Journal of Agricultural Science; Vol. 11, No. 6; 2019
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Chemical Attributes of Soil and Response of Wheat to Serpentinite in Direct Seeding System

Alves A. Alovisi[1], Munir Mauad[1], Alessandra M. T. Alovisi[1], Luciene K. Tokura[2], Robervaldo S. Silva[1], Cezesmundo F. Gomes[3], Reinaldo P. Ricieri[2], Jair A. C. Siqueira[2], Gabriele B. Oliveira[1], Bruno F. Lima[1] & Waldenio A. Araújo[1]

[1] Faculty of Agrarian Sciences, Federal University of Grande Dourados, Dourados, MS, Brazil

[2] State University of West Paraná, Cascavel, Paraná, Brazil

[3] Faculdade Anhanguera de Dourados, Dourados, MS, Brazil

Correspondence: Alessandra M. Tokura Alovisi, Faculty of Agrarian Sciences, Federal University of Grande Dourados, Dourados City, State of Mato Grosso do Sul, Brazil. E-mail: alessandraalovisi@ufgd.edu.br

Received: February 14, 2019 Accepted: March 16, 2019 Online Published: May 15, 2019
doi:10.5539/jas.v11n6p460 URL: https://doi.org/10.5539/jas.v11n6p460

This study was financed in part by the National Council for Scientific and Technological Development (CNPq).

Abstract

The serpentinite is an alternative for the correction of soil acidity and is composed of calcium and magnesium silicate. The objective of this study was to evaluate the residual effect of the serpentinite application on soil chemical attributes and the effects on wheat crop productivity in a no-tillage system. The experimental design was a randomized block design, in a subdivided plot scheme, with four replications. The plots were constituted by serpentinite doses (0, 2, 4, 8 and 16 Mg ha^{-1}) and in the subplots the soil collection layers (0.0-0.10 and 0.10-0.20 m). The chemical attributes of the soil evaluated at 41 months after the application of serpentinite, presented favorable results of the residual power of this corrective. The main results observed are related to the increase of pH, decrease of aluminum content and potential acidity, and increase of Ca, Mg and Si contents, cation exchange capacity (CTC) and base saturation. The residual of the serpentinite in the soil contributed with an improvement in the chemical attributes of the soil, which favored the increase of the dry mass, number of spikes and yield of the wheat crop.

Keywords: *Triticum aestivum* L., soil fertility, acidity correction, magnesiumsilicate, silicon

1. Introduction

Most of the soils of Brazil present problems of acidity, low availability of nutrients and silicon (Si) for the plants, thus requiring constant corrections and fertilization to raise productive potentials.

The serpentinite is a rock of metamorphic origin, ultrabasic mainly formed by dolomite, calcite and silica, therefore a source rich in magnesium and calcium with contents of up to 42% of MgO, being able to contribute to the balance of Ca/Mg ratio of the soil, besides presenting high amounts of silicon (up to 45% SiO_2) among other minerals, contributing to the replacement of these minerals in the soil (Friedman, 2013).

According to Tavares et al. (2010) the serpentinite can be defined with a calcium and magnesium silicate with average SiO_2 and MgO contents of 40.56 and 45.70%, respectively. Teixeira et al. (2010) consider the serpentinite with a silicate rock powder with chemical characteristics necessary to be considered a soil corrective.

The serpentinite is therefore soil corrective, source of nutrients and silicon, beneficial element, mainly for the accumulating cultures of this element, such as the tropical grasses, being able to bring benefits due to the increase of the rigidity of the cellular wall, providing better architecture of the plant, increasing photosynthetic efficiency.

In Brazil, studies have reported that potatoes have increased productivity by supplying Si to plants, such as wheat (Sarto et al., 2015), sugarcane (Alovisi et al., 2018) and rice (Tokura et al., 2007). This increase in productivity may be related to changes in soil chemical attributes.

Considering that the use of serpentinite tends to be the agricultural practice in Brazil, a better understanding of the effects of this corrective in the chemical properties of the soil and in the development of the wheat crop is essential to adopt management strategies to improve agricultural production.

In view of the above, the objective was to evaluate the residual effect of the serpentinite on the chemical characteristics of the soil and the effects on wheat yield in the no-tillage system.

2. Material and Methods

The experiment was carried out under field conditions in the experimental area of the Federal University of Grande dourados (UFGD) in Dourados-MS, geographical coordinates 54°59′13″ west longitude and 22°14′08″ south latitude, with altitude of 434 m, in a typical Dystrophic Red Latosol, clay texture (Santos et al., 2013). According to Köppen, the region's climate is classified as Am, tropical humid or subhumid (Alvares et al., 2013), with an average annual rainfall of 1,400 mm, and average temperatures range from 18 °C to 25 ºC in the colder and respectively. The experimental area was already cultivated with annual crops (soybean, corn and wheat) for more than 20 years.

