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Influence of Calcium Silicate on Soil Fertility and Corn Morphology

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Abstract

The objective of this study was to evaluate whether the development of corn (*Zea mays*) and soil fertility are influenced by the application of increasing doses of calcium silicate ($CaSiO_3$) in substitution to limestone. The experiment was carried out under greenhouse conditions and the experimental design was in randomized blocks, in a 3x2+1 factorial arrangement and four replications. The factors were: doses of $CaSiO_3$ (7.62 $mg.dm^{-3}$, 19.05 $mg.dm^{-3}$ and 38.09 $mg.dm^{-3}$) and liming (absence and presence). The soil of the control treatment did not receive limestone or $CaSiO_3$. At 21 days after emergence (DAE), it was found that the control treatment plants had significantly lower height and stem diameter. At 35 DAE was observed that using exclusively $CaSiO_3$ promoted 6% higher stem height values. At 63 DAE, no oscillations were observed in the biomass of aerial part and root between liming and $CaSiO_3$ doses ($P>0.05$). Using the limestone allied the silicate doses increased in higher concentration of Mg in the soil. The lowest dose of $CaSiO_3$ reduced the concentrations of Ca and Mg. Calcium silicate can be used as an alternative source to limestone for soil acidity correction.

Keywords: acidity, biomass, $CaSiO_3$, stem

1. Introduction

Limestone is a concealer used for centuries to correct soil acidity (Thomason et al., 2019); however, because it presents slow mobility in the soil profile, it can slow its effect in the deeper layers (Ramos et al., 2006) and decelerate the accumulation of biomass aerial part (Lopes et al., 2011; Fabrice et al., 2014).

The use of alternative corrections has been evaluated according to the limitations of limestone. For this reason, the use of silicate-based products were identified as promising corrective, which could positively impact the production of biomass and grains (Crusciol et al., 2013; Ning et al., 2016). In addition, calcium silicate can promote in expressive increases in the contents of exchangeable Ca and Mg, reducing soil acidity and providing silicon (Si) for plants (Zanao et al., 2017).

Silicon (Si) is a non-essential nutrient for plants, but it stands out in many cultures such as sugarcane (Oliveira et al., 2010), rice (Hyun-Hwoi et al., 2017) and forage grasses (Silveira et al., 2010; Lopes et al., 2011). This element is associated with the reduction of biotic and abiotic stresses of the Si storage plants, such as diseases (Guazina et al., 2019), pest injuries (Antunes et al., 2010; Zargar et al., 2019), salinity (Zhu et al., 2019), drought (Saud et al., 2014) and heavy metal toxicity (Bhat et al., 2019).

Reports on the use of calcium silicate in corn crop are still scarce and generate the need for further studies on the impact that this element may cause in soil chemical attributes and plant morphology in case of limestone substitution.

Thus, the objective of this study was to evaluate whether the development of corn (*Zea mays*) and how soil fertility are influenced by the application of increasing doses of calcium silicate ($CaSiO_3$) in substitution to limestone.

2. Material and Methods

The experiment was conducted at the Faculty of Veterinary Medicine and Animal Science of the Federal University of Mato Grosso do Sul, in the municipality of Campo Grande, MS, under protected cultivation conditions. The regional climate, according to the Köppen classification, is Aw, characterized as tropical, with a well-defined dry season during the cold months and rainy season during the summer. The experimental period comprised from May to June 2018.

2.1 Soil

A soil sample was collected in the 0-20 cm layer, classified as a typical Dystrophic Red Latosol, characterized as follows: clayey texture (590 $g.kg^{-1}$ clay, 300 $g.kg^{-1}$ silt and 110 $g.kg^{-1}$ sand); pH: 5.4 (H_2O); organic matter (OM): 47 g kg^{-1}; base saturation (V%): 44.2%; phosphorus (P): 2 mg dm^{-3}; potassium (K): 0.54 cmolc dm^{-3}; calcium (Ca): 4.2 cmolc dm^{-3}, magnesium (Mg): 2.10 cmolc dm^{-3}; iron (Fe): 1.47 mg dm^{-3}; manganese (Mn): 111.80 mg dm^{-3}; zinc (Zn): 1.75 mg dm^{-3}; copper (Cu): 3.30 mg dm^{-3}; potential acidity (Al+H): 8.7 cmolc dm^{-3}.

