Silicate fertilizer and irrigation depth in corn production [1]

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ABSTRACT

Calcium-magnesium silicates improve the soil physicochemical properties and provide benefits to plant nutrition, since they are sources of silica, calcium and magnesium. The objective of this study was to evaluate the grain yield of irrigated corn fertilized with calcium-magnesium silicate. The experiment was carried out in a greenhouse in Campina Grande – PB, Brazil, using plastic pots containing 80 kg of soil. The treatments consisted of the combination of four irrigation depths, related to water replacement of 50, 75, 100 and 125% of the crop evapotranspiration, with fertilizer levels of 0, 82, 164 and 246 g of calcium-magnesium silicate, with three replications. The experimental design was in randomized blocks, with the irrigation depths distributed in bands while the silicon levels constituted the subplots. Corn yield was influenced by calcium-magnesium silicate and by irrigation depth, obtaining the greatest grain yield with the dose of 164 g pot^{-1} irrigated at the highest water level. The water-use efficiency of in corn production tended to decrease when the irrigation depth was increased. The best water-use efficiency was observed when the irrigation level was between 87 and 174 mm, and the dose of silicate was 164 g pot^{-1}.

Key words: silicon, irrigated corn, grain production.

RESUMO

Adubação silicatada e lâminas de irrigação na produção do milho

Os silicatos de cálcio e magnésio, quando aplicados aos solos, têm efeito sobre suas propriedades físico-químicas e sobre a nutrição de plantas, uma vez que são fontes de silício, cálcio e magnésio. O objetivo deste trabalho foi avaliar a produção de grãos de milho, irrigado e adubado com silicato de cálcio e magnésio. O experimento foi conduzido em casa de vegetação, no município de Campina Grande- PB, utilizando-se vasos plásticos com 80 kg de solo. Os tratamentos resultaram da combinação de quatro lâminas de irrigação, referentes a reposições de água, correspondentes a 50, 75, 100 e 125% da evapotranspiração da cultura, com níveis de adubação de 0, 82, 164 e 246 g de silicato de cálcio e magnésio, com três repetições. O delineamento experimental foi em blocos ao acaso, sendo as lâminas de água distribuídas em faixas e as doses de silício compondo as subparcelas. A produção do milho foi significativamente influenciada pelas dosagens de silicato de cálcio e magnésio e pelas lâminas de água, obtendo-se a maior produção de grãos com a dosagem de 164 g vaso^{-1} e maior lâmina de irrigação. A eficiência de uso da água na produção de grãos de milho tendeu a diminuir, sempre que as lâminas de irrigação aumentaram. A melhor eficiência de uso da água ocorreu com a utilização de lâminas entre 87 e 174 mm e da dose de silicato de 164 g vaso^{-1}.

Palavras-chave: silício, milho irrigado, produção de grãos.

INTRODUCTION

Metallurgy slags, when applied especially on low fertility sandy soils, improve its physicochemical properties and provide benefits to plant nutrition, since they are sources of silica, calcium and magnesium (Korndörfer *et al.*, 2004). Most of the studies involving metallurgy slags have shown its effect on soil acidity correction and as soil fertilizer, since it enhances calcium and magnesium levels and, possibly, increases the phosphorus availability (Prado & Fernandes, 2000).

Calcium plays an important role as an essential part of the plant cell, straightening the cell wall structure. Similarly, positive effects of silicon on metabolic, physiologic and structural activities have been observed in several plants, either silicon accumulating or not (Liang *et al.*, 2007). According to Ma *et al.* (2001), this plant classification is related to the molar ratio Si:Ca in plant tissues, i.e., accumulating and non-accumulating plants present the aforementioned ratio of greater than one and less than 0.5, respectively. However, according to Ma *et al.* (2003), silicon is accumulated in high levels on tissues of almost every plant species; in case of phytosanitary issues, silicon can provide an increase on plant resistance to insects and diseases (Epstein, 2001; Belanger *et al.*, 2003; Richmond & Sussman, 2003).

Responsible for activating a great variety of plant enzymes and being an important component of the chlorophyll, magnesium plays vital roles in plant production, such as silicon, which, according to Epstein (2001) and Nojosa *et al.* (2006), is the responsible for the increase of chlorophyll levels and for the leaf metabolism.