The characterization of soil chemical attributes before the application of the serpentinite was performed at depths of 0.0-0.10 and 0.10-0.20 m. The chemical determination of the soil followed the methodology described by Silva (2009), with the following results: pH in water: 5.7 and 5.4; pH in $CaCl_2$: 5.0 and 4.6; Ca ($cmol_c\ dm^{-3}$): 3.6 and 1.5; Mg ($cmol_c\ dm^{-3}$): 1.9 and 0.9; K ($cmol_c\ dm^{-3}$): 0.27 and 0.11; Al ($cmol_c\ dm^{-3}$): 0 and 0.6; H + Al ($cmol_c\ dm^{-3}$): 6.1 and 5.7; SB ($cmol_c\ dm^{-3}$): 119 and 82; P Mehlich-1 ($mg\ dm^{-3}$): 16.4 and 4; MO ($g\ dm^{-3}$): 27 and 17 and V%: 48 and 31, at depths of 0.0-0.10 and 0.10-0.20 m, respectively.

The experimental design was a randomized block design in a subdivided plot scheme, with four replications. The plots were composed of five serpentinite doses (0, 2, 4, 8 and 16 Mg ha^{-1}), with characteristics (SiO_2: 38.40%, Al_2O_3: 1.31%, FeO_2: 12.66% CaO: 0.66%, MgO: 35.07%, K_2O: 0.01%, N_2O: < 0.01%, TiO_2:0.03%, MnO: 0.09% and P_2O_5: 0.02% and in the subplots the layers of soil collection (0.0-0.10 and 0.10-0.20 m). The serpentinite was applied to haul in each plot, according to the treatment and incorporated up to 0.10 m deep. After application of the serpentinite the area was cultivated with corn (crop 2013), soy (crop 2013/2014), wheat (2014), soybean (2014/2015), and brachiaria (2015).

Before the sowing of wheat, the soil was sampled at depths of 00-0.10 and 0.10-0.20 m. The soil samples were air-dried, sieved, sieved with a 2 mm aperture mesh, and the chemical analysis was carried out where the pH in water, pH $CaCl_2$, calcium, magnesium, exchangeable aluminum, phosphorus extracted by Melich-1 and potassium, according to methodology described by Silva (2009). The values of CTC pH 7.0, sum of bases (S) and saturation by bases (V%) were obtained by calculation. For this determination, the methodology described by Korndörfer, Pereira, and Nolla (2004).

The sowing of wheat was carried out with the use of mechanical seeders on 05/25/2016. The BRS 18-Terena wheat variety was used and 160 kg ha^{-1} of seeds were seeded, with a row spacing of 0.18 m, targeting a population of 500 thousand ha^{-1} plants. At sowing, no maintenance fertilization was used because fertility levels were adequate for the wheat crop.

For leaf analysis of wheat, 30 leaf leaves were collected at the beginning of flowering. The leaves were dried in an air circulation oven at 60 ºC until reaching constant weight and later milled in a Willey mill to determine macronutrient and micronutrient concentration (Malavolta, Vitti, & Oliveira, 1997). For the determination of silicon, the methodology described by Korndörfer et al. (2004).

At the end of the crop cycle, the entire aerial part was cut to quantify the dry matter of the aerial part (in grams) of the plants, counting the number of tillers, number of spikes, percentage of fertile tillers, number of ears, number of spikelets, number of grains per spikelet, number of grains per spike, mass of 1000 grains and yield. All variables were performed in 6 rows of 1.0 m length randomly at the time of harvest in each experimental unit. The grains were quantified and the data transformed in kg ha^{-1} to 13% (wet basis).

Data were submitted to analysis of variance and, when there was a significant effect of the serpentinite doses, the regression studies were applied at 5% level, with the aid of the statistical program Sisvar (Ferreira, 2014).

3. Results and Discussion

3.1 Soil Chemical Attributes

After 41 months of application of the serpentinite, it was observed that there was a significant effect for all chemical attributes of the soil one for interaction between serpentinite doses and depth of soil collection, others only isolated effects of doses and depths.

For the organic matter and soil phosphorus content, there was only a depth factor effect, with higher values in the superficial layer (0.0-0.10 m), with 30.44 and 24.82 g kg^{-1} of organic matter and 13.60 and 6.39 mg dm^{-3} phosphorus in the soil, respectively for the layers of 0.0-0.10 and 0.10-0.20 m. These results can be explained by the higher deposition of organic residues that occur in this soil layer over the years and by the low mobility of phosphorus both horizontally and vertically, especially in clay soils (Marschner, 2002).

There was a significant interaction of the factors serpentinite and depth, for the variables calcium, magnesium, sum of bases, cation exchange capacity (CTC) and silicon, indicating that the effects of serpentinite doses on these variables depends on the soil layer studied. The residual of the serpentinite doses influenced in a positive and linear way the Ca contents in the soil, raising the levels from 27.61 to 35.57 mmolc dm^{-3} in the layer 0.0-0.10 m depth, but not altered the contents at a depth of 0.10-0.20 m, with a mean of 27.65 mmolc dm^{-3} (Figure 1A). This increase was relatively high considering the CaO contents present in the serpentinite (0.66%). It is possible that the increase in this intensity could be associated with the absorption of this nutrient by Urochloa (crop present before soil collection) and, after forage decomposition, calcium has been released at the soil surface, since the production of phytomass of Urochloa was higher in the higher doses of serpentinite. According to Pacheco et al. (2013) calcium may be the third most accumulated element in the Urochloa phytomass losing only to N and K.