2.2 Treatments and Experimental Design

The experimental design was in randomized blocks, in a 3x2 factorial arrangement with an additional treatment and four replications. The factors were: doses of $CaSiO_3$ (7.62 $mg.dm^{-3}$, 19.05 $mg.dm^{-3}$ e 38.09 $mg.dm^{-3}$) and liming (absence and presence). The commercial source of $CaSiO_3$ had 25% Ca, 6% of Mg and 10.6% of Si. Liming was performed with dolomitic limestone (80% PRNT - total relative neutralizing power) to reach the base saturation level of 70%. The soil of the additional treatment (control) did not receive limestone or. Each experimental plot was represented by a vessel containing 8 dm^{-3} of soil. Sowing fertilization was performed, applying 14.83 $mg.dm^{-3}$ of simple superphosphate and 2 $mg.dm^{-3}$ potassium chloride, in addition to de 0.8 $mg.dm^{-3}$ of urea.

After the basic fertilization, the addition of $CaSiO_3$ and limestone in the doses corresponding to the treatments, the soil was homogenized and packaged in pots with 8 dm^{-3} that were kept in a plastic greenhouse. The soil remained incubated for 32 days and was irrigated when necessary for soil moisture to remain at the point of field capacity.

Subsequently, three seeds of corn hybrid SYN 555 were seeding per pot. Ten days after sowing, there was thinning in order to maintain a seedling per pot. In the application of N in coverage, 1.87 $mg.dm^{-3}$ of ammonium sulfate was used when the plants reached the phenological stage of V4 (four expanded leaf blades) of the Ritchie et al. (1993) scale.

2.3 Morphologic Evaluation

Leaf area estimation was performed at 21 days after emergence (DAE) of plants in the phenological stage V4, by measuring the length (L) and width (W) of all expanded leaves. From this information, the leaf area (LA) was obtained through the expression: LA = L x W x 0.75 (Tollenaar, 1992). The leaf area per plant was calculated by adding the areas of all expanded leaves. Another six determinations of leaf area were performed at 28, 35, 42, 49, 56 and 63 days after emergence, which corresponded to the phenological stages V5, V7, V8, V9, V10 and V12.

In each plant, the diameter and stem height measurements were taken, defined as the distance between the soil and the lygula of the last completely expanded leaf blade.

2.4 Biomass Estimation of Part Aerial Part and Root

For the estimation of aerial part biomass, the plants were cut, at the height corresponding to the first knot above the soil surface, to the 63 DAE. The samples were sent to the laboratory, so the plants were fracted in leaf blades and stem. For the estimation of root biomass, they were removed from the vessels, deposited in a sieve with 1 to 2 mm mesh and washed in gentle running water. Subsequently, the samples of aerial part and root were destined to the greenhouse of forced air circulation at 55 ℃ until it reached constant weight.

2.5 Chemical Characteristics of the Soil

An aliquot of soil was removed from each vessel and forwarded to the laboratory for the determination of the following chemical attributes, according to Embrapa (1997): pH in H_2O, OM (g kg^{-1}), base saturation (V%), P (cmolc dm^{-3}), K (cmolc dm^{-3}), Ca (cmolc dm^{-3}), Mg (cmolc dm^{-3}), Fe (mg dm^{-3}), Mn (mg dm^{-3}), Zn (mg dm^{-3}), Cu (mg dm^{-3}) and potential acidity (Al+H cmolc dm^{-3}).

2.6 Statistical Analysis

Data were subjected to analysis of variance and, when appropriate, Tukey's multiple comparisons test was performed at 5% significance, using a statistical program R version 3.5.0.

3. Results and Discussion

3.1 Morphology

At 21 DAE, no changes were observed in leaf area values of corn plants subjected to soil correction with $CaSiO_3$ and limestone, in relation to those cultivated under the control treatment (Table 1). Possibly, this fact can be explained by the fact that the plants had not received the effects of the treatments because they were developing the root system (Fancelli, 2017).

Table 1. Leaf area (m^2 $plant^{-1}$), stem heights (cm) and stem diameter (cm) of corn subjected to $CaSiO_3$ doses as a function of liming

DAE	Factorial	Control	P value	SEM
		---------------------- Leaf area ---------------------		
21	0.612^a	0.492^a	0.999	0.043
28	2.35^a	0.940^b	0.003	0.142
35	5.40^a	0.450^b	0.008	0.574
42	8.94^a	1.09^b	<0.001	0.636
49	13.22^a	1.81^b	<0.001	0.831
56	20.73^a	2.99^b	<0.001	0.974
63	29.28^a	4.39^b	<0.001	1.16
		--------------------- Stem height ----------------------		
21	11.12^a	8.42^b	0.015	0.162
28	18.54^a	9.62^b	<0.001	0.232
35	25.41^a	11.22^b	<0.001	0.380
42	36.95^a	14.37^b	<0.001	0.566
49	49.54^a	19.50^b	<0.001	0.942
56	58.83^a	28.12^b	<0.001	1.08
63	67.45^a	38.75^b	<0.001	1.16
		--------------------- Stem diameter ----------------------		
21	0.645^a	0.437^b	0.003	0.019
28	0.979^a	0.462^b	<0.001	0.020
35	1.35^a	0.460^b	<0.001	0.022
42	1.72^a	0.510^b	<0.001	0.022
49	2.03^a	0.620^b	<0.001	0.035
56	2.16^a	0.625^b	<0.001	0.033
63	2.20^a	0.897^b	<0.001	0.031

