE | F | RNV | Ca | Mg |
|---|---|---|---|---|---|---|---|---|
| | | Percent (%) | | | | | | |
| Biotite Schist | 8.2 | 0.07 | 1.45 | 1.65 | 68.40 | 1.13 | 0.05 | 0.84 |
| Phlogopite | 8.5 | 0.13 | 0.57 | 0.45 | 82.32 | 0.37 | 0.09 | 0.34 |
| MBP(3) | 10.8 | 2.73 | 0.55 | 11.29 | 87.92 | 9.92 | 1.95 | 0.33 |
| Breccia | 8.3 | 2.23 | 1.34 | 4.78 | 71.20 | 3.41 | 1.59 | 0.80 |
| Ultramafic | 9.4 | 10.84 | 8.95 | 39.47 | 71.24 | 28.12 | 7.74 | 5.39 |
| CBP(4) | 7.6 | 2.07 | 1.62 | 5.99 | 98.32 | 5.89 | 1.48 | 0.97 |

(1)Moreira et al. (2006); 2Brasil (2007); (3) mining byproduct; (4) Chapada byproduct.

The value of water pH and relative neutralization value (RNV) shows that these products provide plants with K and micronutrients, with potential to change soil acidity (Table 4). The pots containing treatments were sown with 10 rice seeds cv. Curinga on 11/19/2010. After emergence, exceeding seedlings were eliminated leaving two plants. The soil moisture was kept constant at filed capacity. Maintenance fertilization was done with 450 mg kg$^{-1}$ P and 300 mg kg$^{-1}$ N, split in three topdressings, and 50 mg kg$^{-1}$ S, without micronutrients addition. The experiment was harvested 120 days after emergence, when plants were cut near to soil surface. From the harvested material, shoot and roots were collected and washed. All materials were placed in paper bags and dried at 75°C in forced ventilation oven until constant weight for dry matter and yield evaluations. Shoot and grain samples were milled separately and 2-g-samples were collected, and digested with nitric-perchloric acid to determine K, Ni, Cu and Zn content ~~in the extract~~according to the method described by Tedesco et al. (1995). Nickel, Cu and Zn were determined by atomic absorption spectroscopy and K by flame spectrophotometry. The analysis of quality were based on National Institute of Standards and Technology (NIST) reference BCR® 414 – Plankton which defines the content limits for Ni (18.8), Cu(29.5) and Zn (111.6) in mg kg$^{-1}$.

The accumulation of K, Ni, Cu and Zn was determined on shoot dry matter and grains. Indexes of potassium fertilization efficiency were calculated for grain and shoot yield: i) agronomic potassium use efficiency (KUE) = (yield with K – yield without K): dose of $K_2O$; and potassium recovery (KR) = K in shoot with K - K in shoot without K; dose of $K_2O$ (Fageria et al., 2010). Analysis of variance utilized software SISVAR (Ferreira, 2011). For comparison between the effect of doses, rocks and their interaction, regression analyses were performed according to the best fit equations.

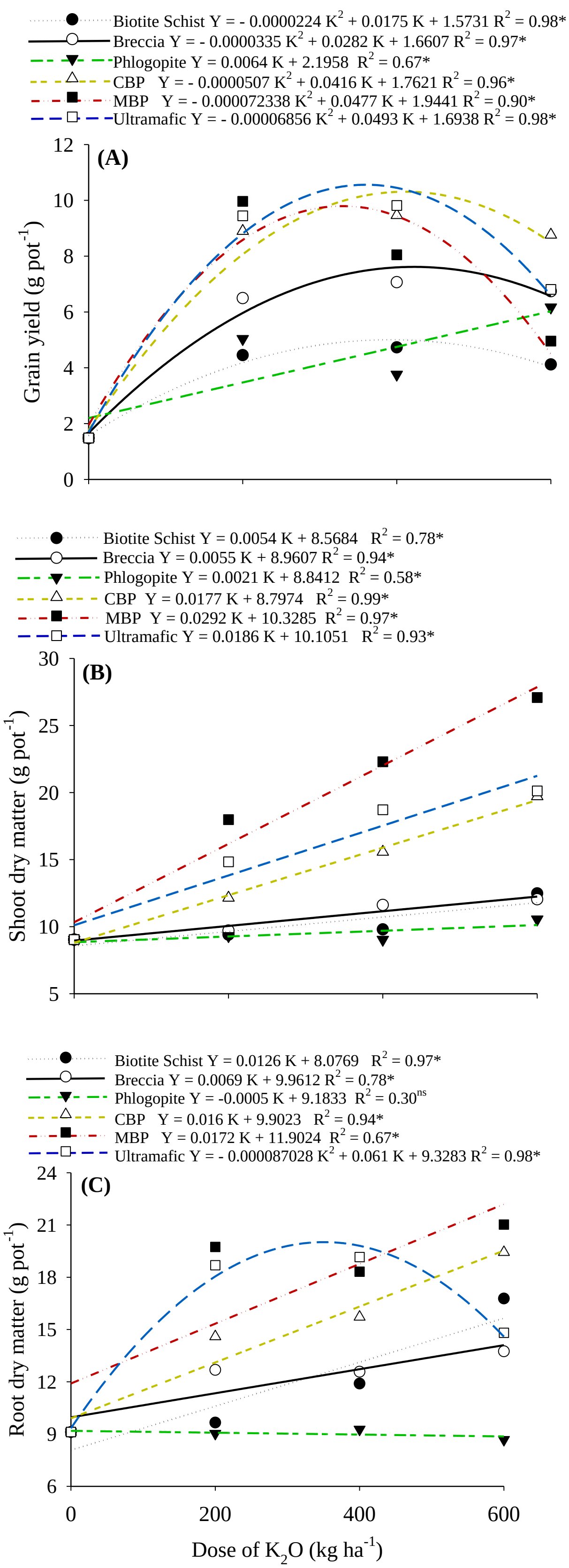


**Figure 1.** Effect of crushed rocks applied as equivalent $K_2O$ dose on rice grain yield (A), shoot (B) and root dry matter (C).

