

Glauconitic siltstone as a multi-nutrient fertilizer for *Urochloa brizantha* cv. Marandú

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Abstract

Potassium (K) is one of the most absorbed nutrients by forage plants and it is found at low levels in tropical soils, requiring large amounts of fertilizers. The use of glauconitic siltstone as multi-nutrient fertilizers is an economic alternative to improve pasture-based production systems due to their low-cost production and long-term nutrient release. This study evaluated the effect of the glauconitic siltstone (GS) powder on three successive crops of *Urochloa brizantha* cv. Marandú (Syn. *Brachiaria brizantha*). Two experiments were carried out under greenhouse conditions, one using a Typic Dystrustox and the other a Typic Quartzipsamment. Both experiments were arranged in a completely randomized design with one factor, i.e., five glauconitic siltstone doses (0, 5, 20, 40, and 80 mg dm⁻³ of K₂O) and four replications. In addition, three additional treatments were used, as potassium chloride, wollastonite and manganese sulfate at doses of 80 mg dm⁻³ of K₂O, 270 mg dm⁻³ of silicon (Si) and 2 mg dm⁻³ of manganese (Mn), respectively. The sources were incubated for 60 days on the two soil types and, after the incubation period, *Urochloa brizantha* plants were grown. Three consecutive cuts were performed at 68, 104 and 168 days after sowing. The application of the GS in tropical soils promoted increases in plant dry matter, as well as K, Si and Mn levels in soil samples and accumulated in plants. In general, greater effects were obtained following the application of GS after consecutive cropping cycles due to its long-term release. Results described in this study provide an important understanding of the use of glauconitic siltstone as multi-nutrient fertilizers in tropical soils, being an efficient alternative to improve soil fertility and increase tropical pasture productivity.

Keywords: forage plants; manganese; plant nutrition; potassium; rock powder; silicon.

Abbreviations: AEI_ agronomic efficiency index; DAS_days after sowing; DM_plant dry matter; GS_glauconitic siltstone; KCl_potassium chloride; MnSO₄_manganese sulfate.

Introduction

Pasture-based production systems are the most practical and economical cattle feeding management (Dias-Filho, 2014), ensuring a low-cost livestock production to feed the growing world population (Cerri et al., 2016). However, despite efforts to maintain pasture productivity, progressive degradation is often reported to occur after about 5–15 years of pasture use (Asner et al., 2004) and, consequently, a reduction of the land value and delaying of animals slaughter age (Peron and Evangelista, 2004).

One of the main causes of pasture degradation has been linked to soil fertility declining due to nutrient removal caused by the unsuitable farming process. In this regard, nutrient supply is an important factor for pasture production, considering that the nutrient availability has a great influence on the plant nutrition and on cattle food quality (Bonfim-da-Silva; Monteiro, 2006). Moderate inputs of fertilizers are typically applied to address soil chemical deficiencies in improved pastures (Miles et al., 2004), especially in tropical areas, e.g. Brazilian pastures. Yet the use of soluble fertilizers being a good initial investment to increase tropical pasture productivity, the majority of pastures degrade after only a few years if not properly

maintained with periodic inputs of fertilizer (Fonte et al., 2014).

Potassium (K) is one of the most absorbed nutrients for forage plants (e.g. *Brachiaria* spp.) and it is found at low levels in tropical soils, requiring large amounts of fertilizers. More than 90% of Brazilian potash needs is imported to supply the nutrient demand since the country presents poor quality and small-sized K soluble reserves (Oliveira et al., 2017), which considerably increase the costs of food production in the country.

Since livestock farming is developed with low investments and K plays an important role in the correct pasture management, alternative sources of this nutrient are frequently searched. Recent investigations suggest that the use of K-rich rocks may increase the long-term K contents in soils (Zörb et al., 2014). The direct use of glauconitic siltstone can be a viable, economical and ecological alternative, given its low production cost and long-term release.

Glauconitic siltstone is an example of K-rich rock which may increase soil fertility in the medium to long-term, according to their solubility and reaction with soil. Glauconitic provides K₂O contents ranging from 7 to 14 dag dm⁻³ and no chloride

(Cl) concentration, which allows it to be used in organic agriculture. These rocks also present other 68 elements, including silicon (Si) and manganese (Mn), with a potential to be used not only as a K fertilizer, but as a multi-nutrient fertilizer. Additionally, the nutrient release from this fertilizer is slow and gradual, reducing losses by leaching and favoring a long-term release.