Mg levels were also influenced significantly and significantly in the two soil layers evaluated (Figure 1B) with relative increases of 56% and 50% in the layers 0.0-0.1 m and 0.1-0.2 m, respectively. This increase was expected due to the serpentinite in its chemical composition, 35.07% of MgO due to the presence of dolomite, proving to be an efficient alternative for poor soils in this element. Ramos et al. (2006) and Moraes et al. (2018) also report that the main justification for magnesium increases was due to the high content of this element in magnesium silicates. The Ca and Mg contents were higher in the 0.0-0.10 m layer (Figures 1A and 1B), which are due to the solubilization of the corrective and release of Ca and Mg, as well as the mineralization of the nutrients of the residues Urochloa plants deposited on the soil.

The sum of bases was influenced by the residual of the serpentinite doses, where the data adjusted to the increasing linear model at the two depths evaluated (Figure 1C). At the depth of 0.0-0.10 m, an estimated 40% increase in the residual dose of 16 Mg ha^{-1} is observed (Figure 1C). In the 0.10-0.20 m layer the increase was 14%. The highest SB values were observed in the 0.0-0.10 m range (Figure 1C). These results are related to the highest values of Ca, Mg and K found in this layer.

For the cation exchange capacity (CTC layer), the data were fitted to the polynomial model, with a minimum CTC value (95.13 mmolc dm^{-3}) obtained with the residual estimate of the application of 16 Mg ha-1 in the layer of 0.10-0.20 m and maximum value of CTC (105.67 mmolc dm^{-3}) reached with the residual estimate of the application of 12.94 Mg ha^{-1} in the layer of 0.0-0.10 m (Figure 1D). Although no significant values of CTC were obtained for the dose factor alone, CTC in the soil presented higher values in the superficial layer, decreasing with increasing depth, this behavior is due to the higher Ca, Mg, K and organic matter layer of 0.0-0.10 m.

The soil silicon content presented a linear behavior, with soil Si content of 19.66 mg dm^{-3}, in the residual dose of 16.0 Mg ha^{-1}, 25% increase in the 0.0-0 layer, 10 m (Figure 1E). The increase in Si availability in soil with the application of silicates is also reported by Sarto et al. (2014). In the 0.10-0.20 m layer, soil Si contents did not fit any mathematical model, presenting a mean of 16.42 mg dm^{-3} (Figure 1E). Pereira et al. (2007) point out that Si presents low mobility in the soil, which may explain the higher levels in the layer where the serpentinite was added.

For the variables pH in water, pH $CaCl_2$, potassium content, aluminum content, potential acidity and base saturation, there was only an isolated effect of the residual of the serpentinite doses. The values of pH in water (Figure 2A) and pH in $CaCl_2$ (Figure 2B) increased linearly with increasing serpentinite doses, with consequent reduction of aluminum content (Figure 2) and potential acidity (Figure 2E), which confirms the neutralizing action of the serpentinite. According to Korndorfer and Nolla (2003), hydrolysis of the silicate anion present in the serpentinite occurs the release of hydroxyls (OH^-), which reacts and neutralizes the H + in solution, raising the pH and precipitating Al^{3+} in the form of Al hydroxide [$Al(OH)_3$)], low solubility and inactive in soil solution and therefore non-toxic to plants. The reduction of soil acidity with the use of silicates was also observed by other authors such as Alovisi et al. (2018), and Moraes et al. (2018).

For the potassium content, an adjustment of the data to the quadratic function, with a minimum content of K (3.23 mmolc dm^{-3}), achieved with the residual application of the dose of 5.61 Mg ha^{-1} of serpentinite (Figure 2C). Despite the lower value of K in this dose, soil content is still in the high availability range for plants, according to Sousa and Lobato (2004).

The percentage of base saturation (V%) in the soil presented a linear behavior, with V% of 54%, estimated in the residual of the application of 16.0 Mg ha^{-1} of serpentinite (Figure 2F). Silva et al. (2017) recommend the base saturation of 60% for wheat cultivation. In this study, the V% recommended for wheat cultivation was very close to the treatment that received the dose of 16 Mg ha^{-1} of serpentinite, even after 41 months of its application.