Owino-Gerroh & Gascho (2004) and Mali & Aery (2009) observed a reduction of plant lodging and a gain of productivity in corn and macassar beans by using increasing doses of silicon.

In grain crops such as corn, rice and sorghum, silica is deposited in the form of silica bodies, mainly on epidermal cells, which are siliceous and bulliform, and on stomata and leaf trichomas (Currie & Perry, 2007). Silica accumulation in the transpiration organs causes the formation of a double layer of cuticular silica, reducing the water loss by transpiration, which increases the water-use efficiency by the plant and enhances the resistance to biotic and abiotic stresses, such as the ones caused by chewing insects (Nwugo & Huerta, 2008). According to Kaya *et al.* (2006), the addiction of silicon increased the tolerance to water stress in corn seedlings, maintaining the membrane permeability.

Therefore, the need of further research on the effects of metallurgy slag in agricultural crops in evident. Thus, the objective of this study was to evaluate the effects of calcium-magnesium silicate and water levels on corn grown under greenhouse conditions.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse of the Department of Agricultural Engineering at Universidade Federal de Campina Grande, Campina Grande, Paraíba State, Brazil, in 2009.

For the experiment, plastic pots with 100 L capacity drilled in the base for drainage, were used. The pots were filled with 80 Kg of soil (Entisol Eutrophic) collected in the topsoil, presenting the main characteristics: sand $= 841.5$ g kg^{-1}; silt $= 87.5$ g kg^{-1}; clay $= 71.0$ g kg^{-1}; pH (H$_2$O) $= 6.6$; Ca $= 2.55$ cmol$_c$ kg^{-1}; Mg $= 2.23$ cmol$_c$ kg^{-1}; Na $= 0.06$ cmol$_c$ kg^{-1}, K $= 0.28$ cmol$_c$ kg^{-1}; H $= 0.79$ cmol$_c$ kg^{-1}; Al $= 0.00$ cmol$_c$ kg^{-1}, organic matter $= 8.4$ g kg^{-1} and P $= 28.5$ mg kg^{-1}.

The experimental design was a randomized block, with three replicates. The water levels were distributed in bands while the subplots were constituted by the doses of calcium-magnesium silicate. The treatments consisted of the combination of four water levels regarding to the water replacement (50, 75, 100 and 125% of the crop evapotranspiration), with four doses of calcium-magnesium silicate (0, 82, 164 and 246 g) of the soil in each pot with one plant, consisting one experimental unit. The calcium-magnesium silicate came from the slag of stainless steel production (Acesita), treated by Recmix do Brasil, containing: 25.0 % of calcium; 6.0 % of magnesium and 10.5 % of silicon.

The soil was mixed with the silicate, according to the treatments aforementioned. Initially, the mixture was incubated and kept at field capacity for 30 days, so the silicate could react with the soil. After that, the mixture was fertilized with nitrogen, phosphorus and potassium, according to Novais *et al.* (1991), using 100 mg of N; 300 mg of P$_2$O$_5$ and 150 mg of K$_2$O per kilogram of soil, using as source: urea (46 % of N), triple superphosphate (46 % of P$_2$O$_5$) and potassium chloride (60 % of K$_2$O), respectively. All the phosphorus was added in one application while the nitrogen and potassium doses were added in two applications, the first one during the seeding and the second one 15 after the germination.

After fertilization, five seeds of corn BRS Caatingueiro were sown per pot, and two plants per pot were grown up to the end of the experiment.

For water supply, the pressurized irrigation method was used, adopting the drip irrigation system. The water used for irrigation came from the urban supply.

The amount of water applied in irrigation was quantified based on the Class A pan installed in the greenhouse. The reference crop evapotranspiration (ET$_0$) inside the greenhouse was calculated by multiplying Kp (equal to 1.0) by the evaporation (EV) daily measured in the Class A pan, according to the equation ET$_0$ = Kp x EV. To calculate the crop

evapotranspiration (ET_c), the crop coefficient (K_c) was multiplied by the reference crop evapotranspiration, according to the equation $ET_c = K_c \times ET_0$.

