Glauconitic Siltstone as a Source of Potassium, Silicon and Manganese for Flooded Rice

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Abstract

The objective of this study was to evaluate the efficiency of glauconitic siltstone as a multi-nutrient source for flooded rice. Two experiments were carried out under greenhouse conditions, one using a Ferralsol and the another an Arenosol. Glauconitic siltstone was applied in different doses (0, 5, 20, 40, and 80 mg dm^{-3} K$_2$O) and potassium chloride, wollastonite, and manganese sulfate were respectively used as standard sources, at doses of 80 mg dm^{-3} K$_2$O, 270 mg dm^{-3} Si, and 2 mg dm^{-3} Mn. The sources were incubated for 90 days on the two soil types and, after the incubation period, rice plants were sown, and two consecutive rice growths were performed. The application of glauconitic siltstone in tropical soils promotes increases in the plant and grain dry matter of rice plants, as well as K, Si and Mn contents in soil samples and accumulated in plants. Greater effects following the application of glauconitic siltstone are obtained after the second rice growth due to its gradual release.

Keywords: *Oryza Sativa*, beneficial elements, multi-nutrient source, rice-yields, sustainable agriculture

1. Introduction

Potassium chloride (KCl) is the most used source of potassium (K) fertilizer in the world (Ernani et al., 2007). However, crops fertilized with high KCl doses can present significantt chlorine (Cl) accumulation in leaves, which may inhibit some metabolic processes (Geilfus, 2018), as well promoting soil salinity and, as a consequence, water stress to plants (Watanabe et al., 2017).

Moreover, intensive application of KCl may also result in losses of K by leaching, since the K ion has a greater hydration radius than most other cations, resulting in a low retention cation-exchange capacity of soil (Dolcater et al., 1968). Potassium leaching is often a problem, especially in tropical areas with soil fertility constraints.

The total amount of K in Brazilian soils ranges from 0.5 to 25 g dm^{-3} (Ribeiro et al., 2010). Despite being the most absorbed element for the majority of crops, the content of soil available K to plants is low.

Recent investigations suggest that the addition of glauconite-rich rocks may increase the K content in soils (Zörb et al., 2014). In Russia, glauconitic sandstone is a K-rich rock used in K fertilizer production. In addition, there are reports of the use of glauconitic sandstone as K fertilizer in India and in some African countries, resulting in higher soil K contents and superior yields (Karimi et al., 2012).

In Brazil, especially in Minas Gerais state, the glauconitic siltstone (GS) could allow the country to become self-sufficient in K-fertilizing for several decades (Nader & Ackroyd, 2017). GS is a dark-green, fine grained siltstone, usually laminated, composed of glauconite (40-80%), quartz (10-20%), K-feldspar (10-15%), muscovite (5%), biotite (2%), and traces of titanium oxide, manganese oxide, goethite (< 1%), barium and rare-earth elements phosphates (Moreira et al., 2016). The average K$_2$O total is 10% (Nader & Ackroyd, 2017). GS provides K$_2$O and no Cl, allowing for use on organic agriculture. In addition, GS has silicon (Si) and manganese (Mn), with the potential to be used not only as a K fertilizer, but also as a multi-nutrient fertilizer (Violatti et al., 2019).

In this context, GS could reduce the demand for KCl, which may deplete soils and their microbiota when inappropriately managed (Karimi et al., 2012). The objective of this study was to evaluate the efficiency of GS as a multi-nutrient source for flooded rice. This crop was chosen since yield responses in rice to soil K, Si and

Mn amendments have frequently been recorded on weathered tropical or sub-tropical soils on which they are mainly grown. Owing to its capability to supply K, Si and Mn to plants, we expect to promote an innovative and sustainable use of GS powder in agricultural areas.

2. Materials and Methods

Two experiments were carried out under greenhouse conditions from 02/28/2016 to 10/29/2016, one using a clayey soil and the another, a sandy soil. The samples of the two different soil types were collected at 0-20 cm soil layer in Uberlândia, Minas Gerais, Brazil, which were classified as Ferralsol (Oxisol in Soil Taxonomy; Latossolo Vermelho Distrófico according to Santos et al., 2013) (69% of clay, pH ($CaCl_2$) 4.4, 6.6 mg dm^{-3} Si, 20 mg dm^{-3} K, 0.3 cmolc dm^{-3} Ca, and 0.02 mg dm^{-3} Mn) and Arenosol (Entisol in Soil Taxonomy; Typical Neossolo Quartzarênico Órtico according Santos et al., 2013) (9% clay, pH ($CaCl_2$) 4.4, 3.3 mg dm^{-3} Si, 20 mg dm^{-3} K, 0.2 cmolc dm^{-3} Ca, and 0.12 mg dm^{-3} Mn) (FAO, 2015).

