



Pesquisa Agropecuária Tropical

ISSN: 1517-6398

ISSN: 1983-4063

Escola de Agronomia/UFG

Cruz, Carlos Augusto Campos da; Orioli, Valdeci; Bernardes, João Victor Silva;
Sargentim, Mateus Martini; Silva, Gabriel Augusto; Kochenborger, Ana Clara Dutra

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Pesquisa Agropecuária Tropical, vol. 51, e67857, 2021

Escola de Agronomia/UFG

DOI: <https://doi.org/10.1590/1983-40632021v5167857>

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Research Article

Efficiency of phonolite as a potassium source for Paiaguás palisadegrass¹

Carlos Augusto Campos da Cruz², Valdeci Orioli Júnior², João Victor Silva Bernardes², Mateus Martini Sargentim², Gabriel Augusto Silva², Ana Clara Dutra Kochenborger²

ABSTRACT

Potassium chloride (KCl) is the most widely used potassium source to meet crops requirements. However, Brazil's dependence on imports to meet the national demand demonstrates the need to assess the efficiency of other sources of this nutrient. The present study aimed to assess the agronomic efficiency of phonolite *in natura* and its mixture with a water-soluble source (KCl), for Paiaguás palisadegrass. The experiment was conducted in a greenhouse, with a sandy clay loam typic Hapludox. A completely randomized block design was used, in a 3 x 5 factorial scheme, consisting of three K sources (KCl, phonolite and a 30 % of KCl + 70 % of phonolite blend) and five doses of the nutrient (0, 50, 100, 150 and 200 mg kg⁻¹), with four replications. The phonolite doses promoted a linear increase in the dry weight production, albeit inferior to KCl for all the cuttings, whereas the KCl (30 %) and phonolite (70 %) blend showed a better fertilization efficiency than phonolite alone, which exhibited an intermediate effect. The agronomic efficiency was 29 % for the phonolite alone and 63 % for the blend, and the critical K levels in the soil and shoots were, respectively, 1.4 mmol_c dm⁻³ and 8.7 g kg⁻¹.

KEYWORDS: *Urochloa brizantha* (Hochst. ex A. Rich.) R. D. Webster, potassium fertilizer, potassium silicate.

RESUMO

Eficiência de fonolito como fonte de potássio para capim Paiaguás

Dentre as alternativas para suprir as demandas de K das culturas, o cloreto de potássio (KCl) é a fonte mais utilizada. Porém, a alta dependência de sua importação para suprir a demanda nacional leva à necessidade de se avaliar a eficiência de outras fontes desse nutriente. Objetivou-se avaliar a eficiência agrônômica de fonolito *in natura* e de sua mistura com uma fonte solúvel em água (KCl), para capim Paiaguás. O experimento foi conduzido em casa-de-vegetação, com Latossolo Vermelho distrófico de textura média, adotando-se delineamento inteiramente casualizado, em esquema fatorial 3 x 5, sendo três fontes (KCl, fonolito e mistura de 30 % de KCl + 70 % de fonolito) e cinco doses (0; 50; 100; 150; e 200 mg kg⁻¹) de K, com quatro repetições. As doses de fonolito promoveram aumento linear na produção de massa seca, mas foi inferior ao KCl em todos os cortes, enquanto a mistura de KCl (30 %) e fonolito (70 %) aumentou a eficiência fertilizante, em relação ao fonolito aplicado exclusivamente, mostrando-se intermediária. A eficiência agrônômica foi de 29 e 63 % para o fonolito e a mistura, respectivamente, e os níveis críticos de K no solo e na parte aérea foram, respectivamente, 1,4 mmol_c dm⁻³ e 8,7 g kg⁻¹.

PALAVRAS-CHAVE: *Urochloa brizantha* (Hochst. ex A. Rich.) R. D. Webster, fertilizante potássico, silicato potássico.

INTRODUCTION

Grasses from the *Urochloa* genus, such as *Urochloa brizantha* cv. Paiaguás, have become increasingly important in the Brazilian livestock sector as a food source for ruminants, due to their low nutrient requirements (Moreira et al. 2009, Costa et al. 2010, Germano et al. 2018).

The limited natural fertility of most Brazilian soils (Briguenti et al. 2011) is directly related to the causes of low yield. The Brazilian Savanna contains

highly weathered soils with a low cation exchange capacity, and most consist predominantly of 1:1 clays, which are naturally K deficient (Lopes 2005).

Adequate amounts and proportions of nutrients are important for grasses, particularly K, an essential plant nutrient (Benett et al. 2008, Marschner 2012). In general, well-nourished *U. brizantha* shoots and green leaves exhibit high K concentrations of 12-30 g kg⁻¹, during their active growth (Weber et al. 1996). Orioli Júnior & Coutinho (2009), Megda & Monteiro (2010) and Morais et al. (2016) observed,

¹ Received: Feb. 24, 2021. Accepted: Apr. 26, 2021. Published: July 29, 2021. DOI: 10.1590/1983-40632021v5167857.