## RESULTS AND DISCUSSION

There were significant differences ($p<0.05$) for rock dose, source and interaction dose × source for grain yield, shoot and root dry matter, K, Ni and Zn content and accumulation in rice shoot grains. Crushed rocks promoted increases on rice shoot and root dry matter as potassium doses increased, although the effect over grain yield was variable (Figure 1A, B and C). The highest rice grain yield was attained with ultramafic in the dose of 360 kg of $K_2O$ $ha^{-1}$ (10.56 g $pot^{-1}$), while the lowest occurred without crushed rocks application. Regardless of $K_2O$ dose, biotite schist and phlogopite presented the lowest rice grain yield. Seed yield, regardless $K_2O$ doses, reached maximum value with Chapada byproduct and ultramafic. The effect of potassium on yield of several rice genotypes indicated values between 10.07 and 16.37 g $plant^{-1}$, with genotypes average 13.62 g $plant^{-1}$ (Fageria et al., 2010). With this reference, on silicate rocks experiment, the ultramafic was superior to phlogopite and alkaline breccia and did not differ from potassium chloride (Barbosa et al., 2006). Rice shoot and root dry matter had a linear response to $K_2O$ supplied by rocks. The exception was for rice root dry matter with ultramafic, where quadratic is attributed to yield decrease at the highest dose. This may be related to sodium excess present in the composition of ultramafic (Table 1). Once Na was released to soil, it may have caused cation unbalance and raised the salinity of solution, reducing root growth with negative effect on grain yield at 600 kg of $K_2O$ $ha^{-1}$ (Table 3).

Adverse effects of salinity and sodium saturation on rice root growth under different management of potassium fertilization was previously described (Carmona et al., 2009). The harmful effect of salinity on nutrient uptake was related to a chemical competition of Ca, Mg and K with Na. The increase in exchangeable sodium associated with ultramafic rock has been related to increasing proportion of Na in CEC, reaching up to 16% at 300 kg $K_2O$ $ha^{-1}$ rock equivalent (Resende et al., 2006; Ribeiro et al., 2010). The decreasing shoot and root dry mass production in the rock equivalent $K_2O$ doses in this experiment were as follows: mining byproduct > ultramafic > Chapada byproduct > biotite schist = breccia = phlogopite. For every 100 kg of $K_2O$ $ha^{-1}$, there was a response of 2.92 g $pot^{-1}$, on shoot dry mass production; while for phlogopite, this value was 0.21 g $pot^{-1}$, highlighting the difference among these alternative fertilizers to release nutrients and improve rice nutrition with positive effect over biomass production. The K content in rice shoot varied between 5.09 to 12.21 g $kg^{-1}$ (Figure 2A), indicating a cycling effect when crop residues are returned to soil after harvest. It may be utilized by succeeding crops, on conventional and organic system for which available sources of potassium are scarce.

In general, K content in shoot increased proportionally to crushed rock dose. The highest grain yield, shoot and root dry matter was associated to increasing K from mining byproduct and ultramafic. The lowest content occurred when rice was fertilized with phlogopite. The nickel content in plant parts had differentiated effect with crushed rocks application (Figure 2B). In shoot it was high (Table 3), when ultramafic, phlogopite and biotite schist were used as K source. The ultramafic rocks present high total contents of Ni in its composition (Brady and Weil, 2002). The mineral dissolution however is variable and can influence Ni availability and all other nutrients present in the rock. Thus, it is relevant to study extractors that allow quantify available Ni, since the total content may not be released during the crop cycle. In mature leaf tissues of various species, Ni sufficiency ranges from 0.1 to 5 mg $kg^{-1}$, with toxicity varying between 10 to 100 mg $kg^{-1}$ (Kabata-Pendias and Pendias, 2001). Therefore, in this study, the Ni in rice shoot was sufficient for plant nutrition. Another micronutrient released by these alternative fertilizers is zinc, which contents in rice shoots were in a range from 84.33 to 7.29 mg $kg^{-1}$ (Figure 2C), in the dose of 275 kg $K_2O$ $ha^{-1}$ from mining byproduct and 308 kg $K_2O$ $ha^{-1}$ applied by ultramafic, respectively. Zn content in rice dry matter has been defined as adequate when reaches 67 mg $kg^{-1}$, while at 673 mg $kg^{-1}$ it becomes toxic. Thus, among the selected materials, mining byproduct emerges as an alternative source of this micronutrient for rice cropping systems, besides the supply of K, Ni and Cu. Moreover, it must be pointed out that the need of Zn application in most Brazilian soils, due to low availability of this nutrient to crops (Oliveira et al., 2005). This finding strengthens the possibility of utilizing alternative sources that take also micronutrients, as Zn and in smaller amounts of Cu and Ni.