At first, K_c adopted was equal to 0.7 during the phenological stage, corresponding to the emission of the second to the fourth completely expanded leaf. The K_c adopted varied according to the corn development, using 0.87 until the emission of the eighth leaf, 1.04 from the eighth to the tenth leaf and 1.20 from the tenth to the twelfth completely expanded leaf. This last value ($K_c = 1.20$) was adopted during tassel emission, flowering (ear emission), pollination and kernel milk stage. At the kernel dent stage, before the physiological maturity, when the kernels presented a black layer in the ear intersection, the K_c adopted was 0.35. The leaf was considered completely expanded when the joint line leaf-sheath could be easily seen.

The water levels, in volume (assessed in liters), were calculated by multiplying the ET_c at each development stage of the crop by 0.5, 0.75, 1.0 and 1.25, obtaining the irrigation depths I_1, I_2, I_3 and I_4 (mm day^{-1} or L m^{-2} day^{-1}), corresponding to the replacement of 50, 75, 100 and 125% of the crop evapotranspiration. Afterwards, the irrigation depths I_1, I_2, I_3 and I_4 were multiplied by the surface area of the pot ($S_{pot} = 0.13$ m^2), obtaining the volume required to supply the daily water levels.

The harvest was manually performed, when the grains were dry. The production was evaluated by weighing the kernels (obtaining the kernel weight per plant, in grams), after drying in a forced-air convection oven at 60°C, until approximately 13% of moisture.

The water-use efficiency (WUE) was calculated by the ratio between corn yield (weight of dry kernels) and the water consumption during the production stage, when different irrigation depths were used (totalizing 86 days).

The effects of irrigation depths and calcium-magnesium silicate doses were evaluated through polynomial regression using the program SISVAR version 5.1. The curves with the greatest R^2, obtained by regression analyses through the F test, followed the quadratic models:

$$G = a\,I^2 + b\,I + c \tag{1}$$

$$G = a\,D_{Silicate}^2 + b\,D_{Silicate} + c \tag{2}$$

$$WUE = a\,I^2 + b\,I + c \tag{3}$$

$$WUE = a\,D_{Silicate}^2 + b\,D_{Silicate} + c \tag{4}$$

Where G is the grain yield, WUE is the water-use efficiency, I is the irrigation depth and $D_{silicate}$ is the dose of calcium-magnesium silicate; a, b and c are the regression coefficients.

RESULTS AND DISCUSSION

Corn yield and the water-use efficiency (WUE) were influenced by irrigation depths and calcium-magnesium silicate doses and by their interaction at 1% probability (Table 1). These results disagree with those obtained by Prado & Korndörfer (2003), which observed no effect of silicate fertilization in corn. Similarly, Orioli Júnior *et al.* (2008) observed that silicium fertilization (0, 50, 100, 150, 200 e 250 kg ha^{-1} of Si) did not influence wheat yield.

Medeiros *et al.* (2009) observed no difference in water-use efficiency in sugar cane fertilized with silicate. According to Melo *et al.* (2003), silicon fertilization (0, 242, 484, 968 e 1452 kg ha^{-1}) under 2 water regime in soil (60 and 80% of field capacity) in 2 Brachiaria species (*Brachiaria decumbens* Stapf and *Brachiaria brizantha* Hochst.), did not improve the drought tolerance nor influenced the dry mass production in both species. Although, the addition of fertilizer rich in calcium-magnesium silicates increased drought tolerance, keeping the membrane permeability, in corn seedlings (Kaya *et al.*, 2006), indicating that those plants used the irrigation water efficiently (Table 1).

The polynomial regression analysis indicated that the average data of production and WUE, regarding to the variation in irrigation depths, were adjusted to the quadratic model significant at 1% probability with high determination coefficients, presenting variations in each dose of calcium-magnesium silicate (Table 2).