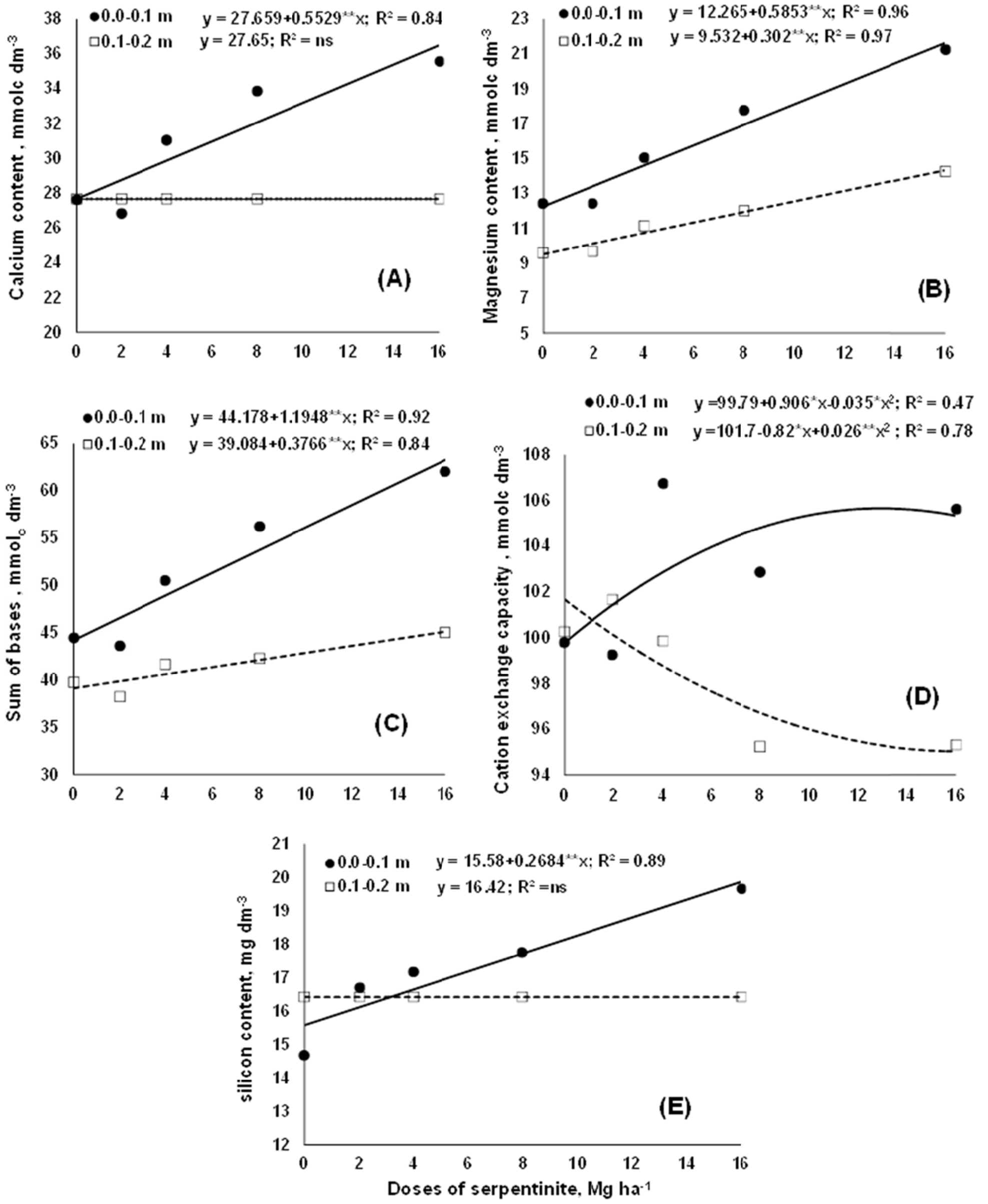

Figure 1. Chemical soil attributes: calcium content (A), magnesium content (B), sum of bases (C), cation exchange capacity (D) and silicon content (E), as a function of doses of serpentinite, at depths of 0-0.10 and 0.10-0.20 m. Dourados-MS, Brazil, 2018. * and ** significant at 5 and 1%, based on significance by the F test