Averages followed by the same letter in the line do not differ from each other, by the Tukey test at 5% probability. DAE: days after emergence. P value: significant effect probability. SEM: standard error of the mean.

In the first evaluation, it was found that the plants that belonged to the control treatment had significantly lower height and stem diameter than those cultivated in corrected soil (Table 1). Therefore, it is possible to infer that there was a high source ratio-drain in the phenological stage V4, leading corn plants in the soil acidity correction scenarios, initially investing in the accumulation of stem biomass (Sangoi et al., 2002; Taiz and Zeiger, 2009).

Thus, in the subsequent assessments, because they were in a phenological stage V5 and fully capable of extracting nutrients from the soil, there were changes between treatments that received doses of calcium silicate, with or without liming and control (Table 1). This was due to the fact that the strategies used to increase the V% increased the amount of Ca, K and Mg in the soil colloids, allowing the plants to present the maximum nutrient absorption potential, which provided a greater development of plant tissues (Oliveira et al., 2010; Zuba Júnior et al., 2012; Moreira et al., 2014).

For leaf area from 21 to 63 DAE, no interaction was observed between the different base saturations and $CaSiO_3$ doses (Table 2). In addition, no differences were observed in the leaf area in both strategies used to reduce soil acidity (P>0.05), and proportionality was also noticed among the doses of $CaSiO_3$ (P>0.05). The leaf area is one of the main determinant components of plant growth since on the surface of the leaf blade the photons needed to activate the processes leading to photosynthesis (Taiz and Zeiger, 2009; Gastal and Lemaire, 2015), with the proportionality observed (Table 2), it is possible to infer that the production flow of leaf biomass can present the same behavior.

Table 2. Leaf area (m^2 $plant^{-1}$) of corn subjected to $CaSiO_3$ doses as a function of liming

	Liming		Dose of $CaSiO_3$ ($mg.dm^{-3}$)			P value		
DAE	Absence	Presence	0.95	2.38	4.76	L	D	L*D
21	0.640	0.585	0.711	0.540	0.585	0.511	0.247	0.511
28	2.45	2.24	2.51	2.20	2.33	0.514	0.705	0.774
35	5.04	5.76	6.60	4.72	4.89	0.548	0.377	0.579
42	8.95	8.93	10.92	7.55	8.35	0.984	0.094	0.581
49	13.14	13.29	15.20	12.46	11.99	0.192	0.198	0.921
56	20.39	21.08	22.81	20.34	19.06	0.724	0.287	0.956
63	29.39	29.17	31.24	27.95	28.65	0.923	0.468	0.226

Averages followed by different letters in the line differ from each other, by the Tukey test at 5% probability. DAE: days after emergence. P value: significant effect probability. L: liming; D: dose; L*D: interaction between liming and dose of $CaSiO_3$ ($mg.dm^{-3}$).

In the initial stage of plant development (21 DAE; Table 3) the lowest dose of calcium silicate was higher in 12% in the stem height in relation to liming allied to calcium silicate ($p<0.05$). The stem diameter at 28 and 35 DAE presented the same behavior, being observed interaction between doses and liming (Table 3). Thus, it is possible to deduce that calcium silicate provided a higher initial development of the plants. This initial acceleration in the tissue flow allows the plant to reach the reproductive stage early, anticipating the harvesting of the forage (Oliveira et al., 2011).