This study evaluated the effect of the glauconitic siltstone powder on three successive crops of *Urochloa brizantha* cv. Marandú (Syn. *Brachiaria brizantha*). Owing to its capability to supply K, Si and Mn to plants, while increasing forage production, we expect to promote an alternative K source.

Results and discussion

Plant dry matter (DM) and agronomic efficiency index (AEI)

The effects of GS on *Urochloa brizantha* plant DM after three consecutive cuts, as compared with KCl, are shown in Fig 1. At 68 and 104 DAS, the application of GS resulted in increases in plant DM, yet the effects are not comparable with the ones obtained with the application of KCl (80 mg dm⁻³ of K₂O) (Fig 1a and 1b). Greater DM values following the application of KCl after the first two plant cuts are related to the great solubility of the standard source, since this salt is water soluble and readily available to plants (Prakash and Verma, 2016). However, at 168 DAS, higher DM values were obtained with the application of GS (20, 40, and 80 mg dm⁻³ of K₂O) when compared to KCl (Fig 1c). The application of slow-release K fertilizers, such as the GS, can supply crop demand for nutrients after consecutive cycles (Resende et al, 2006), as well as minimize losses of K by leaching. Since K presents a small hydrated ion size, the application of soluble K-sources (e.g. KCl) results in a low retention in soil's cation-exchange capacity (CEC) (Yamada and Roberts, 2005). Thus, the nutrient release from this fertilizer is slow and gradual, which reduces losses by leaching and favors a long-term release (Martins et al., 2015). Such results are especially relevant in tropical areas with soil fertility constraints.

Previous studies have also indicated that crops fertilized with high KCl doses can present great Cl accumulation in leaves, promoting soil salinity (Silva et al., 2001) and, as a consequence, water stress to plants (Cruz et al., 2006). In fact, increases in plant DM after consecutive cycle crops with the application of GS may be related to both slow-release characteristic and low salinity potential. In addition, this alternative source presents Mn in its composition, which is an essential nutrient for normal growth and development of most plants (Twyman, 1951) and Si, a beneficial element extracted in large amounts by grasses, especially in intensive cropping (Meena et al., 2014).

The effect of GS application on plant development can also be noted analyzing agronomic efficiency index (AEI) values (Fig 2). In general, smaller AEI values after the first two cuts were obtained after GS application (values lower than 100%). On the other hand, after the third cut, the GS source presented greater agronomic efficiency, being a good alternative of long-term fertilizer.

K levels on soil and accumulated in plants

The application of increasing doses of the GS increased the levels of K on soil and accumulated in *Urochloa brizantha* plants (Fig 3), with a greater effect after the third plant cut (Fig 3d). At 168 DAS, the application of GS in clayey soil at the dose of 20 mg dm⁻³ resulted in higher K accumulated levels in *Urochloa brizantha* plants than KCl (20 mg dm⁻³) treatments, even the glauconitic siltstone fertilizer being applied at a dose four times lower than the standard source (Fig 3d). Potash is one of the most important fertilizers for agricultural lands because it improves water retention, yield, nutrient value, taste, colour, texture, and disease resistance of food crops (Geman et al., 2015). Thus, the GS can be used as a sustainable source of K for long-term crops, as this fertilizer releases K₂O slowly and reduces the demand for chemical fertilizers. Increases in plant K levels following the application of the GS are related to the chemical composition of this source, since the applied product presents 100 g dm⁻³ of K. The GS K-content can be attributed to the occurrence of glauconite in the rock, which it is a hydrated lamellar silicate of K and Fe composed of tetrahedral and octahedral leaves (Gamero et al., 2004). The values of recovery of K-applied also indicate the low-solubility of the GS (Fig 4). In general, the application of KCl both in clayey and sandy soils promoted a higher recovery of K-applied than the GS at 68 and 104 DAS. On the other hand, at 168 DAS, 1.1% and 2.5% of recovery of K-applied were obtained after GS application, whereas the values after the KCl application were equal to 0.9% and 0.7%, both in clayey and sandy soil, respectively.