Nutrient content in shoot is a reference to assess plant nutrition although it may be inversely related to yield due to the nutrient dilution effect in plant. Two plants with the same nutrient concentration in shoot may have different yield, related to nutrient absorption and accumulation in diverse parts of the plant. To understand these effects, nutrient accumulation must be calculated to associate it to dry mass production and grain yield. In this work, K accumulation was higher when rice was fertilized with mining byproduct and ultramafic. The K accumulation increased with increasing doses of this macronutrient applied as crushed rocks (Figure 3A). Every 100 kg $K_2O$ $ha^{-1}$ of mining byproduct and ultramafic contributed to K

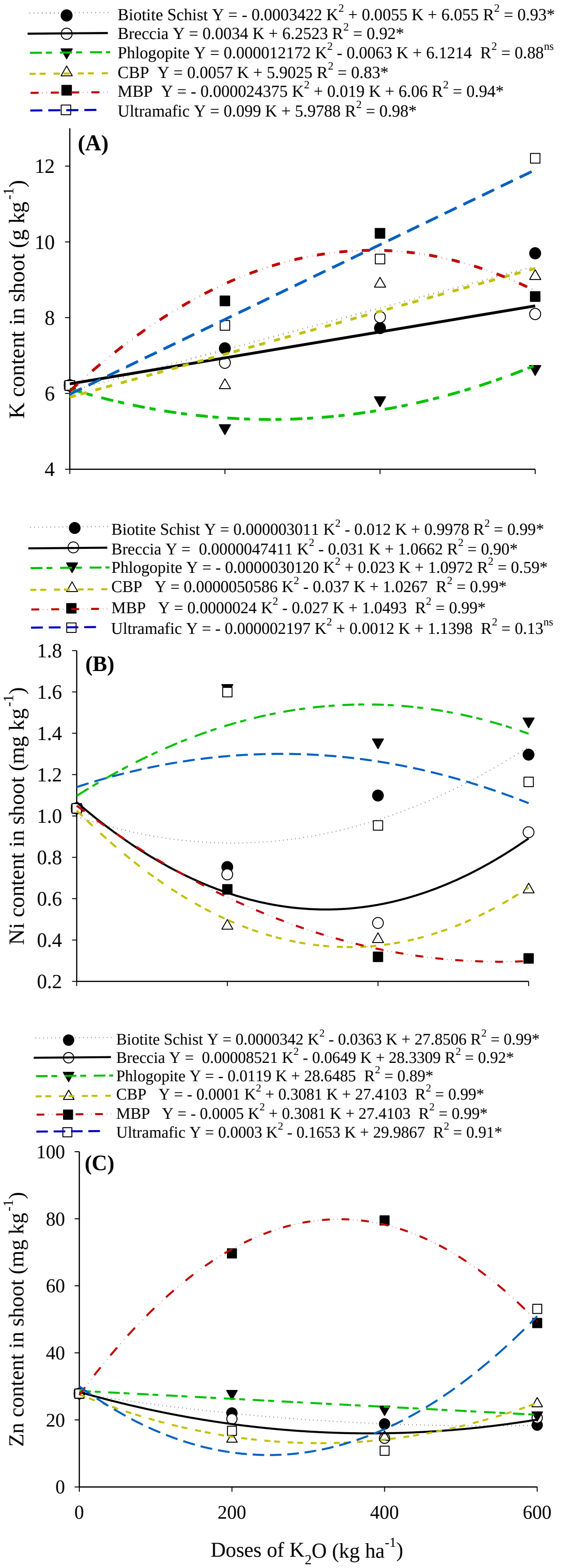


**Figure 2.** Effect of crushed rocks applied as equivalent $K_2O$ dose on potassium (A), nickel (B) and zinc (C) content in rice shoot.

accumulation in shoot of 35.45 and 38.01 mg pot-1, respectively. The rocks promoting high K accumulation in shoot in decreasing order were: mining byproduct = ultramafic > Chapada byproduct > biotite schist = breccia