² Instituto Federal de Educação, Ciência e Tecnologia do Triângulo Mineiro, Uberaba, MG, Brasil.

E-mail/ORCID: carlos.accruz@outlook.com/0000-0001-7802-7471; valdeci@iftm.edu.br/0000-0001-6202-7100; joaovictorsilvabernardes@gmail.com/0000-0001-8522-3358; mateus.sargentim@gmail.com/0000-0002-4782-554X; biel.augusto16@gmail.com/0000-0002-1345-6854; acdkochenborger@gmail.com/0000-0002-3656-1251.

respectively, dry weight increases of 246, 270 and 86 % in *U. brizantha*, as a function of potassium fertilization.

Potassium chloride (KCl) is the potassium source most widely used to meet crop requirements in the Brazilian agricultural sector. Brazil imports approximately 90 % of all the K it consumes (Ibram 2011). The availability of K sources for agriculture has become a major concern in several countries, due to the small amount of good quality potassium suitable for use as fertilizer (Basak & Sarkar 2017).

In Brazil, rocks such as verdigris, nepheline syenites and granites are being studied as potential potassium sources (Santos et al. 2015). Heat treated potassium-bearing rock and KCl were found to have a similar agronomic efficiency (Orioli Júnior & Coutinho 2009). However, ground nepheline syenite from the Poços de Caldas region of the Minas Gerais state showed to be an inefficient K source due to the difficulty involved in releasing the nutrient (Siqueira et al. 1985).

The speed and intensity of nutrient release depend on several factors, with mineralogy considered the most important one, in terms of selecting rocks for use in agriculture (Silva et al. 2012). According to Manning (2011), rocks containing the mineral nepheline release K more easily than those comprised solely of potassium feldspars. Although phonolite contains this component and is the volcanic equivalent of nepheline syenite (Fernandes et al. 2010), research on the agronomic efficiency of this rock is scarce, particularly when applied in the pure form.

It has been suggested that materials insoluble in water that release K slowly, such as phonolite (Martins et al. 2015), could be mixed with potassium chloride, a highly water-soluble potassium source, to meet initial crop needs for this nutrient (Orioli Júnior & Coutinho 2009). As such, the hypothesis of this study is that ground phonolite may be used as a K source for forage grasses. Thus, it aimed to assess the agronomic efficiency of pure phonolite and a mixture of this fertilizer with a water-soluble source (KCl) in *Paiaguás* palisadegrass, as well as to determine the critical K level in the soil and shoots.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse, at the Instituto Federal de Educação,

Ciência e Tecnologia do Triângulo Mineiro, in Uberaba, Minas Gerais state, Brazil (19°39'38.34"S, 47°57'56.84"W and altitude of 799 m), from January to May 2019. The climate in the region is characterized as Aw (warm tropical), according to the Köppen classification, with cold dry winters and warm wet summers (Beck et al. 2018).

Pots containing 5.0 kg of soil classified as medium-textured Latossolo Vermelho distrófico (Santos et al. 2018), or sandy clay loam typic Hapludox (USDA 2014), were used. The soil was collected at a depth of 0.40-0.60 m and exhibited the following chemical attributes: pH (CaCl₂) = 4.6; OM = 14 g dm⁻³; P(resin) = 2.7 mg dm⁻³; K = 0.4 mmol_c dm⁻³; Ca = 3.3 mmol_c dm⁻³; Mg = 0.5 mmol_c dm⁻³; H + Al = 29.0 mmol_c dm⁻³; Al = 1.7 mmol_c dm⁻³; CEC = 33.2 mmol_c dm⁻³; V = 13 %. The analyses were performed according to Raij et al. (2001).

A completely randomized block design, in a 3 x 5 factorial scheme, with four replications, was used. The treatments consisted of a combination of three K sources (KCl, phonolite and a 30 % of KCl + 70 % of phonolite blend) and five doses of the nutrient (0, 50, 100, 150 and 200 mg kg⁻¹), based on the total K content in each source. The KCl contained 60 % of K₂O and the phonolite exhibited the following composition: total K₂O = 8 %; K₂O soluble in citric acid (20 g L⁻¹, at a ratio of 1:100) = 1 %; and SiO₂ = 53.5 %. With respect to particle size, 80 % of the product passed through an ABNT 200 sieve (mesh size = 0.075 mm). The chemical analyses were conducted in line with Brasil (2017). The fertilizers were applied in powder form and incorporated into the total soil volume of each pot.