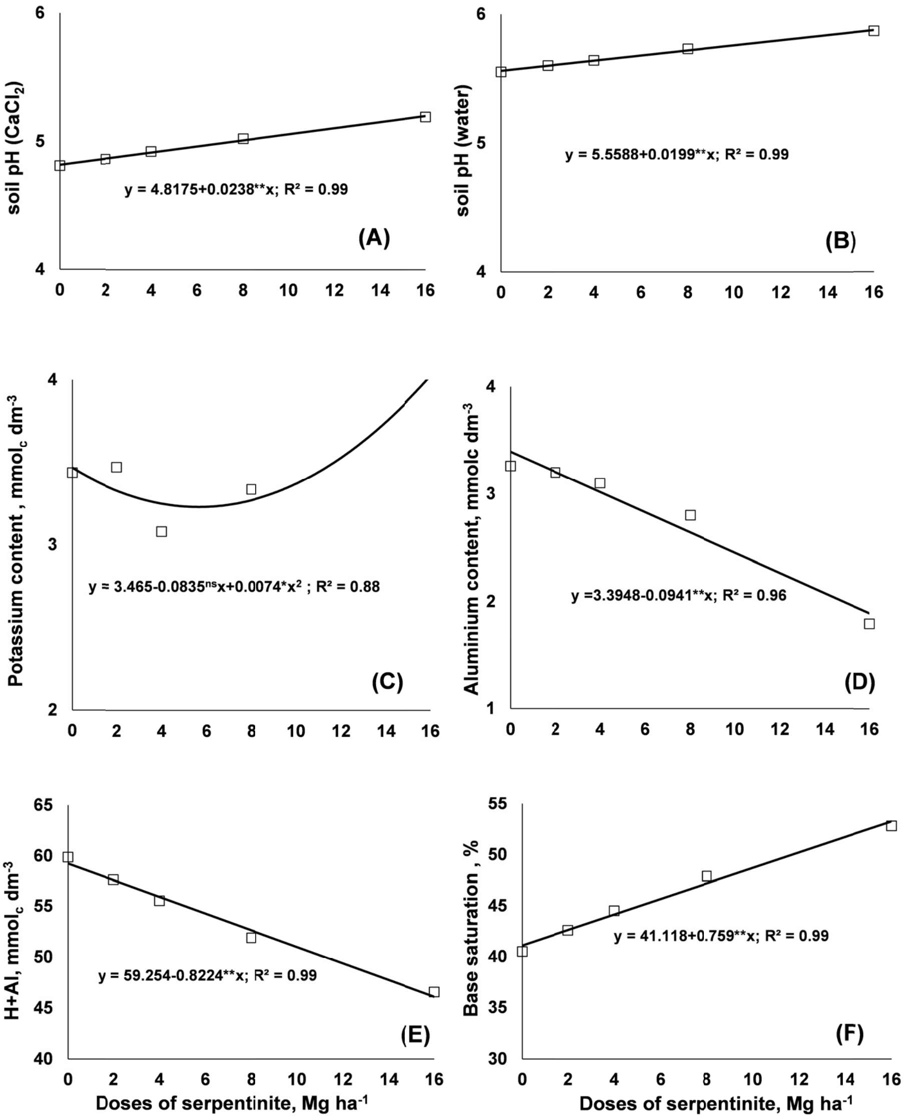

Figure 2. Chemical soil attributes: pH in $CaCl_2$ (A), pH in water (B), potassium content (C), aluminum content (D), potential acidity (E) and base saturation function of serpentinite doses. Dourados-MS, Brazil, 2018. * and ** significant at 5 and 1%, based on significance by the F test.

The results in the soil chemical changes, promoted by the serpentinite application, corroborate with reports by Teixeira et al. (2010) and Moraes et al. (2018), which emphasize the use of the material as soil corrective, with the advantage of having silicon in its composition, which could make the plants less susceptible to environmental stresses.

3.2 Leaf Concentration

There was a linear decreasing effect on the addition of serpentinite doses at concentrations of P, K and Cu (Figures 3A, 3B and 3D, respectively). Higher concentrations of P in the leaves with silicate use are usually found, due to the higher availability of P in the soil promoted by the displacement of phosphorus by silicon in the binding sites and by the increase of soil pH, but this was not observed in this work. However, the significant increase in dry mass obtained in the aerial part of the wheat indicates a better nutritional status of the plant by P, portraying the importance of not considering only a simple evaluation of its concentration in the tissues. The increased wheat mass may have conferred the P concentration the so-called dilution effect for that nutrient, in addition, the concentrations found in all treatments are within the range considered suitable for P in the wheat crop as described by Raij et al. (1997).

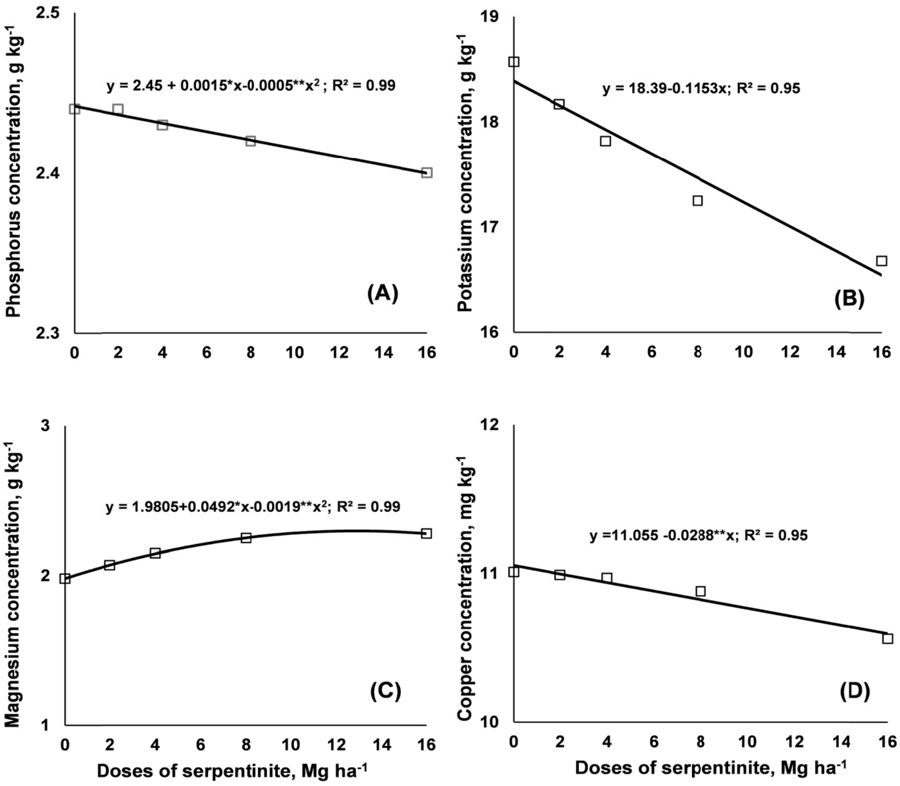

Figure 3. Foliar concentrations of phosphorus (A), potassium (B), magnesium (C) and copper (D), as a function of serpentinite doses. Dourados-MS, 2018. * and ** significant at 5 and 1%, based on significance by the F test