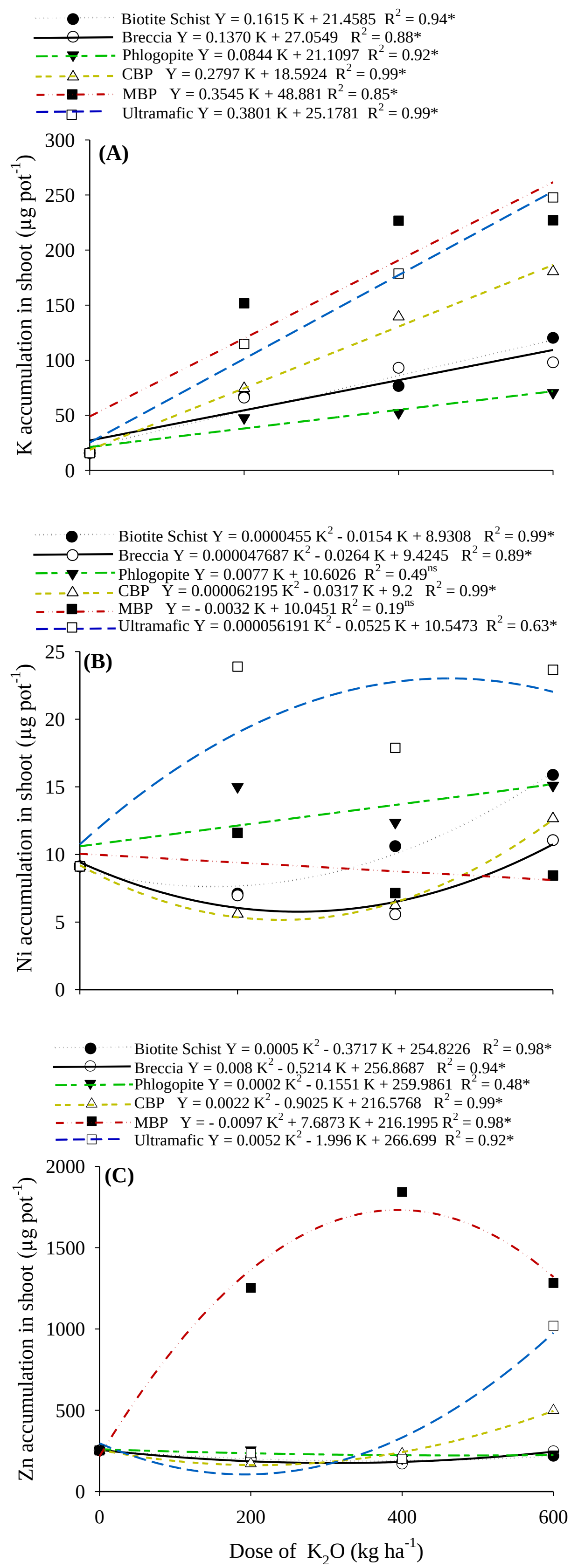


**Figure 3.** Effect of crushed rocks applied as equivalent $K_2O$ dose on potassium (A), nickel (B), cooper (C) and zinc (D) accumulation in shoot.

> phlogopite. These differences in K content and accumulation in shoot shows the potential of K release of alternative fertilizers. Ultramafic, phlogopite and biotite schist differed from one another in Ni accumulation in rice shoot (Figure 3B). In mining byproduct, the element that accumulated most in shoots was Zn, differing from other rocks (Figure 3C). These differences among crushed rocks can be explained by the high total content of Zn in mining byproduct (Table 3), which is more available than the other rocks. Its noteworthy mentioning that crushed rocks were applied as potassium source, in large amounts, taking along variable levels of micronutrients, reflecting in the present results.

Crushed rocks affected significantly ($p<0.05$) Cu content and accumulation in rice shoot proportionally to the doses (Figure 4A and B). Moreover, the types of crushed rocks affected significantly only Cu accumulation in shoot (Figure 4C). Cooper content in rice shoot was higher in absence of crushed rocks. This could be ascribed to nutrient dilution, or high concentration in shoot of control (no crushed rock application) due to reduced biomass production. It can be seen that Cu accumulation, as related to dry mass production, increased with $K_2O$ crushed rock equivalent (Figure 4B). For every 100 kg of $K_2O$ $ha^{-1}$ applied there was response in Cu accumulation in shoot of 3.66 mg $pot^{-1}$. Regardless of $K_2O$ dose, for Cu accumulation, the rocks were sorted into two groups (Figure 4C). In the first group, with higher level in shoot were: Chapada byproduct, ultramafic and mining byproduct and, while in the second with lower Cu, accumulation was: biotite schist, phlogopite and breccia. Plant response was a function of rock quantity based upon $K_2O$ content (Table 3). Nutrient accumulation in grains depends directly on its translocation in plant. Translocation can be defined as the ionic movement from the absorption site in root and transfer to other parts (Malavolta et al., 1997). In this sense, some nutrients may be translocated to edible parts, such as grains that if in excess, causes risk to human health (Martins et al., 2003; Rangel et al., 2006). Ni, Cu and Zn are in the group of elements ~~which~~ that move freely in plant and enter the food chain.

The content and accumulation of K, Ni, Cu and Zn in rice grains increased with increasing $K_2O$ doses applied as crushed rocks (Figures 5 and 6). In most cases, the content and accumulation of a chemical element in different plant parts is function of its availability and the content in plants increases with its concentration in soil (Gussarsson et al., 1995). The rocks which promoted highest K content and accumulation in grains were mining byproduct, ultramafic and Chapada byproduct (Figures 4A and 5A). It has been reported that most of absorbed K accumulates in shoot and a little proportion is transferred to rice grains (Fageria et al., 1982). From the absorbed K, 76 to 86% is found in shoot and 11 to 21% in grains, depending on the cultivar (Fageria, 1991). Potassium content under 4 g $kg^{-1}$ is considered deficient (Reuter and Robinson, 1997). The different doses of rocks promoted