Liming was performed at 15 days after the treatment application to increase the base saturation to 50 %, using agricultural lime (TNP = 80.5 %; CaO = 36 %; and MgO = 12 %). Next, all the experimental units were fertilized with 100 mg kg⁻¹ of N (urea), 200 mg kg⁻¹ of P (single superphosphate) and 0.1 mg kg⁻¹ of B (boric acid). The same fertilizers were incorporated into the total volume of soil in each pot at the treatment application. Water was then added and the soil incubated for 10 days, after which the soil sampling was performed (70 g of soil).

Forty *Urochloa brizantha* (Hochst. ex A. Rich.) R. D. Webster cv. *Paiaguás* seeds were sown in each pot and thinning was performed at 7 days after emergence (DAE), leaving five plants per pot.

The pots were watered daily to maintain the soil moisture content at approximately 70 % of maximum water retention capacity, with the amount of water determined by weighing the pots.

At 13 DAE, 100 mg kg⁻¹ of N (urea) were applied as topdressing and the first cutting performed at 47 DAE, with the second and third ones conducted at 44 days after the previous cutting. The soil sampling was performed immediately after each cutting, collecting 70 g of soil per pot. After each sampling, 100 mg kg⁻¹ of N were applied as topdressing, with ammonium sulfate as source after the first cutting and urea after the second one. The number of tillers and leaves in each pot were counted just before cutting.

The plants were cut at 1 cm above the ground. The plant material was washed, dried in a forced-air oven at 65 °C, for 72 h, weighed to determine the shoot dry weight and ground for K concentration analysis (Bataglia et al. 1983). The K content and shoot dry weight data were used to calculate the K accumulation in the plant. Exchangeable K was determined in each soil sample using a cation-exchange resin as extractor (Raij et al. 2001).

Agronomic efficiency was assessed using the method proposed by Goedert et al. (1986), with KCl as a reference source (EqKCl), calculated as the ratio between the K doses (in the form of KCl and the test source) that provided the same yield, converted into percentage: $EqKCl(\%) = (X_1/X_2) \times 100$, where X_1 is the KCl-based K dose needed to achieve the maximum yield obtained with the test source and X_2 the K dose needed from the test source to achieve maximum yield. It was determined considering a dose of 200 mg kg⁻¹ of K for phonolite alone and the fertilizer blend.

The data were submitted to analysis of variance and the means for the K sources compared using the Tukey test. Polynomial regression was applied for K doses. Unfolding was performed regardless of whether the interaction between the causes of variation was significant. Critical K levels in the plants and soil were determined using the method described by Cate Junior & Nelson (1971).

RESULTS AND DISCUSSION

Regardless of the source, higher K doses resulted in a linear increase in the soil K content in the first sampling; however, a difference was observed among the sources (Figure 1A). For every 1 mg kg⁻¹ of

K added, there was an increase of 0.0241 mmol_c dm⁻³ of K in the soil for the KCl source, 0.0016 mmol_c dm⁻³ for phonolite and 0.0086 mmol_c dm⁻³ for the fertilizer blend. Thus, the highest K dose (200 mg kg⁻¹) resulted in soil K contents of 5.83, 0.97 and 2.76 mmol_c dm⁻³, that is, increases of 477, 49 and 165 %, in relation to the treatment without the nutrient for KCl, phonolite alone and the fertilizer blend, respectively.

These differences are due to the solubility characteristics of each fertilizer. KCl is highly soluble in water, meaning it dissolves and releases potassium immediately after application. Phonolite, in turn, is insoluble in water and exhibits low solubility in citric acid (1 % of the K₂O it contains). As such, the high lattice energy of the K atom in potassium-bearing rocks means that the solubilization of phonolite is highly dependent on its interaction with the soil and occurs slowly (Basak et al. 2017).

In the second sampling, the soil K content increased when the K dose increased only when KCl was used (Figure 1B). The low coefficient of determination observed when the data were fit to the mathematical model ($R^2 = 0.32$) is likely related to the variation in the soil K content between experimental units in a same treatment during the growth cycle, as a function of K uptake by the plants.

Since the solubilization of phonolite depends on its interaction with the soil, its content was expected to increase over a longer period of contact with the soil. However, this was not the case for either phonolite or the fertilizer blend for the duration of the present study, regardless of the dose applied (Figure 1B).

The lack of effect on the soil K content for the fertilizer blend in the second soil sampling may be due to the fact that the plants had absorbed all the K supplied by KCl (30 % of the source) at the initial growth stage, assessed at the first cutting, and the K in the phonolite (70 % of the source) had not yet been released in significant quantities. At the third cutting, there were no differences in the soil K content as a function of K doses and sources (Figure 1C).