GS used in the experiment was characterized according to macro and micronutrient contents, determined on a flame photometer according to the method described by MAPA (2017), 10 g kg^{-1} total K_2O, 270 g kg^{-1} total Si, and 0.5 g kg^{-1} total Mn. Wollastonite (230 g kg^{-1} Si, 303 g kg^{-1} Ca, and 110 g kg^{-1} Mg), KCl (600 g kg^{-1} K_2O) and manganese sulfate ($MnSO_4$) (310 g kg^{-1} Mn) were used as standard sources for comparison purposes. The chemical characteristics of nutrient sources used in this study were determined according to methodology described by Teixeira et al. (2017) and Korndörfer et al. (2004) (Si analysis). The treatments were applied to soils as a < 2 mm powder.

Both experiments were arranged in randomized blocks, design with four replications. Four GS rates were used according to the total K_2O content (10 g kg^{-1} K_2O—resulting in the following doses: 0, 5, 20, 40, and 80 mg dm^{-3} K_2O), which resulted in four Si (270, 1080, 2160, and 4320 mg dm^{-3} Si) and Mn doses (0.5, 2, 4, and 8 mg dm^{-3} Mn). Standard treatments were also used as checks: KCl (80 mg dm^{-3} K_2O), wollastonite + KCl (270 mg dm^{-3} Si + 80 mg dm^{-3} K_2O), manganese sulfate ($MnSO_4$) + KCl (2 mg dm^{-3} Mn + 80 mg dm^{-3} K_2O), which resulted in 32 pots for each soil type.

Since wollastonite supplies Ca and Mg to plants, different rates of $CaCO_3$ and $MgCO_3$ were added to adjust the amounts of Ca and Mg in all treatments and increase soil base saturation to 70% and 90% in clayey and sandy soil, respectively.

The products were incubated for 90 days in 8 dm^{-3} of the two different soil types. In order to maintain humidity, around 80% of the field capacity value for each soil, deionized water was added to pots. Soil moisture was rigorously controlled by daily weighing of the plastic containers, replacing the volume lost through evapotranspiration with deionized water.

After the incubation period, 200 mg kg^{-1} N and 400 mg kg^{-1} P_2O_5 were added to samples through ammonium sulfate and triple superphosphate, respectively. The micronutrients were supplied via solution at the rates of 1.5; 5.0; 0.5, and 0.05 mg dm^{-3} Cu, Zn, B, and Mo, through the sources $CuSO_4 \cdot 5H_2O$; $ZnSO_4 \cdot 7H_2O$; H_3BO_3 and $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, respectively. Then, BRS Atalanta irrigated cycle rice cultivar was sown, which presents smooth grains and leaves, high tillering capacity, and strong stalks (Embrapa, 2007). Fifteen seeds were sown per pot, at a depth of 2 cm. After the emergence, thinning was carried out, maintaining 6 plants per pot. At this time, a 2 cm water irrigation level was also added, which was maintained until 15 days before harvesting.

Rice plants were harvested at 89 days after sowing (DAS), and at the same time, the soil samples were collected. Plants samples were dried in an oven and weighed to obtain the plant dry matter (DM) and grain DM values. Afterwards, the samples were ground and submitted to nitric-perchloric digestion. The K and Mn concentrations were analyzed by flame spectrophotometry and atomic absorption spectrophotometry (Teixeira et al., 2017), respectively, whereas Si concentrations were measured at 630 nm using an ultraviolet (UV) visible spectrophotometer (Korndörfer et al., 2004). The product of the plant DM and nutrient concentration in plant samples resulted in the values of K, Si, and Mn accumulated in rice plants.

Soil chemical analyses were performed according to Korndörfer et al. (2004) (soil available Si content) and Teixeira et al. (2017) (soil available K-Resin extraction and Mn contents).

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

$$\text{RAE (\%)} = \frac{\text{GS DM} - \text{control DM}}{\text{KCl DM} - \text{control DM}} \times 100 \tag{1}$$

where, GS DM is the plant DM with the application of GS (80 mg dm^{-3} K_2O), based on the total K_2O; KCl DM is the plant DM, with the application of KCl (80 mg dm^{-3} K_2O); the control DM is the plant DM in the control treatment, without K_2O application (0 mg dm^{-3} K_2O).