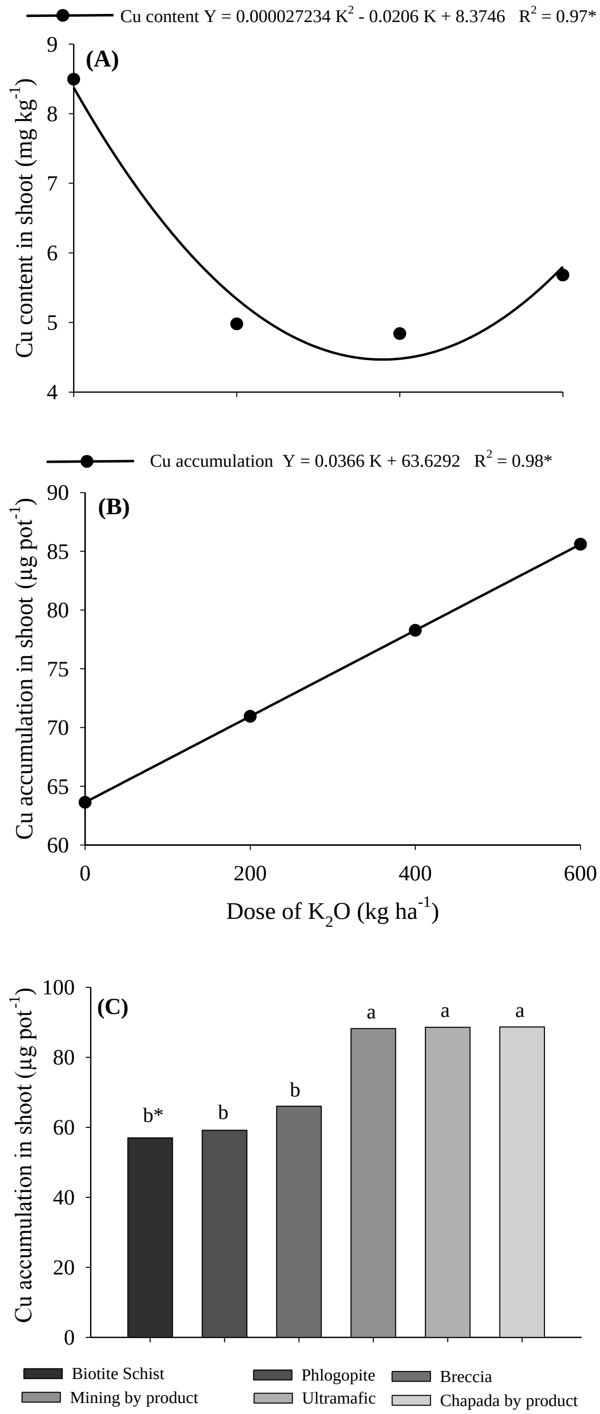


**Figure 4.** Effect of crushed rocks applied as equivalent $K_2O$ dose on copper content (A) and accumulation (B), (C) in rice shoot. * Numbers followed by same letter are not statistically different by Scott-Knott test ($p<0.05$).

variable effect also on Ni content and accumulation in rice grains. The decreasing order of Ni accumulation was: breccia > ultramafic > phlogopite = Chapada byproduct > biotite schist > mining byproduct. The average Cu content and accumulation in rice gains, regardless of dose, was high when Chapada byproduct was applied (Figures 4C and 5C). This is directly related to the presence of Cu in the rock (Table 3) with subsequent release to soil, explaining uptake and translocation of this micronutrient.

These high Cu contents, however, never reached the maximum tolerable level of 30 mg $kg^{-1}$ (Abia, 1985). For Zn, the maximum content allowed in grains is 50 mg $kg^{-1}$ and only with mining byproduct this value was reached. When rice was grown in contaminated areas with Cu and Zn, it was observed as plant restricted Cu transport from root to seed but not with Zn (Silva et al., 2007). Crop nutrient use efficiency is important in assessing plants in terms of nutrient use and yield response~~ (Silva et al., 2010)~~. Agronomic efficiency and potassium recovery decreased with increasing doses applied as crushed rocks (Figure 7). The decreasing order of rocks for agronomic efficiency was as follows: Ultramafic > Chapada byproduct = mining byproduct > Breccia > phlogopite > Biotite Schist. The first three were considerably higher than the others and promoted considerable plant response on grain yield per kg of $K_2O$ applied. Potassium use efficiency of rice genotypes indicated by agronomic efficiency varies between 4.11 to 11.33 mg $mg^{-1}$ with an average of 8.9 mg $mg^{-1}$ (Fageria et al., 2010). The crushed rocks generated values of agronomic efficiency varying with doses of $K_2O$ and with types of crushed rock, in a range from 2.4 to 22.9 mg $mg^{-1}$.This remarks the difference among rocks in their capacity to release K from their structures. Consequently, the nutrient release to plants showed different yield



response to crushed rock (Table 3) and acidity neutralizer (Table 4). The plant capacity to absorb nutrients from soil solution is closely related to potassium agronomic efficiency. Potassium transport in soil is predominantly through diffusion while mass flow responds for a small proportion (Rosolem et al., 2003). Therefore, the root volume with increased superficial area provides the contact of K from soil solution explaining the results obtained here.

The response in rice, yield measured by potassium agronomic efficiency was directly related to root growth (Figure 1C). The potassium recovery was higher by mining byproduct and ultramafic, reinforcing the feasibility of these minerals as an important source of K. At high doses, mining byproduct did not differ from Chapada byproduct and ultramafic. The latter combine nutrients source with acidity neutralizing power, useful in acid, not limed, areas, common in large part of Brazilian savannah. In absence of K application and with potassium chloride application, recovery rates range from 4.9 to 38.6% respectively for different rice genotypes (Fageria et al., 2010). It becomes evident that crushed rocks may be utilized as nutrients sources due to their content of potassium, nickel, copper and zinc release, as measured by accumulation of these nutrients in rice shoot and grain, with positive effect on yield. Furthermore, these crushed rocks have differentiated acidity neutralization power, impacting positively soil amendments. Rice potassium agronomic efficiency and recovery decreased