For the KCl and fertilizer blend sources, higher K doses caused a linear increase in the shoot concentration of this nutrient at all the three cuttings. However, with phonolite as a source, the shoot K content only increased with increasing K doses at the second cutting. Concentrations of the nutrient remained constant for the remaining cuttings (first and third), regardless of the K dose (Figures 1D,

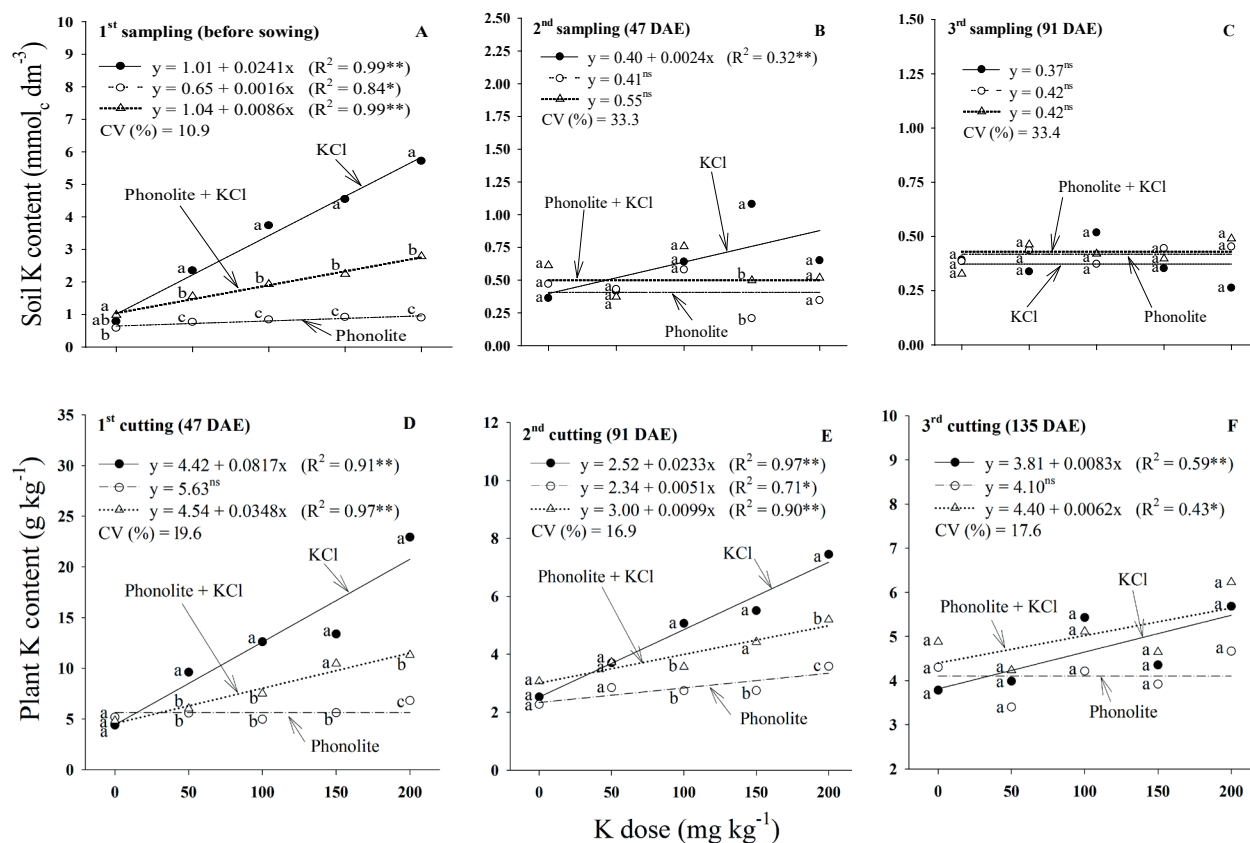


Figure 1. K content in the soil (A, B and C) and shoots (D, E and F) of Paiaguás palisadegrass, as a function of K doses and sources, at three assessment times. Means followed by the same letter within each dose do not differ significantly according to the Tukey test at 5 % of probability. **, * and ^{ns}: significant at 1 % and 5 % of probability and not significant, respectively. CV (%): coefficient of variation. DAE: days after emergence.

1E and 1F). Significant differences between the sources were also observed at the first and second cuttings (Figures 1D and 1E), particularly at the highest dose (200 mg kg⁻¹). In this case, the highest K concentrations in the plants were obtained with KCl application and the lowest for phonolite, with the fertilizer blend resulting in intermediate values.

The KCl application at a dose greater than or equal to 93 mg kg⁻¹ of K at the first cutting led to concentrations of the nutrient considered adequate by Werner et al. (1997), who suggested a sufficiency range of 12-30 g kg⁻¹ of K in *U. brizantha* shoots and leaves.

There was a linear accumulation of K in the shoots as a function of increased doses of the nutrient at all the cuttings. However, plants fertilized with KCl absorbed and accumulated more K than those treated with phonolite at all the cuttings, while the fertilizer blend resulted in intermediate K accumulation values (Figures 2A, 2B and 2C).