After the first rice growth, a second rice growth was conducted to evaluate the residual effect of the sources applied. Thus, the same rice cultivar was sown in the same treatments previously cultivated, but, in this case, without the application of GS, KCl, wollastonite, or manganese sulfate. The experiment followed the same management and analyses as the previous one.

Normality test was applied to verify if the data had a normal distribution. All results showed a normal distribution. Then, data was subjected to variance analysis, followed by regressions analysis at 5% probability. All analyses were performed using the software SigmaPlot 11.0 (Systat Software, 2008).

3. Results and Discussion

The effects of GS on plant and grain DM yields, after two consecutive rice growths, as compared to KCl, ranged from 35 to 64 g pot^{-1} and from 13 to 30 g pot^{-1}, after the first rice growth in clayey and sandy soil, respectively (Figure 1). As regards the DM of rice plants grown in sandy soil, it was found that the GS, at a dose of 60 kg ha^{-1} K_2O, presented the highest values (Figure 1b), while linear increases of 3.7 g pot^{-1} were observed for every 10.0 mg dm^{-3} K_2O applied to the clayey soil (Figure 1a).
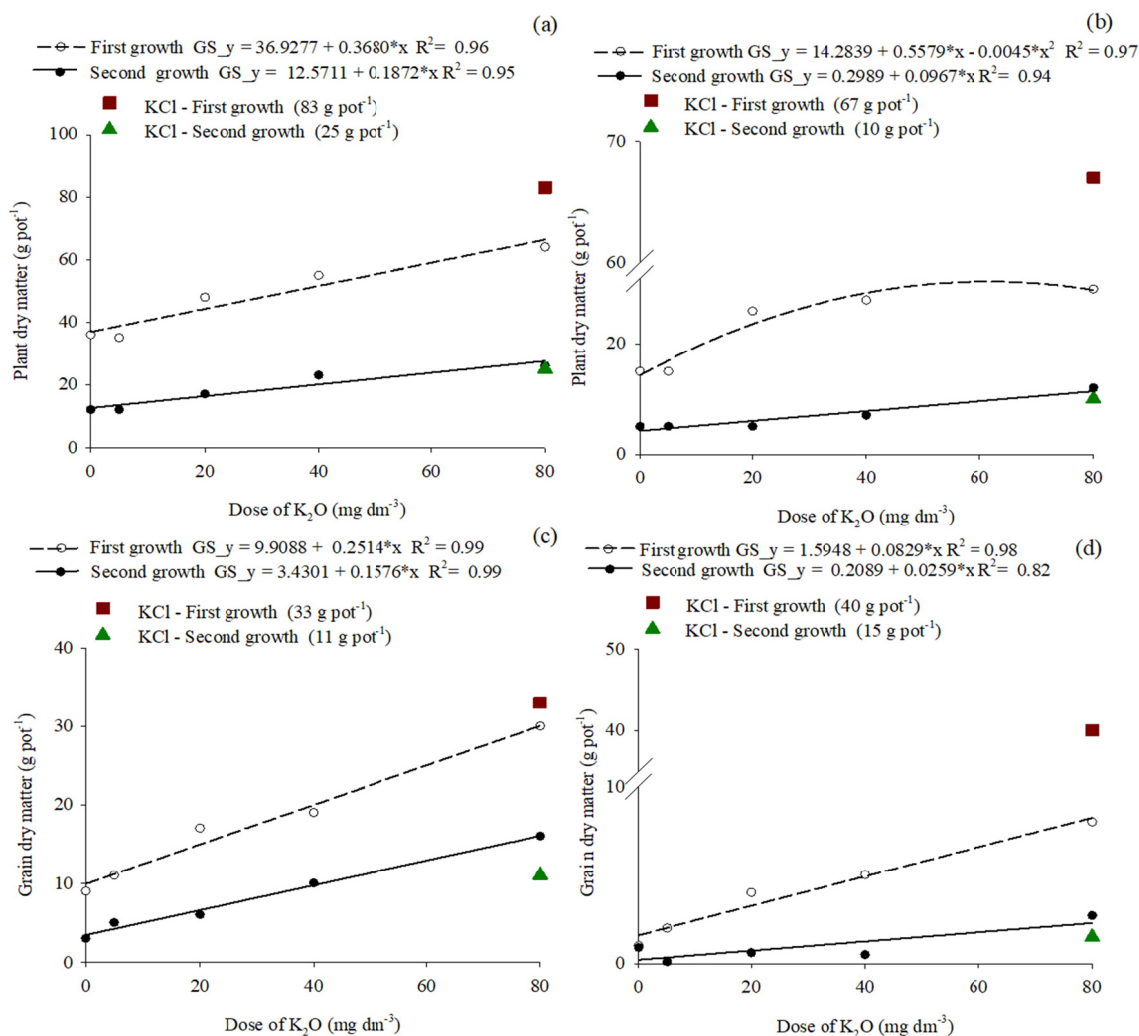