Si and Mn levels on soil and accumulated in plants

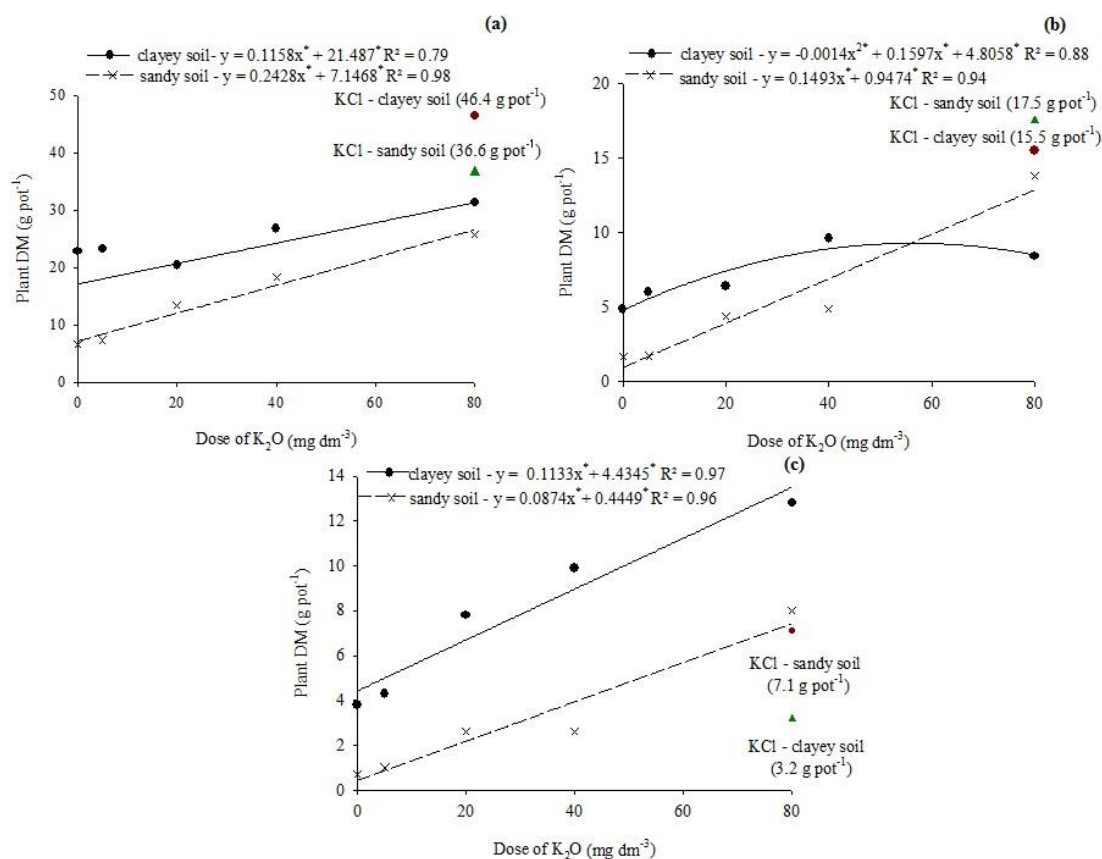
Besides increasing the unnecessary soil and accumulated K levels, the application of GS also improved the levels of Si and Mn on soil and accumulated in plants (Fig 5 and Fig 6). Increases in plant Si levels were obtained after the three plant cuts, yet the effects are not comparable with the ones obtained with equivalent doses of Wollastonite, due to the greater solubility of the standard Si source (Fig 5). Tropical soils (e.g. oxisol) are depleted of soluble sources of Si due to weathering and leaching associated with high rainfall and temperatures, leading to marginal or deficient Si levels in plants (Keeping, 2017). Thus, yield responses to the application of low soluble Si fertilizers have been recorded in these soils, which have significant potential in supplying Si over time, especially for crop species that accumulate Si to levels >1.0% shoot Si dry mass (Ma and Takahashi, 2002), as grasses and forage species.