The K application also increased the dry weight production at all the three cuttings, with differences observed among the sources (Figures 3A, 3B and 3C). At the first two cuttings, particularly at higher K doses (150 and 200 mg kg⁻¹), KCl produced better yields than those obtained with phonolite, whereas the fertilizer blend resulted in intermediate yields (Figures 3A and 3B). The same dynamic was observed for total yield over the study period (Figure 3D).

For the KCl application at the third cutting, the two highest K doses (150 and 200 mg kg⁻¹) produced the best results, with intermediate yields recorded for phonolite, when compared to the other sources (Figure 3C). This is likely because there was less K available in the soil from the KCl present in the fertilizer blend, as a function of its absorption in previous cycles and the solubilization of only a small portion of the K in the phonolite. Additionally, the fast increase of the K concentration in the soil

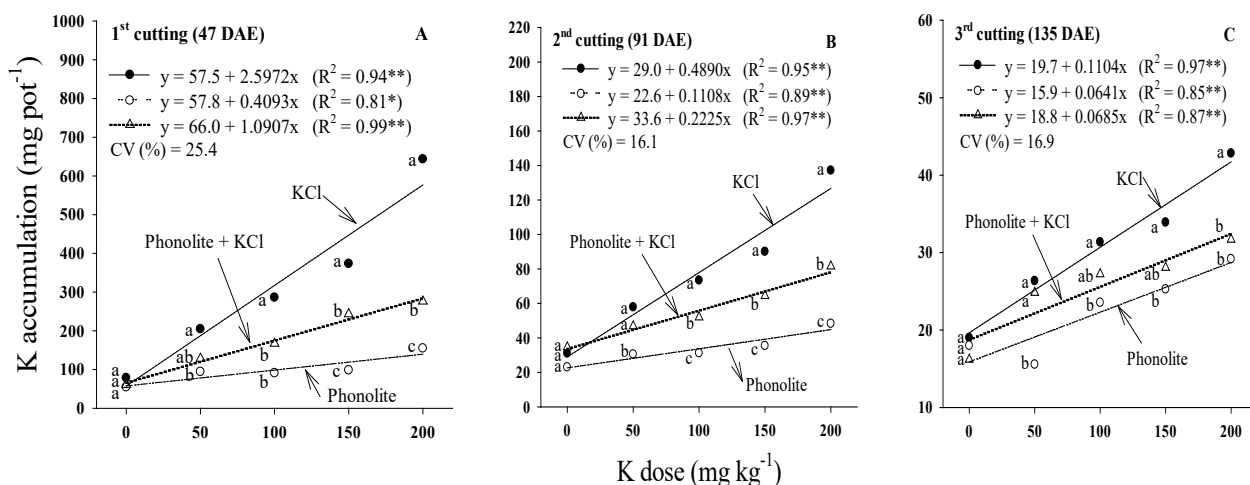


Figure 2. Potassium (K) accumulation in Paiaguás palisadegrass shoots, as a function of doses and sources, at three assessment times (A, B and C). Means followed by the same letter within each dose do not differ significantly according to the Tukey test at 5 % of probability. ** and *: significant at 1 % and 5 % of probability, respectively. CV (%): coefficient of variation. DAE: days after emergence.