Figure 1. Plant dry matter of rice plants growth in clayey (a) and sandy (b) soils and grain dry matter of rice plants growth in clayey (c) and sandy (d) soils with increasing doses of K_2O through glauconitic siltstone (GS) after two consecutive rice growths. Square and triangle symbols refer to the KCl treatment at dose of 80 mg dm^{-3} K_2O after the first and second rice growth, respectively

After the second growth, these values ranged from 12 to 26 g pot[-1] in clayey soil and from 5 to 12 g pot[-1] in sandy soil (Figure 1). Linear increases of plant DM after the second growth were observed following the increase of GS dose to the soil; for every 10 mg dm^{-3} applied to the clayey and sandy soil, there was an increase in plant DM of 1.9 and 1.0 g pot[-1], respectively (Figures 1a and 1b). In general, higher response to GS application was observed in clayey soil, since the soil type affects the availability of K to plants. Potassium leaching is frequently related to the soil texture, being the most easily leached cation, especially in sandy soils, due to its displacement to the solution and to its percolation (Mendes et al., 2016), making it less available to plants.

After the first rice growth, the application of GS resulted in an increase in plant and grain DM, compared to the check, without K_2O, yet the effects were not comparable with the KCl application (Figure 1). The greater yields provided by the standard source were due to the greater solubility, which is mostly water-soluble and readily available to plants (Prakash & Verma, 2016). However, in the second rice growth, GS promoted higher plant and grain DM values than the KCl application.

In general, relative agronomic efficiency (RAE) values following GS application were smaller than KCl values (values minor than 100%) after the first rice growth (Figure 2). In contrast, after the second rice growth, GS sources presented greater agronomic efficiency (values higher than 100%), indicating a good prospect for gradual release use, as previously discussed.
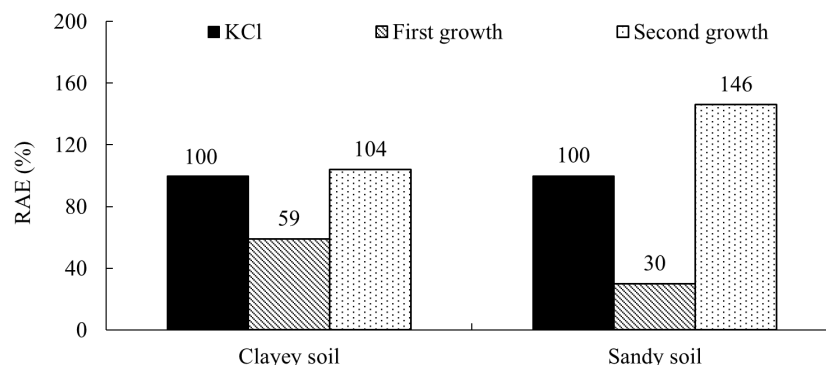

Figure 2. Relative Agronomic efficiency (RAE) (%) of glauconitic siltstone in relation to KCl in clayey and sandy soils after two consecutive rice growths