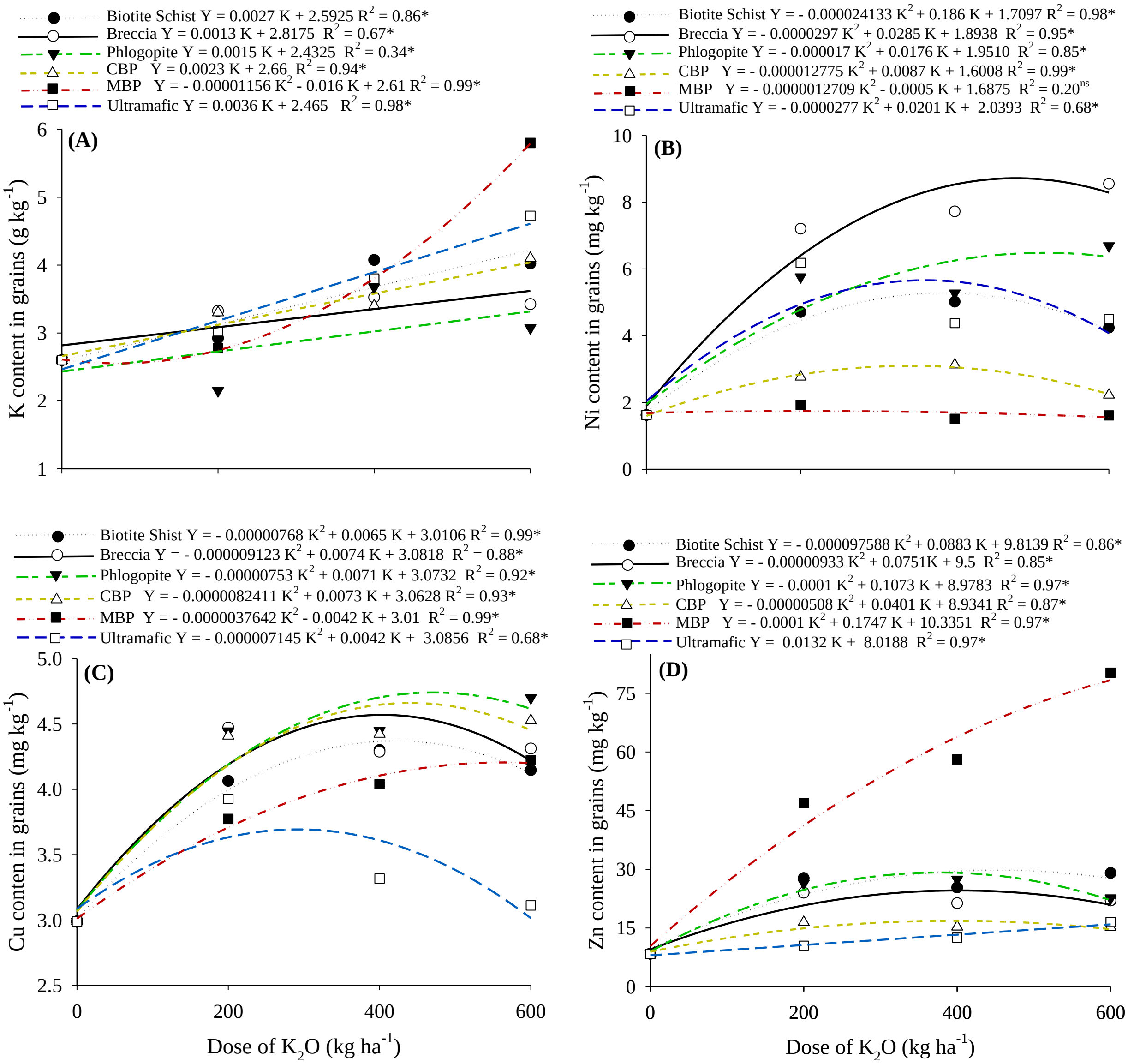


**Figure 5.** Effect of crushed rocks applied as equivalent $K_2O$ dose on potassium (A), nickel (B), cooper (C) and zinc (D) content in rice grains.

with increasing application of crushed rocks, similar to soluble nutrient sources. Mining byproduct is not only a potassium source but also an important source of Zn with more than 2.8% of this nutrient in its composition.

Ultramafic rock and mining byproduct can be used in upland rice, as measured by yield and potassium use efficiency.

## Conclusions

The mining byproducts and potassium-containing-rocks are potential suppliers of micronutrients in addition to reducing acidity in savannah soils. Potassium is highly recovered from mining byproduct and ultramafic. The high doses required to supply K for some material may limit their use in scale farming. Most of them are sources of micronutrients as Zn, Cu, Ni at levels that do not reach toxicity. The slow nutrient release by these materials enables their use in organic farming and in crop-livestock integrated cropping systems. Field experiments are suggested to clarify potential and limitations in the use of these materials as alternative fertilizers.

## ACKNOWLEGMENTS

The authors thank National Counsel of Technological and Scientific Development (CNPq) and Minas Gerais Research Support Foundation (FAPEMIG) for financially