Increases on soil and plant accumulated Mn levels were also obtained following the application of increases doses of GS (Fig 6). In general, a greater effect of GS on plant accumulated Mn levels was observed at 168 DAS due to the low solubility of this source, as previously discussed (Fig 6d). Since soils cultivated with forage crops show very low Mn levels, it is important to focus on Mn-fertilization because of the importance of the nutrient in animal organisms regarding metabolism of carbohydrates and lipids (Ubavić et al., 2008). In addition, Mn plays a key role in many plant oxidation-reduction processes, activation of enzymes, photosynthesis, metabolism of carbohydrates, and synthesis of plant pigments (Burnell et al., 1988).

Table 1. Chemical composition of glauconitic siltstone, KCl, Wollastonite, and MnSO₄.

Source	K ₂ O		Si		Mn
	Total	Soluble	Total	Soluble	
	g dm ⁻³				
Glauconitic Siltstone	100	5	270	5	0.5
KCl	600	600	-	-	-
Wollastonite	-	-	230	120	-
MnSO ₄	-	-	-	-	310

Total and soluble K₂O: Lorentzen and Kingston (1996). Total and available Si: Korndorfer et al. (2004). Total Mn: MAPA (2007).

**Fig 1.** *Urochloa brizantha* plant dry matter (DM) at 68 (a), 104 (b) and 168 (c) days after sowing with increasing doses of glauconitic siltstone applied in clayey and sandy soils. Square and triangles symbols refer to the KCl treatment applied at the dose of 80 mg dm⁻³ of K₂O in clayey and sandy soils, respectively.**Table 2.** Soils chemical and physical properties.

Soil	pH	Si	K	P	Al ³⁺	Ca ²⁺	Mg ²⁺	OM	SB	T	sand	silt	clay
		---mg dm ⁻³ ---			---cmol _c dm ⁻³ ---			-----g dm ⁻³ -----					
Typic Dystrustox	3.8	5.6	18.6	0.2	0.8	0.6	0.1	8.9	7.5	33	210	100	690
Typic Quartzipsamment	3.6	2.6	8.1	3.1	0.9	0.6	0.1	9.9	7	35	900	10	90

Soil pH: 1:2.5 soil sample/water ratio; Si: CaCl₂ 0.01 mol L⁻¹. Available K and P: Mehlich-1 method (HCl 0.05 mol L⁻¹ + H₂SO₄ 0.0125 mol L⁻¹). Exchangeable Al, Ca and Mg: KC 1 mol L⁻¹. OM: potassium dichromate (K₂Cr₂O₇) method. SB: sum of bases. T: cation.

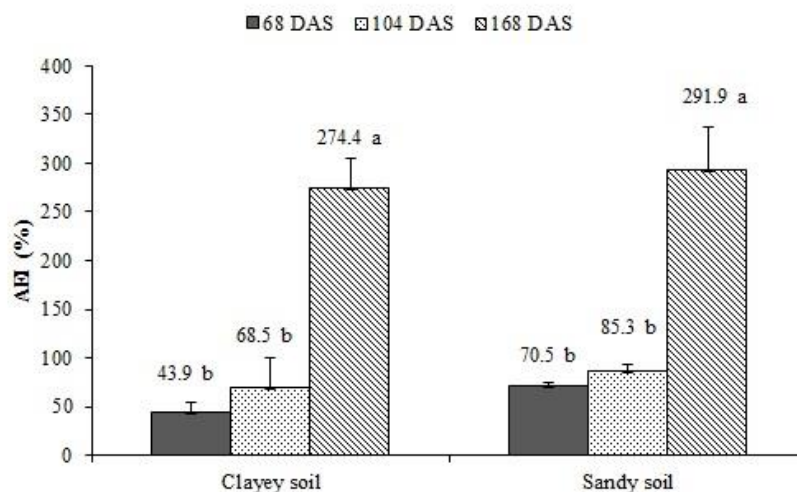


Fig 2. Agronomic efficiency index (AEI) of the glauconitic siltstone in relation to KCl in clayey and sandy soils at 68, 104 and 168 days after sowing. Different letters within each column group denote significant difference between treatments. Least Significant Difference (LSD): Clayey soil: 172.03; Sandy soil: 205.41. Values higher than 100% denote superiority of the GS in relation to KCl treatment.