The application of increased doses of GS improved the contents of K in soil and accumulated in rice plants (Figure 3).
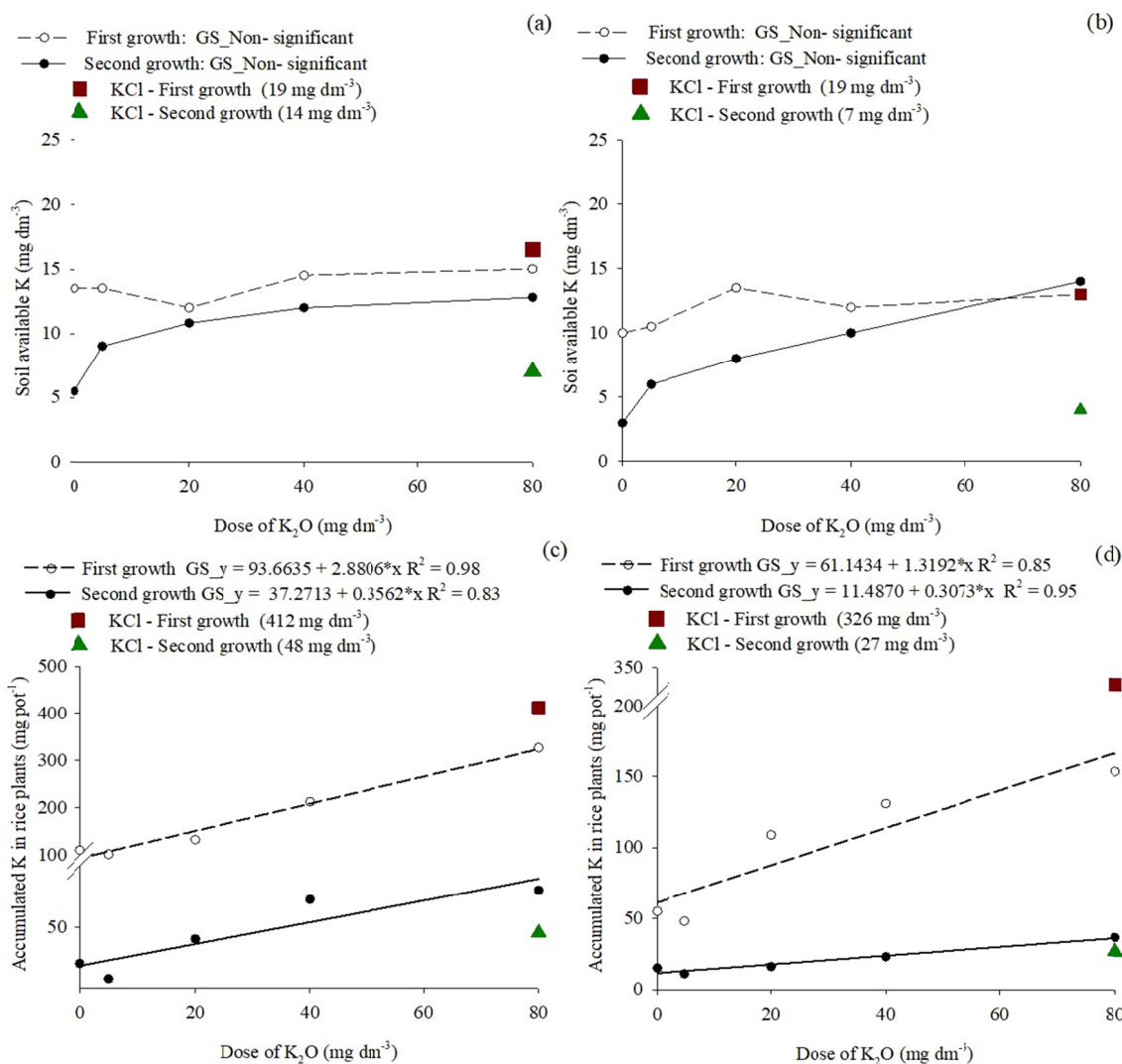
Figure 3. Soil exchangeable K (Resin extraction) contents in clayey (a) and sandy (b) soils and accumulated K in rice plants growth in clayey (c) and sandy (d) with increasing doses of K_2O through glauconitic siltstone after two consecutive rice growths. Square and triangles symbols refer to the KCl treatment at dose of 80 mg dm^{-3} of K_2O after the first and second rice growth, respectively

After the second rice growth, the application of 20 mg dm^{-3} of GS, in both clayey and sandy soils, resulted in higher soil available K contents and accumulated K in rice plants than KCl treatments (80 mg dm^{-3}), even when applying GS at a dose four times lower than the standard source (Figure 3). For each 10 mg dm^{-3} K_2O applied through GS in clayey soil, there was a linear increase of 28.8 mg pot^{-1} and 3.6 mg pot^{-1} of accumulated K in rice plants, after the first and second growths, respectively (Figure 3c). Considering the accumulated K in rice plants growth in sandy soils, increases of 13.2 mg pot^{-1} were observed after the first growth and 3.1 mg pot^{-1} after the second growth (Figure 3d). The use of gradual-release K fertilizers, such as GS, is an alternative to maintain the K status in soils for sustaining crop production (Jaiswal et al., 2016). Thus, GS may contribute to soil fertility improvement in the medium to long-term, according to their solubility and reactivity with soil. In addition, the use of national nutrient sources has great importance in Brazilian agriculture, reducing its dependence on external fertilizer and providing a source with lower chlorine contents and risk of leaching.