The reduction in K concentration in wheat tissue is possibly due to the dilution effect due to the higher dry mass produced by wheat in the higher doses of serpentinite. Although the concentrations of silicon were not significantly influenced by the increase of the serpentinite doses, it is worth noting that some authors observed a decrease in the K concentrations in grasses with increasing silicon concentration in nutrient solution (Greger, Landberg, & Vaculik, 2018). Reboredo et al. (2013) emphasize negative correlation between K and Si within some species. According to Tedesco et al. (2004), concentrations of K in the range of 15 and 30 g kg^{-1} are within the range considered suitable for K in the wheat crop.

Although the serpentinite used in this work contains Cu in its composition, acting as a source, the availability of this element was strongly influenced by the pH of the soil solution as a function of the applied doses (Figure 3D). Considering that soil pH is the soil property that most affects the availability of micronutrients (Ramos et al., 2006), the increase of serpentinite doses favored an increase in pH of the solution (Figures 2A and 2B), which conditioned the precipitation of Cu ions, in the form of hydroxides, decreasing their availability for wheat.

The increase in Mg concentration in wheat leaf tissue with the use of serpentinite, reaching a maximum concentration of 2.30 g kg^{-1}, with a dose of 12.95 Mg ha^{-1} (Figure 3C), may be related to increases of magnesium concentrations in the soil due to the high concentration of MgO (35.07%) present in the serpentinite that provided greater availability and absorption of the nutrient by the plant, as well as the plant's better ability to absorb Mg due to the reduction of H+Al (Faquin, 2005).

According to Salvador et al. (2000) increasing doses of Al reduce the uptake and transport of several elements to shoot, including Mg, also suggesting that increases in Mg concentrations in wheat tissue are related to the increase of Mg in the soil and reduction of acidity. Mg concentrations are within a suitable concentration range for the wheat crop which is 1.1-4.0 g kg^{-1} (Tedesco et al., 2004).

For the concentrations of N, Ca, Si, Fe, Mn and Fe, there was no statistical difference between treatments. The mean concentrations were: 40.44 g kg^{-1} N; 4.30 g kg^{-1} Ca; 14.16 g kg^{-1} Si; 243.19 mg kg^{-1} of Fe; 152.16 mg kg^{-1} of Mn and 25.96 mg kg^{-1} of Zn, values within the limits considered for the good development of wheat (Raij, Cantarella, Quaggio, & Furlani, 1997).

3.3 Wheat Productivity Components

The residual of the application of serpentinite in the soil influenced the values of shoot dry matter, number of tillers, number of ears and yield of the wheat crop. It is observed that the residual of the applied serpentinium doses provided a larger number of tillers, number of ears, shoot dry mass and productivity (Figures 4A, 4B, 4C and 4D). According to Valério et al. (2009), the number of tillers is influenced by several factors, such as hormonal effect, environmental factors, photoperiod, sowing density, water status and nutritional factor, and the nitrogen element seems to be one of the most important in the definition of expression capacity of tillering. Thus, the improvement in the soil acidity correction by the application of serpentinite may have allowed an increase in the volume of the root system and, consequently, a greater volume of soil explored, favoring the absorption of water, nutrients and consequently the greater number of tillers.

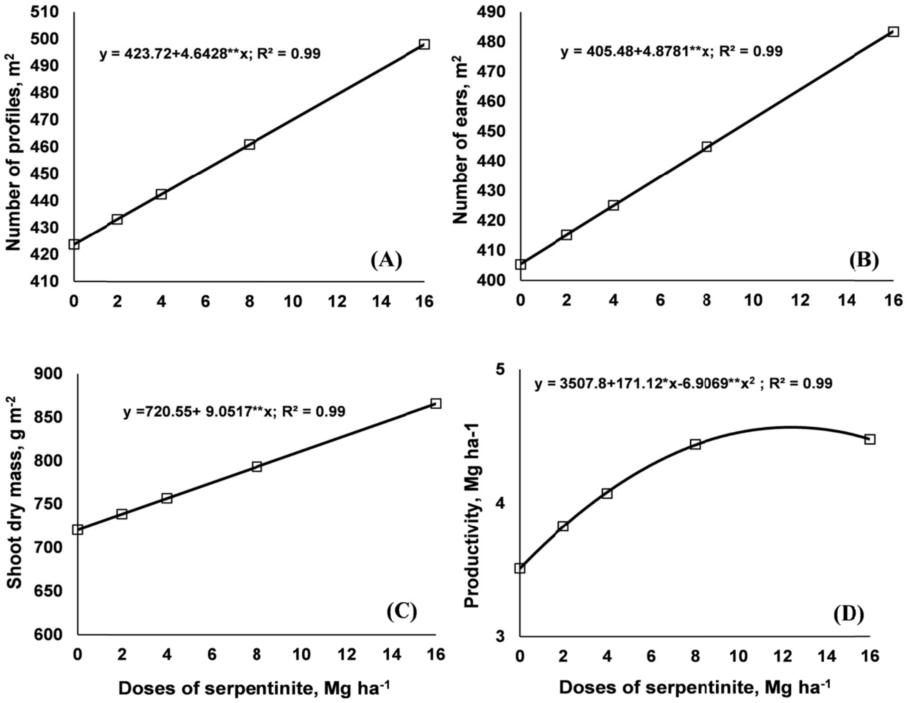

Figure 4. Number of profiles (A), number of ears (B), shoot dry mass (C) and productivity (D), as a function of serpentinite doses. Dourados-MS, Brazil, 2018. * and ** significant at 5 and 1%, based on significance by the F test