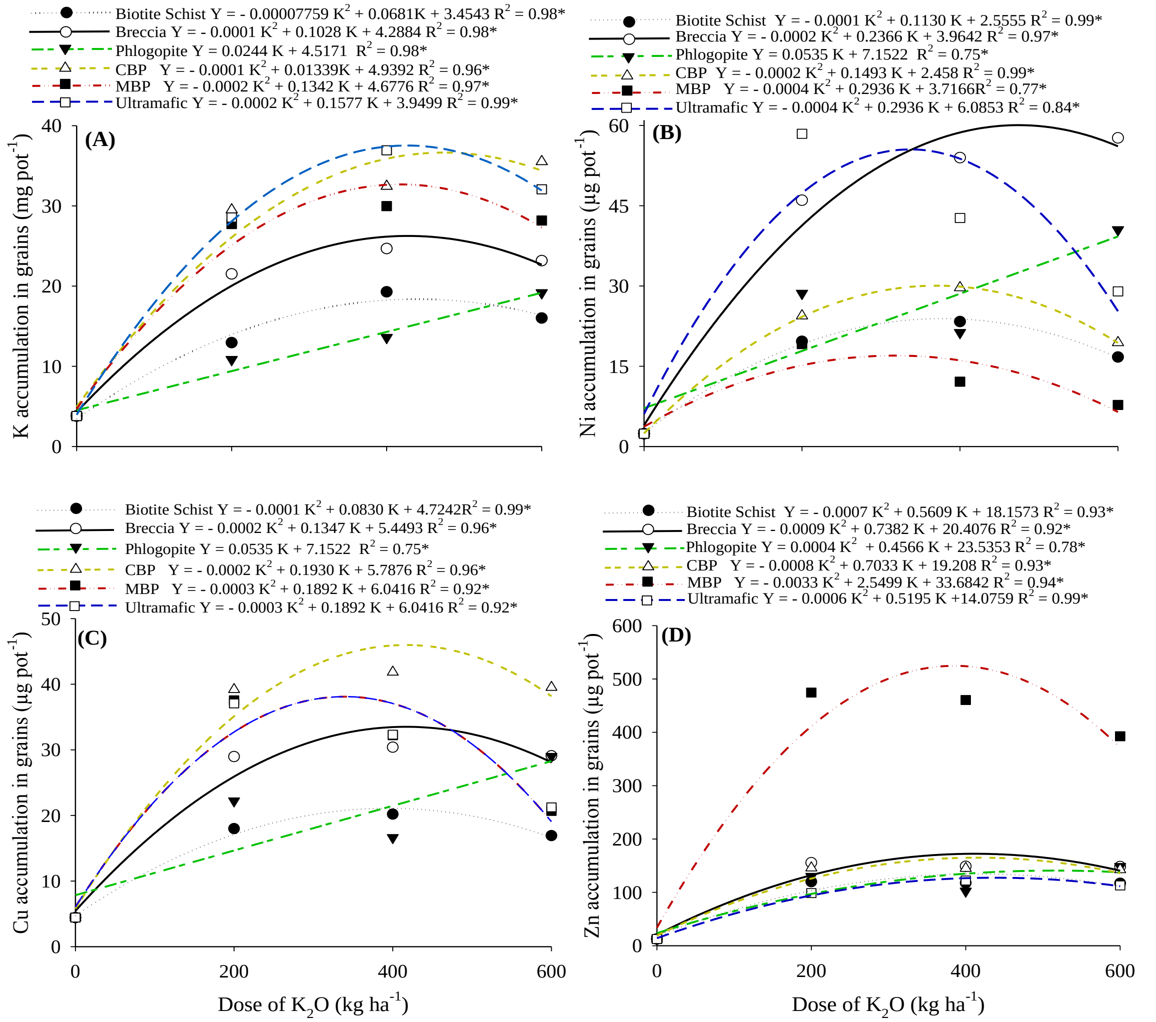


**Figure 6.** Effect of crushed rocks applied as equivalent $K_2O$ dose on potassium (A), nickel (B), cooper (C) and zinc (D) accumulation in rice grains.

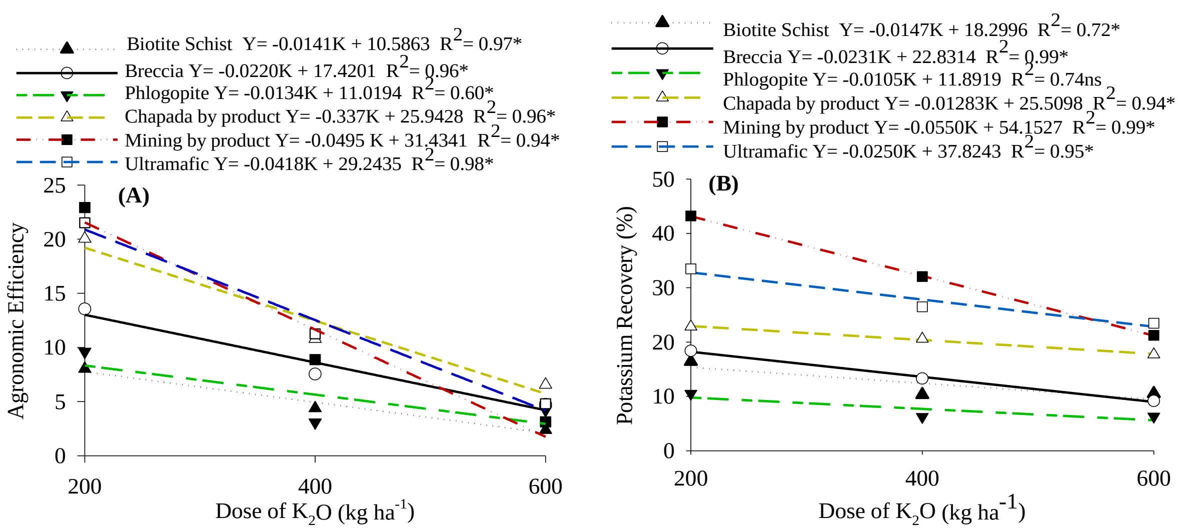


**Figure 7.** Agronomic efficiency (A) and potassium recovery (B) by rice fertilized with alternative sources of nutrients.



supporting this research.