In general, the application of GS also resulted in increases in the content of Si in the soil and accumulation of Si in rice plants, when compared to control treatment, but was not comparable with the results obtained with the wollastonite (Figure 4). Buck et al. (2011) affirm that the wollastonite is normally used as a positive check because it is a reference source used by many Si researchers. Thus, this standard source presents a relatively high degree of purity and is rich in calcium silicate ($CaSiO_3$) (Buck et al., 2011), and its application results in higher

soil and plant Si contents (Tubana et al., 2016). Despite the fact that wollastonite, calcium silicate, is more soluble and contains higher amounts of Si than other Si sources, the refining process of this mineral is labor-intensive and expensive, which limits its mass production as a fertilizer (Tubana et al., 2016).
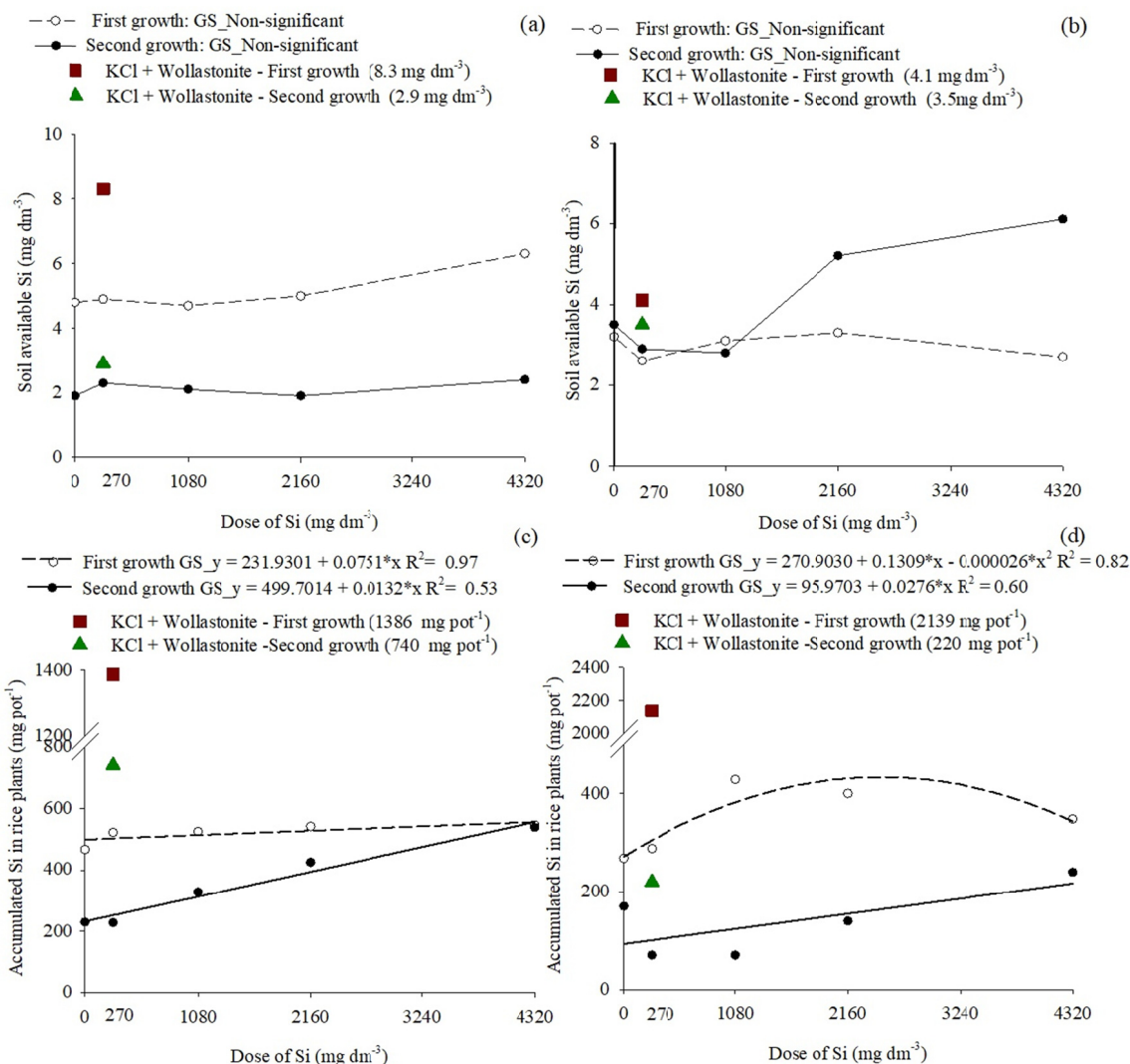