The number of profiles is a strategy that can contribute effectively to high yields, whose importance is characterized by their participation as part of the components of the yield of the plants and as probable suppliers of assimilated to the main stem (Merotto Junior, 1995). Although the number of profiles is questioned by some authors in the contribution to increases in productivity (Valério et al., 2009), it is possible to state based on the data obtained and the conditions under which the work was developed, to establish strategies that contribute to the increase in the number of tillers per plant, can effectively contribute to the achievement of high yields.

Observing Figures 4A and 4B, we can see a very close relationship between number of profiles and number of ears per m^{-2}, reaffirming the importance of nutritional management strategies that increase the tillering in the wheat crop. A similar result was obtained by Sarto et al. (2015), and Castellanos et al. (2016).

For the productivity, a significant quadratic adjustment was observed, with maximum estimated productivity of 4.57 Mg ha^{-1}, for the dose of 12, Mg ha^{-1} (Figure 4D). Increases in dry matter yield and productivity are due to the functions performed by the serpentinite in soil correction, with consequent improvement of soil chemical attributes such as pH, Ca, Mg and increased nutrient availability, providing better conditions for development.

For the variables: percentage of fertile tillers, number of grains per spike, number of spikelets per spike, number of grains per spikelet and mass of 1000 grains, there was no statistical difference between treatments. The mean numbers were: 96.0; 27.0; 13.0; 2.0 and 40.0 g m^{-2}, respectively.

The serpentinite, as a corrective material and prolonged residual effect, can be a viable alternative for correction of acid soils, having the benefits that this material provides to the crop and to the soil, in addition, the serpentinite presents, in its composition, the silicon, which is one of the beneficial elements that the wheat extracts from the soil and that can have direct action in the increase of production.

4. Conclusions

The serpentinite promoted a beneficial residual effect on acidity attributes after 41 months of application.

The application of the serpentinite promoted a positive residual effect on the dry mass, number of spikes and yield of the wheat crop.

References

Alovisi, A. M. T., Aguiar, G. C. R., Alovisi, A. A., Gomes, C. F., Tokura, A. K., Lourente, E. R. P., … Silva, R. S. (2018). Efeito residual da aplicação de silicato de cálcio e magnésio nos atributos químicos do solo e na produtividade da cana-soca. *Revista Agrarian, 11*(40), 150-158. https://doi.org/10.30612/agrarian.v11i40.624

Alvares, C. A, Stapes, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift, 22*(6), 711-728. https://doi.org/10.1127/0941-2948//0507

Castellanos, C. I. S., Rosa, M. P., Deuner, C., Bohn, A., Barros, A. C. S. A., & Meneghello, G. E. (2016). Aplicação ao solo de cinza de casca de arroz como fonte de silício: efeito na qualidade de sementes de trigo produzidas sob stresse salino. *Revista de Ciências Agrárias, 39*(1), 95-104.

Faquin, V. (2005). *Nutrição Mineral de Plantas*. Universidade Federal de Lavras, Fundação de Apoio ao Ensino, Pesquisa e Extensão.

Ferreira, D. F. (2014). Sisvar: A Guide for its Bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia, 38*(2), 109-112. https://doi.org/10.1590/S1413-70542014000200001

Friedman, H. (2018). *The mineral and gemstone kingdom: Minerlas A-Z: Group serpentine, 1997-2013*. Retrieved from http://www.minerals.net

Greger, M., Landberg, T., & Vaculik, M. (2018). Plants Article Silicon Influences Soil Availability and Accumulation of Mineral Nutrients in Various Plant Species. *Plants, 7*(41). https://doi.org/10.3390/plants7020041

Korndörfer, G. H., & Nolla, A. A. (2003). Efeito do silício no crescimento e desenvolvimento de plantas. *Simpósio sobre silício na agricultura*. Lavras: Universidade Federal de Lavras.

Korndörfer, G. H., Pereira, H. S., & Nolla, A. (2004). *Análise de silício no solo, planta e fertilizante*. Uberlândia.

Malavolta, E., Vitti, G. C., & Oliveira, S. A. (1997). *Avaliação do estado nutricional de plantas: Princípios e aplicações.* Piracicaba: Potafós.

Marschner, H. (2002). *Mineral nutrition of higher plants*. San Diego: Academic Press. https://doi.org/10.1016/B978-0-08-057187-4.50017-5

Merotto Junior, A. (1995). *Processo de afilhamento e crescimento de raízes de trigo afetado pela resistência do solo* (Unpublished Master's thesis, Universidade Federal do Rio Grande do Sul, Brazil).