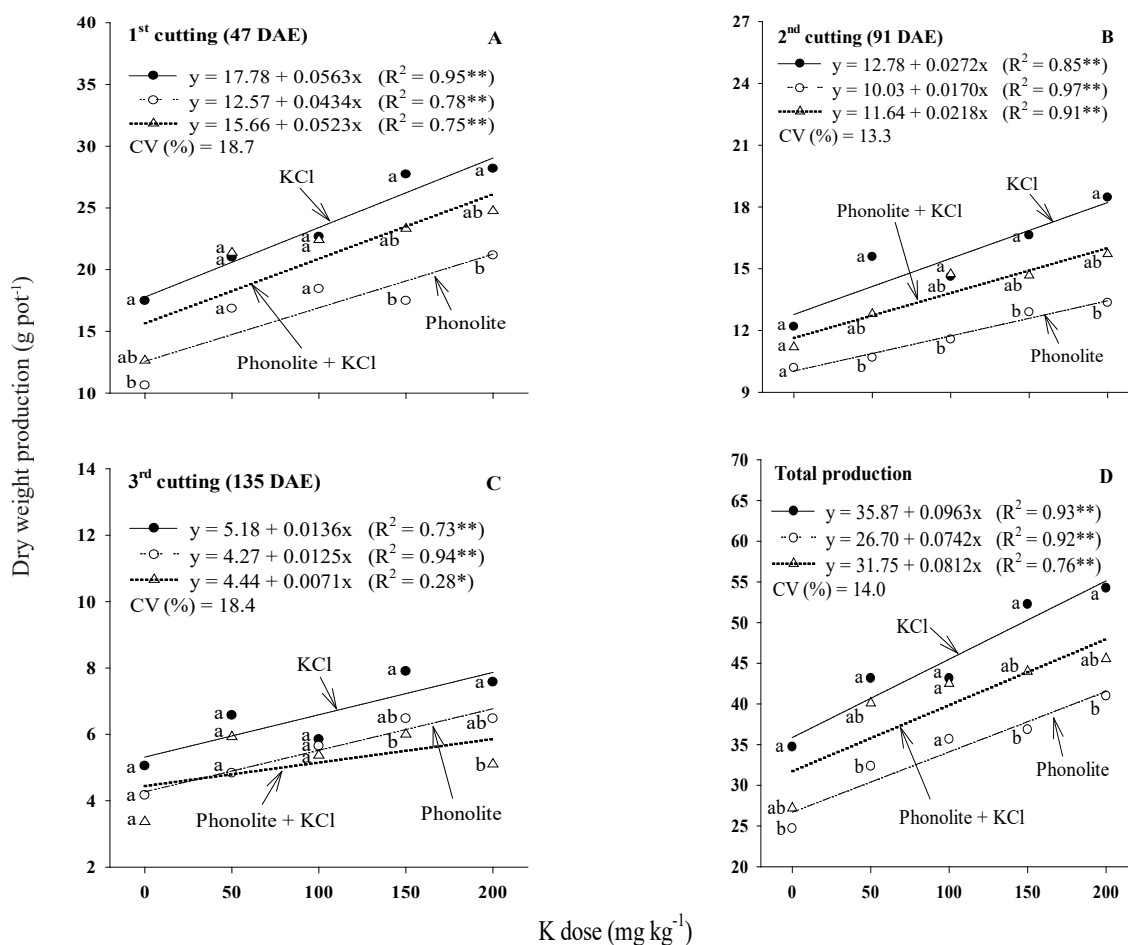


Figure 3. Dry weight production of Paiaguás palisadegrass, as a function of K doses and sources at three assessment times (A, B and C) and for total yield over the study period (D). Means followed by the same letter within each dose do not differ significantly according to the Tukey test at 5 % of probability. ** and *: significant at 1 % and 5 % of probability, respectively. CV (%): coefficient of variation. DAE: days after emergence.

solution resulting from dissolved KCl (Figure 1A) may reduce the phonolite solubilization. Under these conditions, the transfer of structural K to the soil solution is minimal, because its concentration in the solution is far greater than the constant equilibrium of the mineral (Benites et al. 2010).

Given that the K content in the soil (Figures 1A, 1B and 1C) and plants (Figures 1D, 1E and 1F) did not increase with the phonolite application at all the three cuttings, but the K uptake and accumulation (Figures 2A, 2B and 2C) and dry weight production did (Figures 3A, 3B and 3C), it is believed that phonolite solubilization occurs slowly (Martins et al. 2015) during the forage growth cycle, largely via the action of organic acids exuded by the root system (Basak et al. 2017) and absorbed by the plants as they are released, so that no major changes in the soil K content as a function of K doses were observed at assessments conducted before each cutting.

The small or minimal influence of K doses on its concentration in the plants when phonolite was applied (Figures 1D, 1E and 1F) is likely due to the dilution effect. When K levels in the soil are low, its application promotes a heightened growth response in plants that is proportionally greater than the K uptake, preventing its concentration from increasing in plant tissues (Andrade et al. 2000).

As observed here, other authors have reported the beneficial effect of potassium fertilization on dry weight production in *U. brizantha* (Orioli Júnior & Coutinho 2009, Megda & Monteiro 2010, Morais et al. 2016) and that KCl is a fertilizer more efficient than phonolite (Bianchini & Marques 2019, Boldrin et al. 2019). Given the low efficiency of phonolite, adding 30 % of KCl to the blend to provide the K needed for initial plant growth was insufficient to produce the same amount of dry weight obtained with the application of the water-soluble source (KCl) alone.

The number of tillers remained constant at the first cutting, regardless of the K dose and source (Figure 4A). This may indicate less initial dependence on the nutrient for tillering, since the potassium fertilization did not influence the number of tillers in the second (except for KCl) and third cuttings, and, in general, no differences were observed among the fertilizers (Figures 4A, 4B and 4C). The application of 112 mg kg⁻¹ of K with KCl as source produced the highest number of tillers (34 pot⁻¹) at the third

cutting. The phonolite application resulted in a linear increase in this variable, as a function of greater K doses at the first cutting, with 29 tillers pot⁻¹, whereas a quadratic effect was observed at the third cutting, with the largest number of tillers (30 pot⁻¹) obtained when 145 mg kg⁻¹ of K were applied. However, for the fertilizer blend, the highest number of tillers was obtained for 128 mg kg⁻¹ of K applied at the second cutting (31 pot⁻¹) and 130 mg kg⁻¹ of K at the third cutting (35 pot⁻¹).