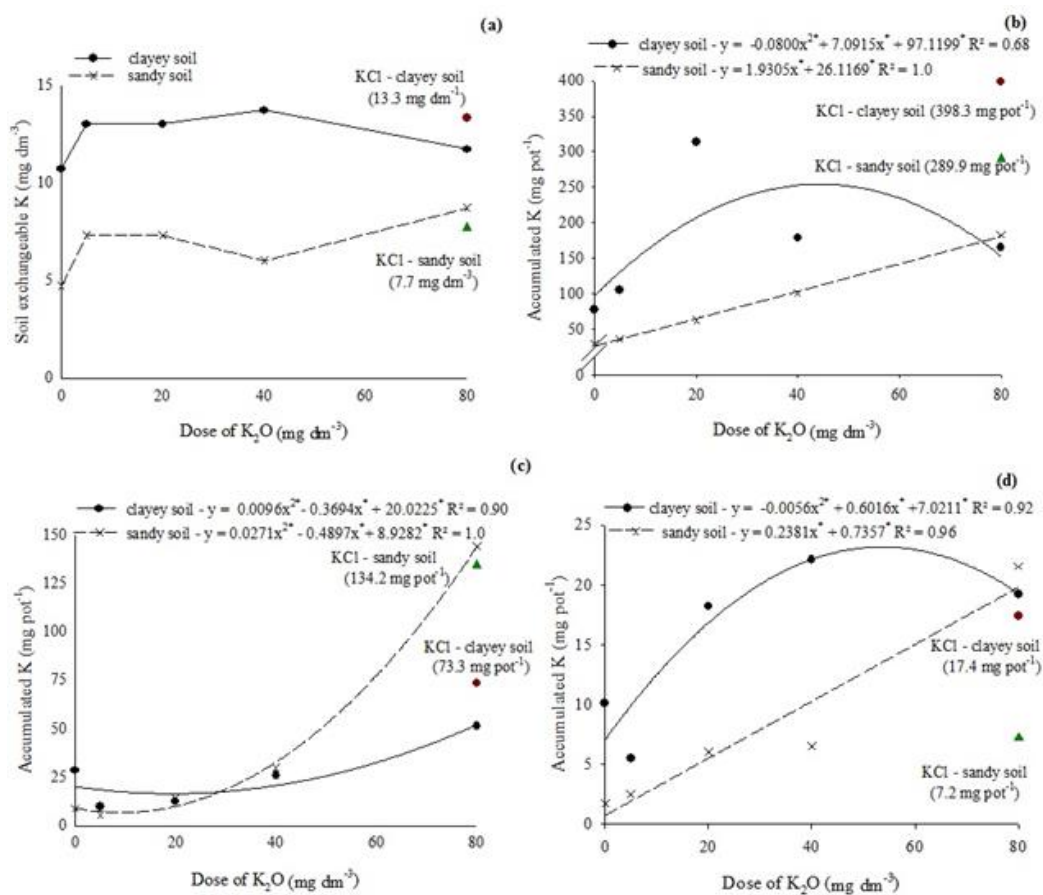


Fig 3. Soil exchangeable K (a) and K accumulated in *Urochloa brizantha* plants at 68 (b), 104 (c) and 168 (d) days after sowing with increasing doses of glauconitic siltstone applied in clayey and sandy soils. Square and triangles symbols refer to the KCl treatment applied at the dose of 80 mg dm⁻³ of K₂O in clayey and sandy soils, respectively