Moraes, E. R., Reis, A. C., Silva, N. E. P., Ferreira, M., & Menezes, F. G. (2018). Nutrientes no solo e produção de quiabo conforme doses de silicato de cálcio e magnésio. *Revista de Agricultura Neotropical, 5*(1), 60-65. https://doi.org/10.32404/rean.v5i1.2097

Pacheco, L. P., Barbosa, J. M., Leandro, W. M., Machado, P. L. O., Assis, R. L. de, Madari, B. E., & Petter, F. A.(2013). Ciclagem de nutrientes por plantas de cobertura e produtividade de soja e arroz em plantio direto. Pesquisa A*gropecuária Brasileira, 48*(9), 1228-1236. https://doi.org/10.1590/S0100-204X2013000900006

Pereira, D., Yenes, M., Blanco, J. A., & Peinado, M. (2007). Characterization of serpentinites to define their appropriete use as dimension Ssone. *Geological Society, 271*, 55-62. https://doi.org/10.1144/GSL.SP.2007.271.01.06

Raij, B. V., Cantarella, H., Quaggio, J. A., & Furlani, A. M. C. (1997). *Recomendações de Adubação e Calagem para o Estado de São Paulo* (2nd ed.). São Paulo, SP: Brazil.

Ramos, L. A., Nolla, A., Korndorfer, G. H., Pereira, H. S., & Camargo, M. S. (2006). Reatividade de corretivos da acidez e condicionadores de solo em colunas de lixiviação. *Revista Brasileira de Ciência do Solo, 30*, 849-857. https://doi.org/10.1590/S0100-06832006000500011

Reboredo, F., Lidon, F. C., Pessoa, F., Duarte, M., & Silva, D. M. (2013). *The uptake of macronutrients by an active silicon accumulator plant growing in two different substrata* (Unpublished Master's thesis, Universidade Nova de Lisboa, Portugal). https://doi.org/10.9755/ejfa.v25i12.16735

Salvador, J. O., Cabral, C. P., Moreira, A., & Malavolta, E. (2000). Influência do alumínio no crescimento e na acumulação de nutrientes em mudas de goiabeira. *Revista Brasileira de Ciência do Solo, 24*(4), 787-796.

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., … Oliveira, J. B. (2013). *Sistema brasileiro de classificação de solos* (3rd ed.). Brasília, DF: Brazil.

Sarto, M. V. M., Lana, M. C., Rampim, L., Rosset, J. S., & Wobeto, J. R. (2015). Effects of silicate application on soil fertility and wheat yield. *Semina, 36*(6), 4071-4082. https://doi.org/10.5433/1679-0359.2015v36n6Supl2p4071

Sarto, M. V. M., Lana, M. C., Rampim, L., Rosset, J. S., Wobeto, J. R., Ecco, M., … Costa, P. F. (2014). Effect of silicate on nutrition and yield of wheat. *African Journal of Agricultural Research, 9*(11), 956-962. https://doi.org/10.5897/AJAR2013.7617

Silva, F. C. da. (2009). *Manual de análises químicas de solos, plantas e fertilizantes* (2nd ed.). Rio de Janeiro, RJ: Brazil.

Silva, S. R., Bassoi, M. C., & Foloni, J. S. S. (2017). *Informações técnicas para o trigo e triticale*. 10º Reunião da comissão Brasileira de Pesquisa de Trigo e Triticale, Londrina, PR: Brazil.

Sousa, D. M. G., & Lobato, E. (2004). *Cerrado: Correção do solo e adubação* (2nd ed.). Brasília, DF: Brazil.

Tavares, E., Castilhos, Z., Luz, A., França, S., Cesar, R., & Bertolino, L. C. (2010). Potencial de aplicação dos serpentinito como insumo na agricultura sustentável. *Anais do I Congresso Brasileiro de Rochagem* (pp. 157-165). Embrapa Cerrado.

Tedesco, M. J., Gianello, C., Anghinoni, I., Bissani, C. A., Camargo, F. A. O., & Wietholter, S. (2004). *Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina* (10th ed.). Porto Alegre, RS: Brazil.

Teixeira, A. M. S., Sampaio, J. A., Garrido, F. M. S., Medeiros, M. E., Bertolino, L. C., & Pérez, D. V. (2010). *Estudo do uso de serpentinito como corretivo de solos agrícolas*. II Simpósio De Minerais Industriais Do Nordeste, Campina Grande-PB. https://doi.org/10.13140/2.1.4079.5200.

Tokura, A. M., Furtini Neto, A. E., Curi, N., Carneiro, L. F., & Alovisi, A. A. (2007). Silício e fósforo em diferentes solos cultivados com arroz de sequeiro. *Acta Scientiarum. Agronomy, 29*(1), 9-16. https://doi.org/10.4025/actasciagron.v29i1.58

Valério, I. P., Carvalho, F. I. F., Oliveira, A. C., Benin, G., Maia, L. C., Silva, J. A. G., … Silveira, G. (2009). Fatores relacionados à produção e desenvolvimento de afilhos em trigo. *Semina, 30*, 1207-1218.

Copyrights