On the other hand, the number of leaves was only influenced by K doses at the third cutting, and no differences were observed among the sources (Figures 4D, 4E and 4F). Under a quadratic effect, 118 and 121 mg kg⁻¹ of K produced the highest number of leaves (160 and 159 pot⁻¹) for the KCl and fertilizer blend, respectively. This variable increased linearly when phonolite was applied, with the highest K dose (200 mg kg⁻¹) resulting in 145 leaves pot⁻¹. The fact that the number of leaves and tillering were affected by the treatments, particularly in the third cutting, may be related to the height at which the plants were cut (at the ground level), which could increase the plant dependence on nutrients in the soil over time.

Potassium may favor tillering and increase the number of leaves in forage grasses (Megda & Monteiro 2010). However, in the present study, the influence of K doses and sources on these variables do not fully explain the variations observed for the dry weight production, which increased at all the three cuttings as a function of K doses, regardless of the source used. However, potassium fertilization can also increase the leaf area of forage grasses (Megda & Monteiro 2010), what is certainly related to the dry weight results obtained.

The EqKCl equation indicated that the phonolite and the fertilizer blend were less efficient than KCl (Figure 5), due to the slow and limited release of the K present in the phonolite. The addition of 30 % of KCl to supply the K needed for initial plant growth did not produce a similar effect to that observed for KCl alone. Pooled data for all the cuttings demonstrated that the use of KCl may provide the same yields obtained with phonolite and the fertilizer blend at a dose of 200 mg kg⁻¹ by applying 29 and 63 % of this dose, respectively. Thus, all the sources studied can be used to supply K to *Paiaguás* palisadegrass; however, the selection should take into account the necessary dose based

