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Acidity neutralization and silicon availability using calcium silicate in soil cultivated with wheat (*Triticum aestivum* L.)

Luiz Antônio Zanão Júnior[1], Idelvan Bonadiman Blanco[2], Natália Pereira[2*], Juliane Aparecida Schneider[3]

[1]Agronomic Institute of Paraná, IAPAR, Santa Tereza do Oeste, 85825 000, Paraná, Brazil
[2]Department of Agricultural Engineering, Western Paraná State University, UNIOESTE, Cascavel, 85810 110, Paraná, Brazil
[3]Department of Agricultural Sciences, Paraná State University of Ponta Grossa, UEPG, Ponta Grossa, 84030-900, Paraná, Brazil

***Corresponding author: pe.nataliaa@gmail.com**

Abstract

Most tropical soils have acidity issues. The amount of corrective treatment needed to neutralize such acidity depends on the corrective material and the cultivated species. Thus, this study aimed to evaluate soil acidity neutralization by using calcium silicate ($CaSiO_3$), compared to calcium carbonate ($CaCO_3$), and the effect of increased silicon (Si) availability in soil cultivated with wheat. The treatments under analysis were: A) control (no application of corrective material); B) a calcium carbonate P.A. ($CaCO_3$) dose of 1.5 g kg^{-1}; C) twice this $CaCO_3$ dose, i.e. 3.0 g kg^{-1}; D) calcium silicate ($CaSiO_3$), at the doses of 2.15 and 4.30 g kg^{-1}; and E) $CaSiO_3$ at the dose of 4.30 g kg^{-1} for providing the same amount of Ca observed with $CaCO_3$ doses and also providing Si, at the doses of 0.09 and 0.18 g kg^{-1}, respectively. The experimental design was complete randomized blocks with 5 replicates. After 30-day incubation, pH in $CaCl_2$, Ca, hydrogen + aluminum (H + Al), and Al and Si content, cation-exchange capacity (CEC) at pH 7.0, and soil base saturation were measured. Plant height, number of stalks and grains per plant, dry mass and grain yield, and Si leaf content were also evaluated. Both $CaCO_3$ and $CaSiO_3$ were efficient in correcting acidity and increasing Ca content, base saturation, and CEC at pH 7.0 in soil. The application of $CaSiO_3$ has led wheat to absorb more Si, and this provided higher grain yield and greater mass.

Keywords: *Triticum aestivum* L., calcium carbonate, calcium silicate.

Introduction

Most tropical agriculture soils have medium to high acidity. According to Fageria and Baligar (2001), more than 85% of the tropical area in South American soils is acidic. Acid soils have low natural fertility, because this is associated with a small amount of calcium (Ca), magnesium (Mg), and potassium (K), and excessive aluminum (Al) and manganese (Mn), in addition to greater binding capacity of phosphorus (P) (Malavolta, 2006; Fageria and Baligar, 2008). Thus, soil acidity is associated with toxicity by Al^{3+} and, in some cases, by micronutrients, nutrient deficiency, decreased activity of beneficial microorganisms, and growth of the root system. All of these factors lead to lower absorption of water and nutrients (Fageria and Baligar, 2003). Good development of wheat plants takes place in low-acid soils, with corrected pH and at least 50% of base saturation (Souza et al., 2007).

Acidity correction is crucial for the good performance of crops, such as wheat. In order to correct it, there is application of substances that release hydroxyls (OH^-), capable of neutralizing the protons (H^+ and Al^{+3}) in soil solution, and this resumes the productive potential of crops (Souza et al., 2007). Ca and Mg carbonates, known as agricultural limestones, are the products most commonly used (Barbosa Filho et al., 2004).

$CaSiO_3$, like agricultural limestone, is a corrective material, as it releases OH^- capable of reducing soil acidity (Carvalho et al., 2000). Besides, it provides soil with silicon (Si), in the form of orthosilicic acid (H_4SiO_4) (Marafon and Endres, 2011).

Si is not regarded as a crucial element for plants, because it is dispensable for their life cycle (Gocke et al., 2013). However, it is seen as a beneficial element, due to the fact that it is related to increased resistance to attack by pests and diseases; it also improves absorption and use of nutrients and decreases the stress caused by toxicity or deficiency of some elements (Ma and Yamaji, 2008; Tripathi et al., 2014). These benefits contribute to increase the yield of many crops, especially those belonging to the Poaceae family, such as wheat and rice (Rafi et al., 1997; Zanão Júnior et al., 2010). These two plants actively absorb Si, in the form of H_4SiO_4, and accumulate it quickly (Casey et al., 2003; Ma et al., 2006).