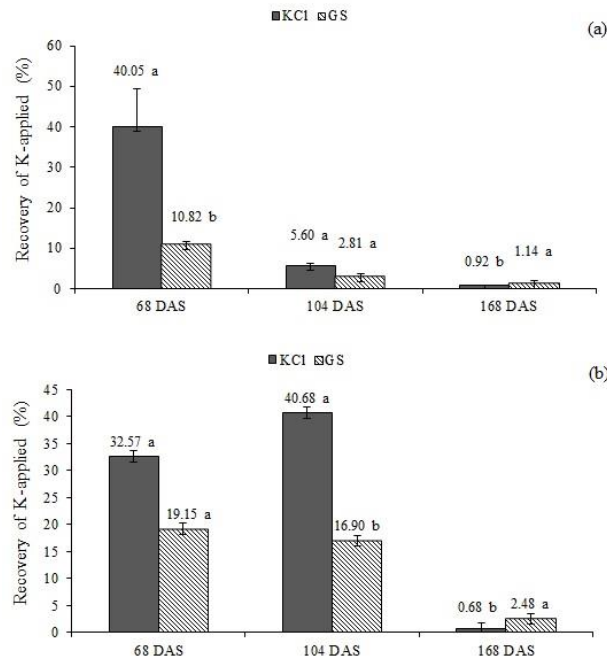


Fig 4. Recovery of K-applied (%) from *Urochloa brizantha* plants after glauconitic siltstone application in clayey (a) and sandy (b) soils. Different letters within each column group denote significant difference between treatments. Least Significant Difference - Clayey soil: 68 DAS: 17.73; 104 DAS: 7.33; 168 DAS: 0.20. Sandy soil: 68 DAS: 18.48; 104 DAS: 11.03; 168 DAS: 1.65.

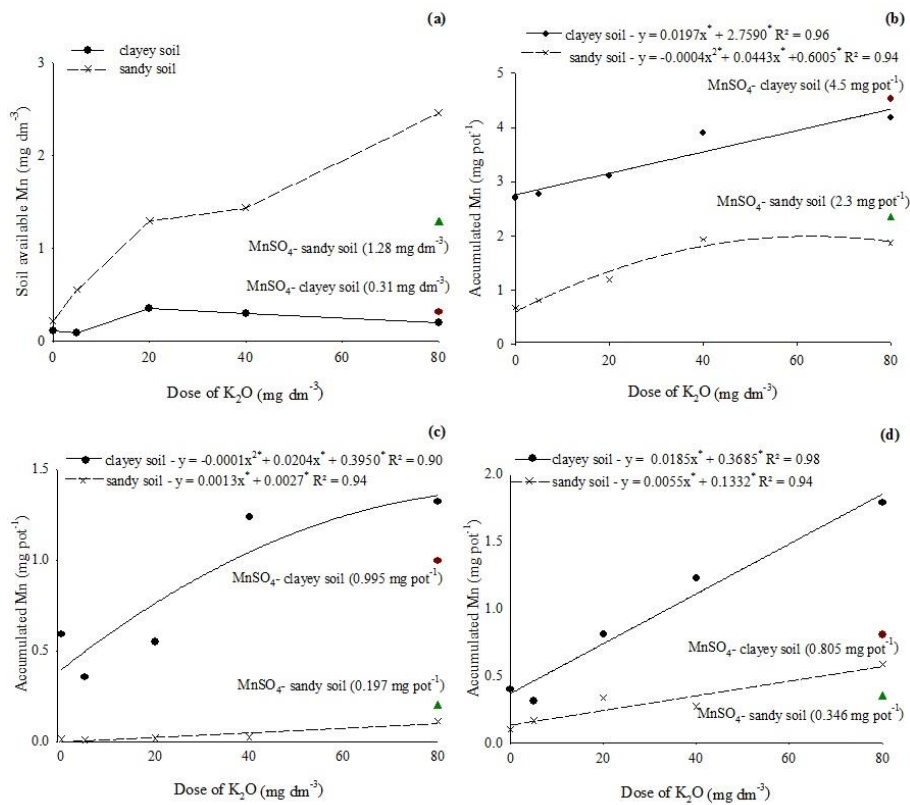


Fig 5. Soil available Si (a) and Si accumulated in *Urochloa brizantha* plants at 68 (b), 104 (c) and 168 (d) days after sowing with increasing doses of glauconitic siltstone applied in clayey and sandy soils. Square and triangles symbols refer to the Wollastonite treatment applied at the dose of 270 mg dm^{-3} of Si in clayey and sandy soils, respectively.