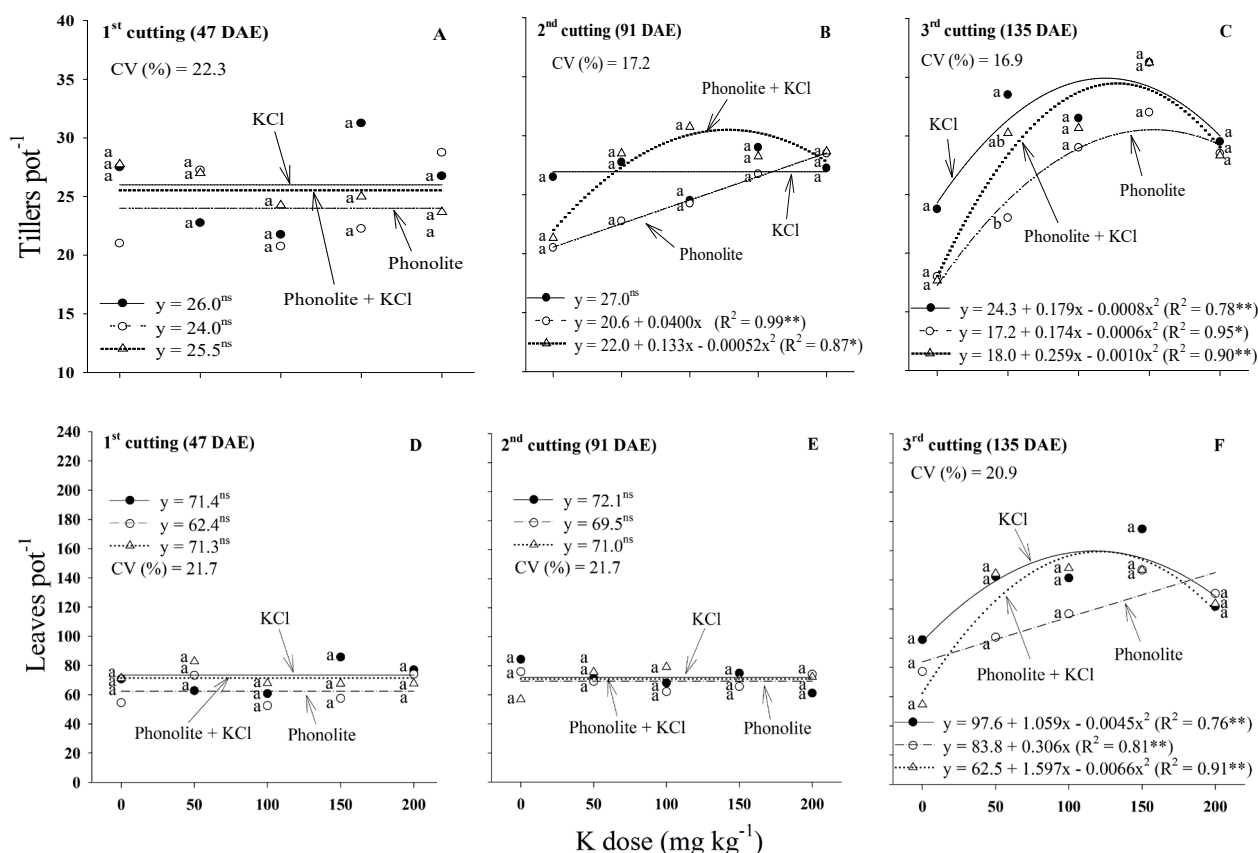


Figure 4. Number of tillers (A, B and C) and leaves (D, E and F) of Paiaguás palisadegrass, as a function of K doses and sources, at three assessment times. Means followed by the same letter within each dose do not differ significantly according to the Tukey test at 5 % of probability. **, * and ns: significant at 1 % and 5 % of probability and not significant, respectively. CV (%): coefficient of variation. DAE: days after emergence.

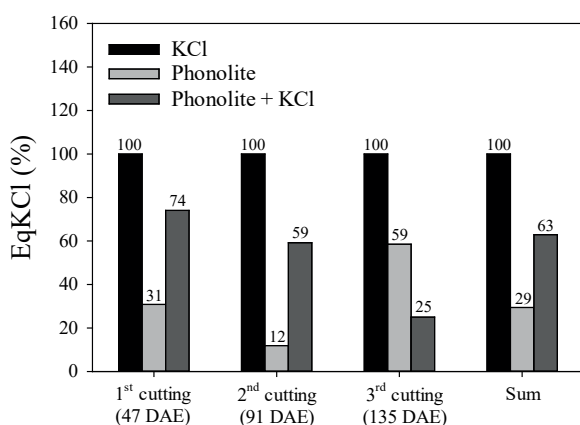


Figure 5. Average comparative agronomic efficiency with KCl, as the reference source (EqKCl) for each cutting and the sum of all the cuttings. DAE: days after emergence.

on its efficiency and the price per unit of nutrient for each fertilizer.

The obtained results support the calibration of soil chemical analysis and recommendations on managing the soil fertility using alternative sources. As a result, the critical K level was determined by establishing two classes of probable response to potassium fertilization (Figure 6).

The critical level of $1.4 \text{ mmol}_c \text{ dm}^{-3}$ obtained is similar to the $1.53 \text{ mmol}_c \text{ dm}^{-3}$ reported by Orioli Júnior & Coutinho (2009), for Marandu grass. Although critical levels have been established for annual crops, the value obtained here is also similar to those used in most the Brazilian states (Raij et al. 1997, Alvarez V. et al. 1999).

The critical K level for shoots was 8.7 g kg^{-1} (Figure 6), lower than the range suggested by Werner et al. (1997) for *U. brizantha* ($12\text{-}30 \text{ g kg}^{-1}$ of K) and the value reported by Orioli Júnior & Coutinho (2009) for Marandu grass (19.1 g kg^{-1}), likely due to the different nutrient requirements between species and cultivars.

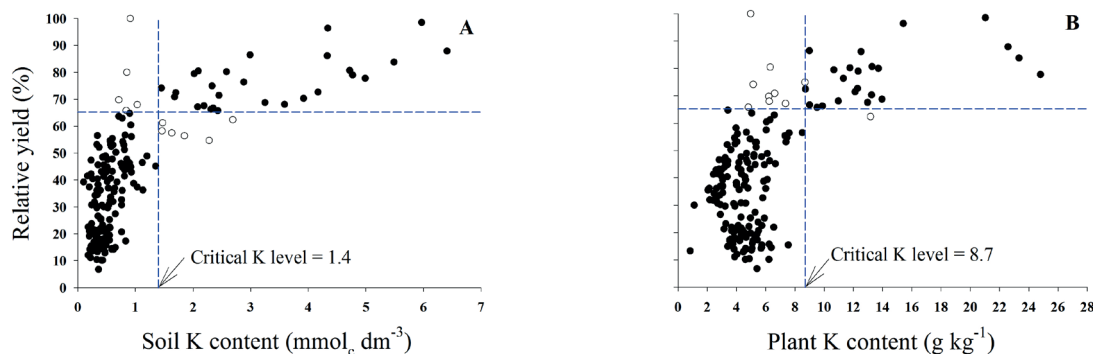


Figure 6. Critical K levels in the soil (A) and Paiaguás palisadegrass shoots (B).

CONCLUSION

Whether applied alone or in a fertilizer blend, phonolite was less efficient than KCl for all the cuttings (in a period of 135 days after emergence). On average, the agronomic efficiency for phonolite alone was 29 %, and 63 % when mixed with KCl. The critical K levels in the soil and Paiaguás palisadegrass shoots were 1.4 mmol_c dm⁻³ and 8.7 g kg⁻¹, respectively.

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