In wheat, it was found that Si decreased the incidence and severity of diseases (Bélanger et al., 2003; Guével et al., 2007) and increased the resistance to pests (Dias et al., 2014), to salinity (Tuna et al., 2008), and to water deficit (Gong et al., 2005).

Both due to Si supply and acidity correction, the literature has found positive effects in applying $CaSiO_3$ in wheat cultivation. Ahmad et al. (2007) and Sarto et al. (2015) observed that applying this corrective material promotes higher crop yield.

In addition to other factors, the amount of corrective treatment needed to neutralize acidity depends on the corrective material and the cultivated species (Fageria and Baligar, 2008). Thus, this study aimed to evaluate the power to neutralize soil acidity by using $CaSiO_3$, compared to $CaCO_3$, and detect the effect of increased Si availability in soil cultivated with wheat.

Results and discussion

Neutralization of soil acidity using $CaSiO_3$ and $CaCO_3$

With no application of corrective materials, the soil had lower pH in $CaCl_2$, accompanied by higher levels of Al^{3+} and lower levels of Ca^{2+}, base saturation, and CEC at pH 7.0, characterizing high acidity. After 30-day incubation, these features were modified in soil samples that received corrective materials (Table 1).

$CaSiO_3$, besides significantly increasing pH values, also decreased potential acidity (H + Al), neutralized the exchangeable Al content, and increased base saturation and soil CEC, as well as $CaCO_3$, and this confirms its efficiency in correcting soil acidity (Table 1). Korndörfer et al. (2010), Zanão Júnior et al. (2010), and Wally et al. (2015) also found that $CaSiO_3$ has an effect similar to $CaCO_3$ on soil acidity correction, on CEC increase, and on improving soil chemical properties.

Among the corrective materials, the ability to neutralize Al was similar, in both doses used (Table 1). The smallest doses of corrective materials, 1.5 g kg^{-1} of $CaCO_3$ and 2.15 g kg^{-1} of $CaSiO_3$, calculated to achieve a base saturation of 50%, were efficient and managed to achieve it. By applying higher doses of $CaCO_3$ (3.0 g kg^{-1}) and $CaSiO_3$, (4.30 g kg^{-1}), base saturation values of 66% and 63% were achieved, respectively. The ideal percentage of base saturation for wheat ranges from 50% to 70% (Comissão Brasileira de Pesquisa de Trigo e Triticale, 2014).

The values of Ca content, base saturation, and CEC at pH 7.0 were higher and those of potential acidity were lower when using the highest doses of $CaCO_3$ and $CaSiO_3$. Zanão Júnior et al. (2010) and Silva et al. (2014) also found that $CaSiO_3$ was as efficient as $CaCO_3$ in increasing Ca content and pH in soil. The higher the dose of corrective materials used, the higher the amount of Ca and proton-neutralizing materials added, according to Souza et al. (2007).

Silicon content

In soil samples where $CaSiO_3$ was applied as a corrective material, Si content increased when compared to the other treatments, because this element was solubilized and released, corroborating the findings of Ramos et al. (2006), Pereira et al. (2007), and Korndörfer et al. (2010). No difference was observed between $CaSiO_3$ doses used to increase Si content in soil and the latter increased to 18.17 and 28.21 mg dm^{-3}, respectively, for the doses of 2.15 and 4.30 g kg^{-1}. In both cases, Si content in soil increased to exceed the critical level of 9.8 mg dm^{-3}, recommended by Korndörfer et al. (1999) for rice cultivation.

The plants receiving the $CaSiO_3$ treatment, at its lowest dose, accumulated about 4.2 g kg^{-1} more Si in the leaves when compared to those that did not receive it. When the highest dose was applied, the average difference was 8.8 g kg^{-1} of Si. Such results corroborate Sarto et al. (2014), who reported significantly increased values for Si concentration in wheat leaves and stalks by applying $CaSiO_3$. Lima Filho and Tsai (2007) and Zanão Júnior et al. (2010) also observed greater Si absorption by wheat when fertilized with this element. According to Lima Filho and Tsai (2007), wheat is highly efficient in absorbing Si, becoming bigger in soils with high content of this element, and it is regarded as a Si accumulating plant (Gocke et al., 2013). Data demonstrate that wheat absorbed this element and, along with other factors, it has led to improved plant growth, resulting in a more efficient grain yield.

Yield compounds

Regarding wheat, plant height and number of stalks were not different in terms of doses and corrective material. Sarto et al. (2015), applying $CaSiO_3$ doses to grow the wheat crop, found no significant differences in these variables.