Table 3. Stem height (cm) and stem diameter (cm) of corn subjected to $CaSiO_3$ doses as a function of liming

Doses of $CaSiO_3$ ($mg.dm^{-3}$)	Liming		P value	SEM
	Absence	Presence		
	------------------- Height at 21 DAE -------------------			
0.95	12.00^{Aa}	10.50^{Ab}	0.015	0.411
2.38	11.00^{Aa}	11.50^{Aa}	0.661	0.226
4.76	10.75^{Aa}	11.00^{Aa}	0.384	0.163
	------------------ Diameter at 28 DAE ------------------			
0.95	1.12^{Aa}	0.950^{Ab}	0.016	0.046
2.38	0.900^{Ba}	0.975^{Ab}	0.270	0.032
4.76	0.975^{ABa}	0.950^{Aa}	0.709	0.018
	------------------ Diameter at 35 DAE ------------------			
0.95	1.47^{Aa}	1.30^{Ab}	0.014	0.044
2.38	1.27^{Ba}	1.35^{Aa}	0.260	0.039
4.76	1.35^{ABa}	1.35^{Aa}	0.999	0.032

Averages followed by lowercase equal letters in the rows, and uppercase in the columns do not differ from each other by the Tukey test 5% probability. DAE: days after emergence. P value: significant effect probability. SEM: standard error of the mean.

From 28 to 63 DAE, no interaction was observed ($P>0.05$), at 35 DAE was detected that using only calcium silicate promoted 6% higher stem height values (Table 4), indicating that the plants showed faster development in this phase. From 42 to 56 DAE, no disproportionality was observed between the sources of variation analyzed (Table 4). Stem-related parings indicate that the experimental scenarios using $CaSiO_3$ and allied liming positively influenced the flow of biomass production of aerial part, since the height and diameter of the stalk are indicators of great importance to predict biomass accumulation (Oliveira et al., 2020).

Table 4. Stem height (cm) and stem diameter (cm) of corn in CaSiO3 doses as a function of liming during the vegetative phase

	Liming		Dose of $CaSiO_3$ ($mg.dm^{-3}$)			P value		
DAE	Absence	Presence	0.95	2.38	4.76	L	D	L*D
			---------------------- Stem height ----------------------					
28	18.83	18.25	19.00	18.50	18.12	0.195	0.280	0.195
35	26.16^a	24.66^b	25.00	26.25	25.00	0.045	0.264	0.156
42	37.33	36.58	37.12	36.75	37.00	0.494	0.958	0.430
49	51.00	48.08	51.87	48.50	48.25	0.083	0.145	0.782
56	60.41	57.25	59.87	58.12	58.50	0.116	0.739	0.483
63	69.75^a	65.16^b	66.87	66.25	69.25	0.030	0.432	0.289
			---------------------- Stem diameter ----------------------					
21	0.633	0.658	0.675	0.637	0.625	0.566	0.619	0.467
42	1.70	1.73	1.73	1.68	1.73	0.466	0.392	0.999
49	2.00	2.06	2.05	2.03	2.02	0.361	0.947	0.433
56	2.18	2.14	2.17	2.17	2.13	0.494	0.840	0.873
63	2.25	2.17	2.21	2.26	2.16	0.139	0.267	0.705

Averages followed by different letters in the line differ from each other, by the Tukey test at 5% probability. DAE: days after emergence. P value: significant effect probability. L: liming; D: dose; L*D: interaction between liming and dose of $CaSiO_3$ ($mg.dm^{-3}$).

The Si when absorbed by the plant polymerizes and accumulates in the cell wall of the epidermis, and may influence the development of the stem diameter increasing its structural resistance (Gomes et al., 2009), possibly this may have occurred from 28 and 35 DAE (Table 3), but throughout the development period of corn plants (from the 42 DAE), probably the correction strategies used reached the maximum acidity correction power, allowing greater nutrient availability, which caused proportionality in tissue flow, indicating that biomass production was not compromised.

3.2 Corn Biomass and Soil Chemical Composition

At 63 DAE when the base saturation was corrected using only calcium silicate and/or allied to Liming were superior to the control treatment ($P<0.05$), allowing greater increments in the biomass of aerial part (leaf and stem) and biomass of root (Table 5). Probably this may be related to the reduction of soil acidity provided by both the correction strategies, on the other hand, when it did not adopt any strategy of correction of soil acidity, it was observed that the production of biomass per plant was compromised (Table 5). Thus, with the deceleration of plant growth, it reduced the absorption of K, increasing the concentration of this macronutrient in the soil (Table 5).

Table 5. Averages related to leaf biomass (g vase^{-1}), stem biomass (g vase^{-1}), root biomass (g vase^{-1}) and soil chemical attributes of corn subjected to $CaSiO_3$ doses as a function of liming at 63 days after emergence