**REFERENCES**

ABIA (São Paulo, SP) (1985). Compêndio da legislação dos alimentos. São Paulo, unpaged.
Amaral-Sobrinho NMB, Costa LM, Oliveira C, Velloso ACX (1992). Metais pesados em alguns fertilizantes e corretivos. Rev. Bras. Ciênc. Solo 16:271-276.
Bakken AK, Gautneb H, Sveistrup T, Myhr K (2000). Crushed rocks and mine tailings applied as K fertilizers on grassland. Nutr. Cycl. Agroecosys. 56:53-57.
Barbosa Filho MPB, Fageria NK, Santos DF, Couto PA (2006). Aplicação de rochas silicáticas como fontes alternativas de potássio para a cultura do arroz de terras altas. Esp. Geog. 9:63-84.
Brady NC, Weil RR (2002). The nature and properties of soils. 13th ed. Pearson Education Inc., Upper Saddle River, NJ, U.S.A. P. 960.
Brasil (2007). Ministério da Agricultura. Manual de métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos. Brasília, Brasil. P. 141.
Carmona FC, Anghinoni I, Meurer EJ, Holzschuh MJ, Fraga TI (2009). Estabelecimento do arroz irrigado e absorção de cátions em função do manejo da adubação potássica e do nível de salinidade no solo. Rev. Bras. Ciênc. Solo 33:371-383.
Fageria NK, Barbosa Filho MP, Carvalho JRP (1982). Response of upland rice to phosphorus fertilization on an Oxisol of central Brazil. Agron. J. 74:51-56.
Fageria NK (1991). Response of rice cultivars to phosphorus fertilization on a dark red latosol of central Brazil. Rev. Bras. Ciênc. Solo 15:63–67.
Fageria NK, Santos AB, Moraes MF (2010). Yield, Potassium Uptake, and Use Efficiency in Upland Rice Genotypes. Commun. Soil Sci. Plan. 41:2676-2684.
Ferreira DF (2011). Sisvar: um sistema computacional de análise estatística. Ciência e Agrotecnol. 35:1039-1042.
Gussarsson M, Adalsteinsson PJ, Jensén P, Asp H (1995). Cadmium and copper interactions on the accumulation and distribution of Cd and Cu in birch (*Betula pendula* Roth) seedlings. Plant Soil 171:185-187.
Kabata-Pendias A, Pendias H (2001). Trace elements in soils and plants. 3. ed. Boca Raton: CRC Press, P. 413.
Lopes AS (2005). Reservas de minerais de potássio e produção de fertilizantes potássicos no Brasil. In: Yamada T, Roberts TL (eds) Potássio na agricultura brasileira. Piracicaba: Instituto da Potassa e Fosfato, pp. 21-32.
Malavolta E, Vitti GC, Oliveira SA (1997). Avaliação do estado nutricional das plantas: Princípios e aplicações. 2. ed. Piracicaba: Potafos, P. 319.
Martins ALC, Bataglia OC, Camargo OA, Cantarella H (2003). Produção de grãos e absorção de Cu, Fe, Mn e Zn pelo milho em solo adubado com lodo de esgoto, com e sem calcário. Rev. Bras. Ciênc. Solo 27:563-574.
Moreira A, Castro C, Oliveira FA, Salinet LH, Sfredo GJ (2006). Efeito residual de rochas brasileiras como fertilizantes e corretivos da acidez do solo. Esp. Geog. 9:163-177.
Oliveira C, Amaral-Sobrinho NMB, Marques VS, Mazur N (2005). Efeitos da aplicação do lodo de esgoto enriquecido com cádmio e zinco na cultura do arroz. Rev. Bras. Ciênc. Solo 29:109-116.
Rangel OJP, Silva CA, Bettiol W, Dynia JF (2006). Efeitos de aplicações de lodo de esgoto sobre os teores de metais pesados em folhas e grãos de milho. Rev. Bras. Ciênc. Solo 30:583-594.
Resende AV, Martins ES, Sena MC, Machado CTT, Kinpara DI, Oliveira Filho EC (2006). Suprimento de potássio e pesquisa de uso de rochas “in natura” na agricultura brasileira. Esp. Geog. 9:17-40.
Reuter DJ, Robinson JB (1997). Plant analysis in interpretation manual. 2 ed., Collingwood: CSIRO Publishing, P. 570.
Ribeiro LS, Santos AR, Souza LFS, Souza JL (2010). Rochas silicáticas portadoras de potássio como fontes do nutriente para as plantas. Rev. Bras. Ciênc. Solo 34:891-897.
Rosolem CA, Mateus GP, Godoy LJG, Feltran JC, Brancalião SR (2003). Morfologia radicular e suprimento de potássio às raízes de milheto de acordo com a disponibilidade de água e potássio. Rev. Bras. Ciênc. Solo 27:875-884.
~~Silva DRG, Costa KAP, Faquin V, Oliveira IP, Souza MRF, Souza MAS (2010). Eficiência nutricional e aproveitamento do nitrogênio pelo capim-marandu de pastagem em estágio moderado de degradação sob doses e fontes de nitrogênio. Ciênc. Agrotecnol. 35: 242-249.~~Silva DRG, Marchi G, Spehar CR, Guilherme LRG, Rein TA, Soares DA, Ávila FW (2012). Characterization and nutrient release from silicate rocks and influence on chemical changes in soil. Revista Brasileira de Ciência do Solo, 36:951-962.
Silva MLS, Vitti GC, Trevizam AR (2007). Concentração de metais pesados em grãos de plantas cultivadas em solo com diferentes níveis de contaminação. Pesq. Agropec. Bras. 42:527-535.
Tedesco MJ, Gianello C, Bissani CA, Bohnem H, Volkweiss SJ (1995). Análise de solo, plantas e outros materiais. 2. ed. Porto Alegre: UFRGS, P. 174.
USEPA (Usepa-United States Environmental Protection Agency) (1996). Method 3052. Available at: <http://www.epa.gov/SW-846/pdfs/3050b.pdf> Access: Sept. 21 of 2011.
Van Straaten PV (2006). Farming with rocks and minerals: Challenges and opportunities. An. Acad. Bras. Cienc. 78:731-747.
Wilpert K, Lukes M (2003). Ecochemical effects of phonolite rock powder, dolomite and potassium sulfate in a spruce stand on an acidified glacial loam. Nutr. Cycl. Agroecosys. 65:115-127.