The number of grains per plant, as well as dry mass and grain yield, were higher by applying $CaSiO_3$ (Table 2). Applying 2.15 g kg^{-1} of $CaSiO_3$ to soil led to a 31% increase in the number of grains per plant and a 39% increase in dry mass and grain yield when compared to the control. In wheat cultivation by applying Si to soil, Zanão Júnior et al. (2010) observed an improved plant architecture, providing more upright leaves. Si, by enabling more upright leaves, provides greater leaf exposure to the sun (Epstein, 1999); this increases the photosynthetic rate and, as a consequence, leads to higher grain yield. Tavares et al. (2014) observed a 15% increase in wheat grain yield due to silicon fertilization. Just as the number of grains, applying silicate to the crop's soil led to increased weight. Mauad et al. (2003) and Toledo et al. (2012) also reported that Si fertilization significantly increased the mass of wheat grains. Perhaps this was due to the beneficial effect of Si for the crop, since the leaf content of this element also increased under this condition (Table 2).

Materials and methods

Experimental design and treatments

The experiment was conducted in a greenhouse. The treatments under analysis were: A) control (no application of corrective material); B) a calcium carbonate P.A. ($CaCO_3$) dose of 1.5 g kg^{-1}; C) twice this $CaCO_3$ dose, i.e. 3.0 g kg^{-1}; D) calcium silicate (CaSiO3) at the dose of 2.15 g kg-1 and E) CaSiO3 at the dose of 4.30 g kg-1. These doses of $CaSiO_3$ provides the same amount of Ca added with doses of $CaCO_3$, but also provide Si, at the doses of 0.09 and 0.18 g kg^{-1} in the treatments D and E, respectively. The amount of Ca provided was 0.6 g kg^{-1} for the lowest doses of corrective materials evaluated and 1.2 g kg^{-1} for the highest ones. The experimental design was five replicate randomized blocks. $CaCO_3$ has 56% of calcium oxide (CaO) and it does not have Si in its composition. $CaSiO_3$ has 39% of CaO, in addition to 4.5% of Si (soluble).

Soil characteristics

The samples consisted in a dystrophic Red Latosol (dRL), with a clayish texture (49% of clay), low natural fertility, and low Si content available. They were collected at 0-30 cm depth and sieved through a 2 mm mesh, showing these chemical features: pH ($CaCl_2$) = 4.10; carbon (C) (Walkley-Black) = 18.10 g dm^{-3}; P (Mehlich-1) = 1.9 mg dm^{-3}; H + Al = 7.20 $cmol_c$ dm^{-3}; K (Mehlich-1) = 0.25 $cmol_c$ dm^{-3}; Ca = 0.35 $cmol_c$ dm^{-3}; Mg = 0.55 $cmol_c$ dm^{-3}; vanadium (V) = 14%; iron (Fe) = 65 mg dm^{-3}; copper (Cu) = 0.8 mg dm^{-3}; Mn = 19.2 mg dm^{-3}; zinc (Zn) = 21.2 mg dm^{-3}; and Si ($CaCl_2$) = 4 mg dm^{-3}.

Table 1. pH values in $CaCl_2$ and Al, H + Al, Ca content, CEC at pH 7.0 (T), base saturation (V), and Si in soil due to doses and sources of corrective material added, after 30-day incubation.

Acidity corrective materials	pH	Al	H + Al	Ca	T	V	Si
	($CaCl_2$)	--------------cmol$_c$ dm^{-3}-------------				%	mg dm^{-3}
Control	4.10 c	1.05 a	5.35 a	0.40 c	6.46 c	16 c	5.03 b
$CaCO_3$ (1.50 g kg^{-1})	5.05 b	0.00 b	4.46 b	3.71 b	8.89 b	50 b	5.23 b
$CaCO_3$ (3.00 g kg^{-1})	5.80 a	0.00 b	3.24 c	5.44 a	9.41 a	66 a	5.07 b
$CaSiO_3$ (2.15 g kg^{-1})	5.03 b	0.00 b	4.28 b	3.43 b	8.59 b	50 b	18.17 a
$CaSiO_3$ (4.30 g kg^{-1})	5.70 a	0.00 b	3.18 c	5.31a	9.32 a	63 a	28.21 a
CV%	4.12	14.04	6.43	3.67	6.65	4.54	10.76

Mean values followed by different letters in the column differ at 5% probability by Tukey test.

Table 2. Plant height (PH), number of stalks per plant (SPP), number of grains per plant (GPP), dry mass and grain yield per plant (DMYGPP), and Si leaf content (SiLC), due to doses and sources of correction material added to the soil, after 30-day cultivation.