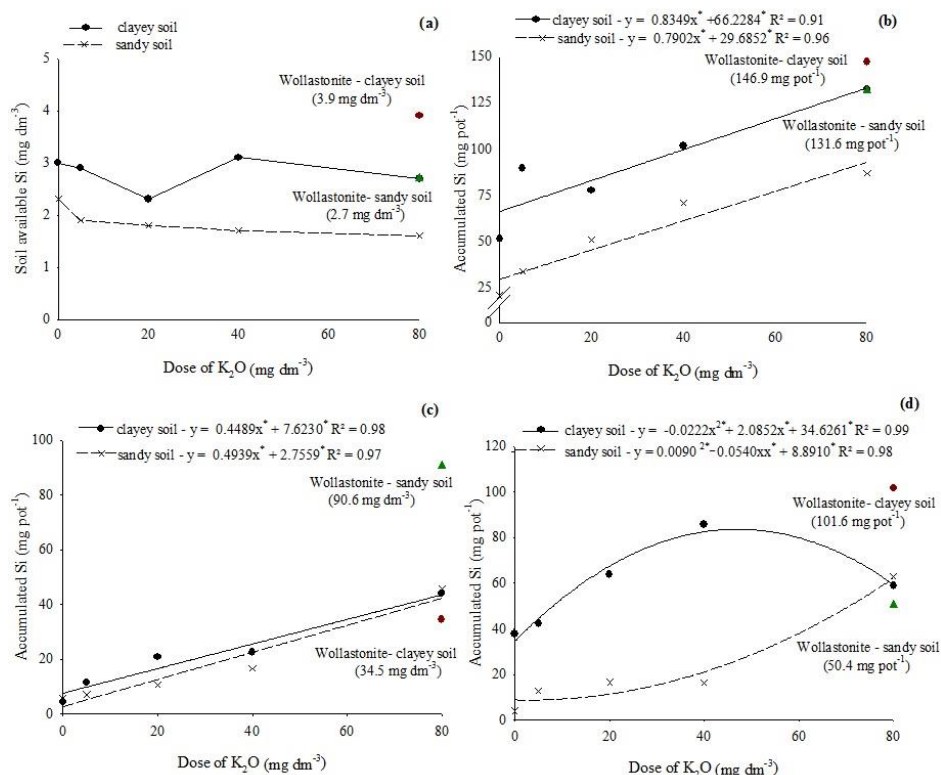


Fig 6. Soil available Mn (a) and Mn accumulated in *Urochloa brizantha* plants at 68 (b), 104 (c) and 168 (d) days after sowing with increasing doses of glauconitic siltstone applied in clayey and sandy soils. Square and triangles symbols refer to the MnSO₄ treatment applied at the dose of 2 mg dm⁻³ of Mn in clayey and sandy soils, respectively.

exchange capacity at pH 7. In general, owing the capability of the GS to supply K, Si and Mn to *Urochloa brizantha* plants, especially after consecutive crop cycles, these results propose an innovative and sustainable use of nutrient-rich rock to improve tropical pasture areas and increase cattle production.

Materials and Methods

Product characterization

The glauconitic siltstone (GS) is originated from the state of Minas Gerais, Brazil, presenting low salinity (1.7 g dm⁻³), silicate rock with quartz feldspar, albite, white micas, and relatively high concentrations of glauconitic (25 dag dm⁻³). In addition to the rock powder, standard sources of K₂O (KCl), Si (Wollastonite) and Mn (MnSO₄) were used for comparison purposes. The chemical composition of the glauconitic siltstone as well as KCl, Wollastonite, and MnSO₄ is shown in Table 1. All treatments were applied to soil as a < 2 mm powder.

Experiment conduction

Two experiments were carried out under greenhouse conditions from 09/07/2016 to 02/21/2017, one using a clayey soil and the other, a sandy soil. The samples of the two different soils types were collected at 0-20 cm depth in the state of Minas Gerais, Brazil, being classified according to U. S. Department of Agriculture soil taxonomy (USDA,

1999) as Typic Dystrustox (clayey soil) and a Typic Quartzipsamment (sandy soil), which physical and chemical properties are described in Table 2.

Both experiments were arranged in a completely randomized design with one factor, i.e., GS doses, and four replications. Five GS doses (0, 5, 20, 40, and 80 mg dm⁻³ of K₂O) were applied, resulting in four Si and Mn doses (270, 1080, 2160, and 4320 mg dm⁻³ of Si; 0.5, 2.0, 4.0, and 8.0 mg dm⁻³ of Mn). In addition, KCl, Wollastonite and MnSO₄ were used as additional treatments at doses of 80 mg dm⁻³ of K₂O, 270 mg dm⁻³ of Si and 2 mg dm⁻³ of Mn, respectively, resulting in 32 pots for each soil type. The treatments were incubated for 60 days in 5 dm⁻³ of the two soil types (clayey and sandy soils) and soil moisture was controlled by daily weighing, replacing the volume lost through evapotranspiration with deionized water.