Vari ável	Factorial	Control	P value	SEM
		--------------------- Biomass ---------------------		
Leaf	20.48^a	1.37^b	<0.001	1.39
Stem	18.21^a	0.550^b	<0.001	1.21
Root	13.15^a	0.575^b	0.002	1.37
		--------------------- Chemical attributes ---------------------		
pH	6.37^a	4.82^b	<0.001	0.099
V (%)	80.51^a	55.72^b	<0.001	1.86
MO	36.84^a	39.37^a	0.415	0.869
		--------------------- Macronutrients ---------------------		
P	59.57^a	2.93^b	<0.001	3.92
K	0.292^b	0.620^a	<0.001	0.008
Ca	7.77^a	4.32^b	<0.001	0.939
Mg	2.75^a	1.65^a	0.999	0.122
H + Al	2.60^b	5.25^a	0.002	0.229
		--------------------- Micronutrients ---------------------		
Fe	12.27	12.63	0.999	0.543
Mn	10.03	8.77	0.999	0.694
Cu	1.71	1.48	0.999	0.346
Zn	1.30	1.11^a	0.999	0.068

Averages followed by different letters in the line differ from each other, by the Tukey test at 5% probability. Value – P: significant effect probability. SEM: standard error of the mean.

No oscillations were observed in the biomass of aerial part (leaf and stem) and root biomass (Table 6) between liming and calcium silicate doses (P>0.05). Using the limestone allied to the doses of silicate reduced the potential acidity and increased in higher concentration of Mg in the soil (Table 6). In addition, higher values of base saturation were observed, being above what was desired (>70%). Among the doses, it was observed that the lower dose of calcium silicate impacted in lower concentrations of Ca and P, already at the highest applied dose generated the lowest estimates of potential acidity. In relation to micronutrients, no disproportionality was observed (Tables 5 and 6).

Table 6. Averages referring to leaf biomass (g vase^{-1}), stem biomass (g vase^{-1}), root biomass (g vase^{-1}) and soil chemical attributes of corn subjected to $CaSiO_3$ doses as a function of liming at 63 days after emergence

	Liming		Dose of $CaSiO_3$ (mg.dm^{-3})			P value		
Variable	Absence	Presence	0.95	2.38	4.76	L	D	L*D
			Biomass					
Leaf	19.28	21.69	23.82	19.18	18.45	0.410	0.275	0.570
Stem	16.21	20.21	19.28	17.78	17.57	0.123	0.829	0.958
Root	11.64	14.65	12.27	13.20	13.97	0.213	0.839	0.136
			Chemical attributes					
pH	6.20	6.55	6.05	6.30	6.78	0.213	0.096	0.969
V (%)	76.44b^{b}	84.59^{a}	74.15^{b}	79.38^{ab}	88.0^{a}	0.035	0.017	0.808
MO	35.99	37.69	37.45	35.71	37.36	0.357	0.679	0.964
			Macronutrients					
P	65.15	54.00	44.28^{b}	64.70^{ab}	69.75^{a}	0.192	0.049	0.442
K	0.285	0.300	0.276^{b}	0.278^{b}	0.323^{a}	0.343	0.048	0.726
Ca	7.55	8.00	6.98^{b}	7.81^{ab}	8.53^{a}	0.249	0.011	0.723
Mg	2.32^{b}	3.19^{a}	2.52	2.82	2.92	0.004	0.451	0.699
H + Al	3.06^{a}	2.13^{b}	3.33^{a}	2.81^{ab}	1.65^{b}	0.046	0.016	0.663
			Micronutrients					
Fe	8.13	9.41	11.90	11.15	13.77	0.108	0.116	0.720
Mn	9.41	8.13	7.95	7.89	10.47	0.358	0.234	0.258
Cu	1.30	2.11	1.48	1.38	2.27	0.279	0.559	0.276
Zn	1.32	1.28	1.41	1.32	1.17	0.792	0.301	0.102

Averages followed by different letters in the line differ from each other, by the Tukey test at 5% probability. DAE: days after emergence. P value: significant effect probability. L: liming; D: dose; L*D: interaction between liming and dose of $CaSiO_3$ (mg.dm^{-3}).

It is noticeable the beneficial effect of $CaSiO_3$ as a possible corrective of soil acidity and calcium supply to the corn crop (Tables 5 and 6), since it positively impacted on soil fertility (Zanao et al., 2017; Liu et al., 2018; Coudert et al., 2019). When the lowest dose of $CaSiO_3$ without limestone was used, the proportional values of biomass were found in relation to the other doses (Table 6), and the recommended dose was to be used in a dystrophic red Latosol. On the other hand, it is still necessary to verify whether this production proportionality will occur when the corn crop reaches the phase of inflorescence and grain filler, considering that, at some moments, the lowest dose used accelerated the development of plants (Tables 3 and 4) and perhaps this event may occur when plants reach the reproductive phase.

4. Conclusion

Calcium silicate can be used as an alternative source for elevation of base saturation, improving the chemical composition of the soil, positively impacting the development of aerial part and root system in corn plants.

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