Figure 4. Soil available Si contents ($CaCl_2$ extraction) in clayey (a) and sandy (b) soils and accumulated Si in rice plants growth in clayey (c) and sandy (d) soils with increasing doses of K_2O through glauconitic siltstone after two consecutive rice growths. Square and triangle symbols refer to the KCl + Wollastonite treatment at doses of 80 mg dm^{-3} K_2O and 270 mg dm^{-3} Si after the first and second rice growth, respectively

The accumulated Si in rice plants growth in clayey soil increased linearly. Every 10 mg dm^{-3} Si through GS increased the Si content by 0.8, and 0.1 mg pot^{-1} after the first and second growth, respectively (Figure 4a and 4b). The Si accumulated after the first growth of rice plants in sandy soil was adjusted to a quadratic equation, with the maximum value at a dose of 2,520 mg dm^{-3} of Si (Figure 4c). For the second growth in sandy soil, increases of 0.3 mg pot^{-1} Si were obtained for each 10 mg dm^{-3} Si applied through GS (Figure 4d).

GS can increase soil and rice Si contents. Improvement in the Si contents is mainly relevant in tropical soils, which are typically depleted of Si due to weathering and intensive cropping. In addition, the use of natural Si sources (as the GS), may be a good alternative in soils cultivated with Si-accumulating crops (*e.g.*, grasses), as some crops, such as rice, are capable of removing expressive soil Si concentrations (Meena et al., 2014). Silicon plays a special role in plant health and ecology, mitigating numerous abiotic and biotic stresses, including water and salinity stress, metal toxicities, nutrient imbalance, fungal and bacterial pathogens and insect herbivores (Keeping, 2017).

Although increases Si content in soil were obtained in both soil types, higher accumulated Si in rice plants were observed in clayey soil (Figure 4a). This fact may be related to positive correlation between soil-available Si content and clay minerals content. Clay minerals with large specific surface have a high capacity to adsorb silicates (Liang et al., 2015).

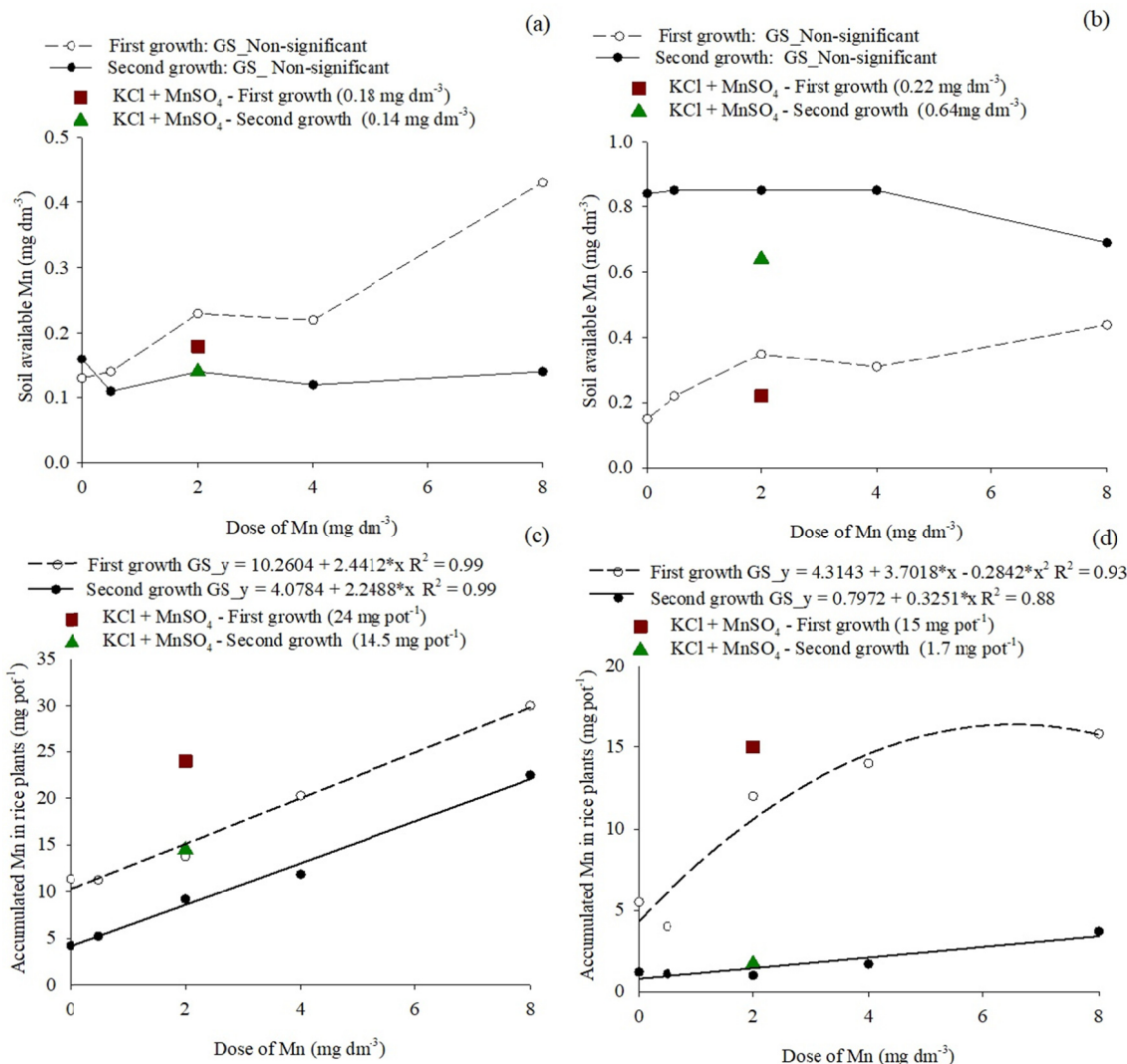GS was also efficient in increasing soil and accumulated Mn contents in rice plants (Figure 5).