	PH	SPP	GPP	DMYGPP	SiLC
	cm			g	g kg^{-1}
Control	57.0 a	4.9 a	205.3 b	4.28 b	8.9 b
$CaCO_3$ (1.5 g kg^{-1})	63.0 a	5.1 a	211.3 b	4.61 b	9.4 b
$CaCO_3$ (3.0 g kg^{-1})	60.9 a	5.1 a	209.3 b	3.90 b	9.2 b
$CaSiO_3$ (2.15 g kg^{-1})	61.9 a	6.1 a	268.5 a	5.93 a	13.3 a
$CaSiO_3$ (4.30 g kg^{-1})	59.9 a	6.0 a	253.5 a	4.89 a	17.9 a
CV%	7.65	14.56	13.78	15.65	12.67

Mean values followed by different letters in the column differ at 5% probability by Tukey test.

Conduction of experiment

Initially, a mass equivalent to the soil volume of 3.0 dm³, for each pot, was weighed and placed in plastic bags with a capacity of 5 dm³, for providing soil acidity correction. The treatments, corresponding to doses of corrective materials, were added to soil dried at air. After soil homogenization with corrective materials, deionized water was added, in order to raise humidity to 80% of the field capacity, with a subsequent 30-day incubation period. After incubation, 400 mg kg^{-1} of P ($CaHPO_4$) were added, incorporated to the entire soil volume. From these samples, 50 g of soil were taken away, at each experimental plot, for chemical characterization. Si content was determined after extraction using $CaCl_2$ (Korndörfer et al., 2004), as well as pH in $CaCl_2$, Ca content, H + Al, Al, CEC at pH 7.0, and base saturation, according to Pavan (1992).

After removing the soil samples, sowing was done at 1 cm depth, distributing 8 seeds per pot of the wheat cultivar IPR 144.

The first thinning was performed 5 days after emergence (DAE), leaving 6 plants per pot. Then, the first application of nitrogen (N) and micronutrients was done, and the only applications of K and sulfur (S). The second thinning was performed 10 DAE, leaving 4 plants per pot. The second and third plots of nitrogen fertilization and micronutrients were performed, respectively, 15 and 30 DAE. Fertilization was conducted using nutrient solutions, always applying the volume of 50 mL dm^{-3}. Soil moisture in the pot was maintained around 80% of the field capacity, using deionized water. The total amount of nutrients applied in fertilization (in mg kg^{-1}), was: N = 160; K = 210; S = 60; Mg = 60; boron (B) = 1; Cu = 1.5; Fe = 2; Mn = 3.5; molybdenum (Mo) = 0.2; and Zn = 5. The salts used were: NH_4NO_3, $CO(NH_2)_2$, KCl, K_2SO_4, $MgSO_4$, H_3BO_3, $CuSO_4.5H_2O$, $FeSO_4.7H_2O$, $MnCl_2.4H_2O$, $(NH_4)_6Mo_7O_{24}.4H_2O$, and $ZnSO_4.7H_2O$.

Traits measured

At the end of the crop cycle, there was evaluation of plant height, number of stalks and grains per plant, dry mass and grain yield, and Si leaf content.

Plant height was determined in all harvested plants, measuring the distance between the base of the plant and the stalk insertion. The number of stalks and grains per plant were determined at harvest. Then, the grains were dried in an oven with air circulation at 65°C, until reaching constant mass. After harvesting, the leaves were washed using distilled water, neutral detergent solution, 1 mL L^{-1}, HCl 0.1 mol L^{-1}, and distilled water again. After superficial washing, they underwent drying in a forced-air circulation oven at 65°C, until reaching a constant weight. Once dried, they were processed in a Wiley mill, using a 0.84 mm mesh. Si leaf content was determined through the alkaline digestion method and dosage was determined through the colorimetric method (Korndörfer et al., 2004).

Statistical analysis

This experiment was conducted twice and data for each variable were grouped, because the homogeneity of variance was confirmed by the Cochran test (Gomez and Gomez, 1984). Data underwent analysis of variance (ANOVA), through the Statistical and Genetic Analysis System (SAEG), and the average values were compared using Tukey test (p = 0.05%).

Conclusion

Soil acidity correction and increased Ca content can be provided both by $CaCO_3$ and $CaSiO_3$. The number of grains per plant, Si leaf content, and dry mass yield of wheat grains were higher by applying $CaSiO_3$. The beneficial effect of using $CaSiO_3$ as soil acidity corrective and calcium supply has a positive consequence for soil fertility. Furthermore, the silicon provided by application of $CaSiO_3$ on soil increases the wheat crop quality and yield.

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