The inflection points of production and WUE curves (Figure 1), estimated by the statistical models shown in Table 2, for calcium-magnesium silicate fertilization at the doses 0, 82 and 164 g plant^{-1} and for irrigation depths, presented the lowest values of 45, 53 and 47 g plant^{-1}, at the irrigation depths of 128, 67 and 26 mm, respectively, for grain yield. For WUE, the respective minimum points were 0.33, 0.49 and 0.58 g mm^{-1} using the irrigation depth of 161, 156 and 150 mm, respectively.

From these minimum points, it was observed an increase tendency of grain yield and WUE, with the increment of the irrigation depth for each dose of silicate used. For the silicate dose of 246 g per pot, an increase was observed until the maximum grain yield of 124 g plant^{-1}, using irrigation depth of 220 mm and WUE of 0.58 g mm^{-1}, with irrigation depth of 162 mm. Onwards from these values a decrease was observed in production as well as in WUE (Figure 1).

According to Herrero & Johnson (1981), the effects of drought stress in corn physiology are evident in the development of the male part of the flower and on the pollen production, causing a reduction of kernels per ear.

Given the aforementioned, the inferior grain yield per plant observed in the treatments with low irrigation depths can be explained by the drought stress which those plants were submitted.

Analyzing the grain yield and the WUE, for each irrigation depth applied and with the variation of calcium-magnesium doses, an adjustment of 1% probability was observed, with high determination coefficients for polynomial regression, as shown on Table 3.

The graphs (Figure 2) of the regression models (Table 3) represent the production and WUE behavior with acceptable accuracy, as their models were significant at 1% probability (Figure 2).

The lower production observed in plants grown in the absence of calcium-magnesium silicate may be related to

Table 1. Analysis of variance for corn production and water-use efficiency

Source of variation	DF	Corn Production			Water use efficiency		
		MS	Fc	Pr > Fc	AS	Fc	Prob F
Block	2	10.46	0.93	0.4446[ns]	0.00083	1.48	0.2989[ns]
Irrigation Depth (I)	3	12404.9	1102.92	0.0000**	0.04593	82.16	0.0000**
Error 1	6	11.25	—	—	0.00055	—	—
Silicate dose (Si)	3	1100.13	42.21	0.0002**	0.03995	49.73	0.0001**
Error 2	6	26.06	—	—	0.0008	—	—
Interaction (I X Si)	9	549.4	22.89	0.0000**	0.02349	25.52	0.0000**
Error 3	18	24	—	—	0.00092	—	—
Total adjusted	47						
Variation coefficients (CV)	4.00%		4.27%				

[ns] Not Significant; ** Significant at 1 % probability; DF – Degree of freedom; MS – Mean Square; Fc- F calculated

Table 2. Regression models and mean squares for corn production and water-use efficiency, regarding to irrigation depths inside each silicate dose

Silicate dose g pot⁻¹	Production (P), g plant⁻¹				
	Regression model	R^2	MS	Fc	Prob F
0	$P = 0.0086^{**} I^2 - 2.202^{**} I + 186.16^{**}$	0.928	3087.07	128.62	0.0000**
82	$P = 0.0035^{**} I^2 - 0.472^{*} I + 68.80^{**}$	0.929	3884.57	161.85	0.0000**
164	$P = 0.0026^{**} I^2 - 0.137^{ns} I + 49.29^{**}$	0.969	4253.16	177.2	0.0000**
246	$P = -0.0019^{*} I^2 + 1.112^{**} I - 39.20^{*}$	0.999	2828.31	117.84	0.0000**

Silicate dose	Water use efficiency (WUE), g mm⁻¹				
	Regression model	R^2	AS	Fc	Prob F
0	$WUE = 0.00006^{**} I^2 - 0.019^{**} I + 1.89^{**}$	0.955	0.0659	79.88	0.0000**
82	$WUE = 0.00003^{**} I^2 - 0.0094^{**} I + 1.22^{**}$	0.442	0.0319	38.76	0.0000**
164	$WUE = 0.000022^{**} I^2 - 0.0066^{**} I + 1.07^{**}$	0.455	0.0155	18.78	0.0000**
246	$WUE = -0.000013^{**} I^2 + 0.0042^{**} I + 0.24^{**}$	0.999	0.0031	3.72	0.0215*