Figure 5. Soil available Mn in clayey (a) and sandy (b) soils and accumulated Si in rice plants growth in clayey (c) and sandy (d) soils with increasing doses of K_2O through glauconitic siltstone after two consecutive rice growths. Square and triangle symbols refer to the $KCl + MnSO_4$ treatment at doses of 80 mg dm^{-3} K_2O and 2 mg dm^{-3} Mn after the first and second rice growth, respectively.

After the first rice growth, soil Mn contents ranged from 0.13 to 0.43 mg dm^{-3} and from 0.15 to 0.44 mg dm^{-3}, following the highest GS dose in clayey and sandy soil, respectively (Figures 5a and 5b). In the second growth, soil Mn contents decreased when compared to control treatment, whereas the element content in plant tissues increased. Linear increases were observed as the applied dose of GS to the clayey soil increased; for every 1.0 mg dm^{-3} Mn applied, there were increases in the accumulated Mn of 2.4 and 2.2 mg pot^{-1} after the first and second growth, respectively (Figure 5c). For plants growth in sandy soil, linear increases of 0.3 mg pot^{-1} Mn were observed after the second growth, while the best results after the first growth are obtained when GS is applied at a dose of 6.5 mg dm^{-3} Mn. Rice plant is known as a Mn tolerant plant species (Horiguchi, 1988), which accumulate from 5 to 10 times more Mn than other grasses (Foy et al., 1978). The presence of Mn in GS can also improve fertility of weathered tropical soils, which present very low Mn contents.

In addition to GS application, flooded conditions also directly influenced the Mn availability to rice plants. Under flooded conditions, soils show low redox potential, thus Mn deficiency has decreased in lowland (Tanaka & Navasero, 1966). As Mn is an essential element for plants and its deficiency decreased growth and yield, as well as making plants more susceptible to pathogens (Socha & Guerinot, 2014), the use of GS associated to flooded rice cultivation may be a good alternative to increase Mn availability for plant uptake.

In general, GS efficiency to supply K, Si and Mn to rice plants shows an innovative and sustainable use of nutrient-rich rock to improve tropical soil fertility and rice yields, especially after consecutive crop cycles.

4. Conclusions

(1) Results described in this study provide an important understanding of the use of glauconitic siltstone not only as a K fertilizer, but as source of silicon (Si) and manganese (Mn) in tropical soils, being an efficient alternative to improve tropical soil fertility and increase rice yields.

(2) The application of glauconitic siltstone in tropical soils promoted increases in plant and grain dry matter of flooded rice, as well as K, Si, and Mn contents in soil samples and accumulated in plants.

(3) Greater effects following the application of glauconitic siltstone are obtained after the second rice growth due to its gradual release.

Acknowledgements

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