After the incubation period, 200 mg kg⁻¹ of N and 400 mg kg⁻¹ of P₂O₅ were added to samples through the ammonium sulfate ((NH₄)₂SO₄) and triple superphosphate, respectively. Micronutrients were also supplied adding 1.5, 5.0, 0.5, and 0.05 mg dm⁻³ of Cu, Zn, B, and Mo through CuSO₄·5H₂O, ZnSO₄·7H₂O, H₃BO₃ and (NH₄)₆Mo₇O₂₄·4H₂O, respectively. Ten seeds of *Urochloa brizantha* cv. Marandú (Syn. *Brachiaria brizantha*) were sown per pot, at a depth of 2 cm. After the emergence of the seedlings, thinning was carried out, maintaining five plants per pot.

At 30, 40, 65, and 82 DAS, ammonium sulfate was applied providing 50 mg kg⁻¹ of N. Daily irrigation was done as well as periodic observations to evaluate the possible incidence of pests and plant diseases in *Urochloa brizantha* cultivation.

Plant and soil analysis

Three *Urochloa brizantha* plant cuts were performed at 4 cm above ground level at 68, 104 and 168 DAS. After the third plant cut, soil samples were also collected. The plant samples were washed, dried in an oven and weighed to obtain values of dry matter of the aerial part (DM). Afterwards, the samples were ground and submitted to nitric-perchloric digestion (Johnson and Ulrich, 1959) and K and Mn levels were analyzed by colorimetric method (Murphy and Riley, 1962). The plant samples were also submitted to Si analysis following a methodology proposed by Korndörfer et al. (2004). The levels of nutrients in the aerial part were converted to accumulated levels using the DM values, obtaining values in mg pot⁻¹. The soil samples were dried and submitted to K and Mn analysis, using the methodology proposed in the Embrapa's Manual of Methods (Donagema et al., 2011), and Si analysis, according to Korndörfer et al. (2004).

Using the nutrient accumulated values, agronomic efficiency index (AEI) of the GS relative to KCl was calculated using the equation proposed by Fageria et al. (2010) as bellow:

$$AEI (\%) = \frac{GS\ DM - Control\ DM}{KCl\ DM - Control\ DM} \times 100$$

Where GS DM is the plant DM with the application of the GS (80 mg dm⁻³ of K₂O), KCl DM is the plant DM with the application of KCl (80 mg dm⁻³ of K₂O) and the control DM is the plant DM in the additional control treatment without K₂O application (0 mg dm⁻³ of K₂O). In addition to AEI, the recovery of K-applied was also calculated through the follow equation:

$$Recovery\ of\ K-applied\ (\%) = \frac{GS\ K - Control\ K}{K\ applied} \times 100$$

Where; GS K is the mean value of K accumulated in plants cultivated with the application of 80 mg dm⁻³ of K₂O of GS, control K is the mean value of K accumulated in plants cultivated in the control treatment without K₂O application (0 mg dm⁻³ of K₂O) and K applied is the amount of K applied at the dose of 80 mg dm⁻³ of K₂O (Fageria et al., 2010).

Statistical analysis

Normality test was applied to verify if the data had a normal distribution. All results showed normal distribution. Then, data was submitted to regression analysis ($p < 0.05$), using SigmaPlot software (11th edition). Means of AEI and recovery of K-applied values were submitted to "least significant difference" (LSD) test ($p < 0.05$) using Sisvar software (5th edition).

Conclusion

The application of the glauconitic siltstone in tropical soils promoted increases in *Urochloa brizantha* plant dry matter, as well as K, Si and Mn levels in soil samples and accumulated in plants. In general, greater effects following the application of the glauconitic siltstone fertilizer were obtained after consecutive cropping cycles due to its medium to long-term release. Results described in this study provide an important understanding of the use of natural nutrient rich-rocks as multi-nutrient fertilizers in tropical soils, being an efficient alternative to improve soil fertility and increase tropical pasture productivity.

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