** Significant at 1 % probability; * Significant at 5 % probability; I – Irrigation depth; R^2 – determination coefficients; MS – Mean squares; Fc - F calculated; Prob F – model significance
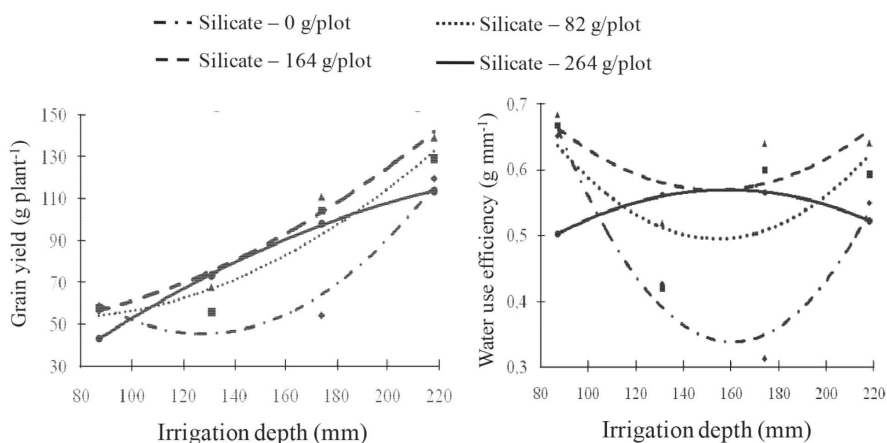

Figure 1. Variation of grain yield and water-use efficiency, according to the irrigation depth for each dose of calcium-magnesium silicate.

the lower levels of calcium and magnesium in the soil, due to the lack of silicate containing those elements.

Although, when 82 g of calcium-magnesium silicate was used, the production increased 21.22% compared to the control (0 g of calcium-magnesium silicate). The treatments fertilized with 164 g of silicate had greater production, with an increase of 69.19% compared to the control. It is worth mentioning that the increase of silicate doses from 82 to 164 g resulted in a production gain of 8.8%, while from 164 to 246 g, the production decreased in 12.99%.

The irrigation curves of 87, 174 and 218 mm presented the peak production of 93, 110 and 121 g plant^{-1}, using silicate doses of 61, 116 and 137 g pot^{-1}, respectively. From these points, the tendency was of production decrease. The irrigation depth of 131 mm presented the lowest production of 54 g plant^{-1} when fertilized with 76.5 g pot^{-1} of calcium-magnesium silicate. Nonetheless, the water-use efficiency for every irrigation depth had a

maximum peak. The highest WUE values were observed at 87 and 174 mm, according to the second-order polynomial regression curves, with 0.70 and 0.78 g mm^{-1}, respectively, fertilized with 93 and 215 g pot^{-1} of silicate. At the irrigation depths 131 and 218 mm, the WUE were 0.63 and 0.62 g mm^{-1}, fertilized with 130 and 117 g pot^{-1} of calcium-magnesium silicate, respectively.

According to the regression models, in the absence of calcium-magnesium silicate, the greatest production average was observed at irrigation depth of 218 mm (125% of ET_c). On the other hand, the production of plants fertilized with calcium-magnesium silicate increased according to the irrigation depths, and the greatest productions were observed at the two highest irrigation depths, 174 and 218 mm, corresponding to 100 and 125% of the ET_c, respectively. These results show the importance of appropriate irrigation depth in crop production.

Fertilization with calcium-magnesium silicate usually enhances the growth in several crops, including corn (Ma

Table 3. Regression models and average squares for corn production and water-use efficiency, regarding to doses of calcium-magnesium silicate inside each irrigation depth

Irrigation depth mm	Production (P), g plant^{-1}				
	Regression Model	R²	AS	Fc	Prob F
87	P = - 0.0006** $D_{Silicate}^2$ + 0.111* $D_{Silicate}$ + 55.81**	0.906	160.46	6.68	0.0031**
131	P = 0.0002* $D_{Silicate}^2$ + 0.314* $D_{Silicate}$ + 54.99**	0.929	232.66	9.69	0.0005**
174	P = - 0.0023** $D_{Silicate}^2$ + 0.744** $D_{Silicate}$ + 55.62**	0.987	1972.49	82.18	0.0000**
218	P = - 0.0013** $D_{Silicate}^2$ + 0.314** $D_{Silicate}$ + 117.97**	0.822	382.74	15.94	0.0000**
Irrigation depth mm	Water use efficiency (WUE), g mm^{-1}				
	Regression model	R²	AS	Fc	Prob F
87	WUE = - 0.000007** $D_{Silicato}^2$ + 0.0013** $D_{Silicato}$ + 0.64**	0.917	0.0217	26.29	0.0000**
131	WUE = - 0.00001* $D_{Silicato}^2$ + 0.0026* $D_{Silicato}$ + 0.46**	0.392	0.0138	16.72	0.0000**
174	WUE = - 0.00001** $D_{Silicato}^2$ + 0.0043** $D_{Silicato}$ + 0.32**	0.986	0.0667	80.94	0.0000**
218	WUE = - 0.000006** $D_{Silicato}^2$ + 0.0014** $D_{Silicato}$ + 0.54**	0.822	0.0082	9.95	0.0001**

87 mm = 11.31 L pot^{-1}; 131 mm = 17.03 L pot^{-1}; 174 mm = 22.62 L pot^{-1} ; 218 mm = 28.34 L pot^{-1};** Significant at 1 % probability; * Significant at 5 % probability; $D_{Silicate}$ – dose of calcium-magnesium silicate; R² – determination coefficients; MS – Mean squares; Fc - F calculated; Prob F – model significance.
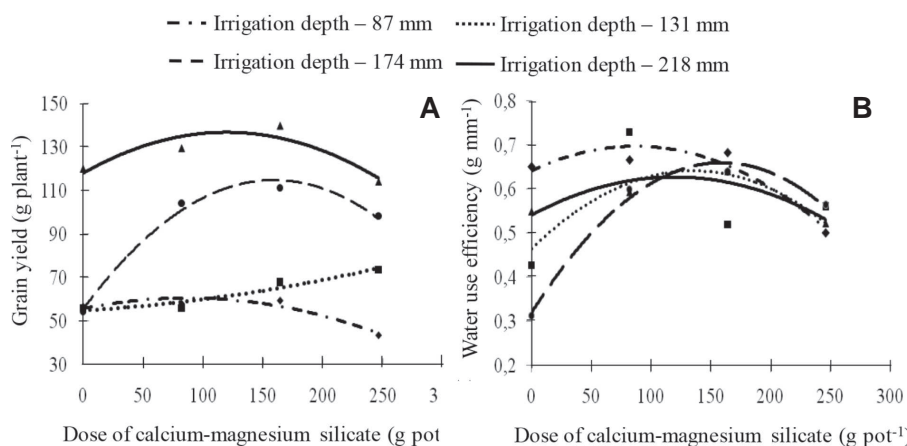
--- - Irrigation depth – 87 mm   ·········· Irrigation depth – 131 mm

-- - - Irrigation depth – 174 mm   ——— Irrigation depth – 218 mm

Figure 2. Variation of grain yield and water-use efficiency, according to the doses of calcium-magnesium silicate for each irrigation depth.

et al., 2001). According to Savant *et al.* (1999) the greater crop production promoted by silicates is due to its effect on plant architecture, making the leaves more erect, enhancing light gathering, which increases CO_2 absorption and reduces transpiration. Thus, silicate fertilization increases photosynthesis rate and provides greater water-use efficiency.

The increase of Si concentration in soil solution also alters the cation-anion balance in the plants and increases the concentration of organic acids in plants tissues, promoting the development (Owino-Gerroh & Gascho, 2004).

CONCLUSIONS

The grain yield was influenced by irrigation depths, by calcium-magnesium silicate doses and by the interaction between those factors.

The dose of calcium-magnesium silicate that provided the greatest grain yield and water use efficiency, among all irrigation depths used, was 164 g pot^{-1}.

The irrigation depth that provided the greatest averages of grain yield, among all calcium-magnesium silicate doses, was 218 mm, while the best water-use efficiency (among all irrigation depths) were observed at 87 and 174 mm.

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