Calcium silicate as softening of hydric stress in maize[1]

Douglas José Marques[2]; Mozart Martins Ferreira[3]; Hudson Carvalho Bianchini[2]; Fernanda de Paula Fernandes[4]; Lívia Mendes Brandão[4] & Rafael de Oliveira Ferreira[4]

[1] Parte do trabalho de Tese do primeiro autor com recursos financiados pela FAPEMIG, CNPq e Capes; [2] Professor; Universidade José do Rosário Vellano-UNIFENAS; Alfenas, MG; E-mail: douglasjmarques81@yahoo.com.br; hudson.bianchini@unifenas.br [3] Professor, Departamento de Ciência do Solo, Universidade Federal de Lavras - UFLA. Caixa Postal 3037, Lavras (MG), Brasil. E-mail: mozartmf@ufla.br, [4] Estudante, Universidade José do Rosário Vellano-UNIFENAS; Alfenas, MG; E-mail: fernandapaula_fernandes@outlook.com; liviamb_12@hotmail.com; rafaelferreira440@hotmail.com

ABSTRACT: The aim of this study was to evaluate different proportions of calcium silicate on leaf water potentials, gas exchange and production parameters in *Zea mays* plants exposed to different irrigation depths. The experiment was organized in factorial scheme completely randomised with five corrective associations (0, 25, 50, 75, and 100% of calcium silicate indicated to liming of this soil) and five irrigation depths (30, 70, 100, 130, and 160% of necessary to water reposition in this soil). The application of 100% of calcium silicate promoted increase in values of predawn and midday water potentials, and beneficial effects also were showed to stomatal conductance, net photosynthetic rate and photosynthetic water use efficiency, when applied the irrigation depths of 70, 100, 130 and 160%.

Keywords: *Zea mays* L., silicon, drought, grain production.

INTRODUCTION

The drought is a common environment component in regions with agricultural potential, due to occurrence and irregular distribution of rainfall and/or inadequate supply of irrigation (Lobato et al., 2008). Therefore, the water deficiency works as limiting factor in several crops (Santos and Carlesso, 1998), such as maize plants. Additionally, the water restriction during vegetative, reproductive, and maturation stages result normally in minor growth and development rates (Lobato et al., 2008), flower abortion (Pimentel, 2004) and reduction in grain production (Leport et al., 1998), respectively.

The irrigation management based water tension in soil has been frequently used in maize plants (Rivera-Hernández et al., 2009), due to soil normally be filled by water and air, in which it promotes a negative tension state. Additionally, the water tension in soil is called of matric potential, being resulting of water affinity with soil.

The use of indicators of water status in plant, such as leaf water potential can also be an important approach in monitoring the availability of soil water and irrigation needs (Bergonci et al., 2000). The water potential is an important and sensitive measure for evaluating water exigency by the plant, in which it oscillated in values approximately to zero in plants under adequate water availability (Kramer and Boyer, 1995). The leaf water potential has been used in studies of the water relations in plants (Hsiao, 1973), and it is considered as the standard plant water state.

The silicon (Si) is considered an benefic element to higher plants (Epstein and Bloom, 2004), being that the absorption process must be active or passive (Ma et al., 2007), and deposition in cell walls of several organs such as leaf and stem can promote beneficial effects (Cunha et al., 2008), and for this reason has been frequently linked to physiological, morphological, nutritional, and molecular aspects in plants (Isa et al., 2010). In biochemical level, Silva et al. (2012) describe increases in chlorophyll levels produced by silicon application. Additionally, Isa et al. (2010) reported silicon accumulation in leaf, and this fact is related to higher mechanical resistance from cell wall (Kim et al., 2002), providing better light reception and increasing photosynthesis capacity and CO_2 uptake capacity (Chen et al., 2011).

Based in this overview, the aim of this study was to evaluate different proportions of calcium silicate on production parameters in Zea mays plants exposed to different irrigation depths.

MATERIAL AND METHODS

Localization, environment conditions, plant material, and soil characteristics

The study was carried out in Departamento de Ciência do Solo from Universidade Federal de Lavras, Minas Gerais, Brazil (21°14' S; 45°00' W; 915 m asl), where the experiment was conducted under conditions of greenhouse, being described maximum, mean, and minimum temperatures during experimental period in Figure 1. To plant material, seeds of *Zea mays* L. (cv. BR 106), in which this cultivar have as agronomical characteristic the plant height of 2.4 m, ear length of 0.16 m, and yield of 5.5 ton ha^{-1}, and large adaptation to Brazilian conditions (Embrapa, 2004). In relation to soil, this is classified as oxisol, (Embrapa, 2006).

Experimental design and treatments

The experiment was organized in factorial scheme completely randomized with five corrective associations (0, 25, 50, 75, and 100% of calcium silicate indicated to liming of this soil) and five irrigation depths (30, 70, 100, 130, and 160% of necessary to water reposition in this soil), being this study composed by 4 repetitions. The volume of each pot is 15 L.

Treatment application and fertilization

In Table 1 is described the amounts of calcium silicate (CaSiO3) and calcium carbonate (CaCO3) present in different associations, and additionally was applied calcium in form of calcium chloride (CaCl2) aiming to equilibrate the amount of this element in treatments. After the treatment application the soil was kept under incubation by 45 days. The fertilization using macro and micronutrients was carried out as described by Novais et al. (1991), with lower adaptations to this experiment.

Curve of water retention and field capacity

The curve of water retention was used to water characterization of the soil, and data were applied in formulas $\theta = 0.4215 \times [1 + (0.2040 \times (\Psi_m)^{1.8757}]^{-0.4669} + 0.2670$ and $\Psi_m = [1/\alpha\ (1/m)\ 1/n]$, in agreement with Genuchten (1980). Where, θ = humidity current ($cm^3\ cm^{-3}$), Ψ_m= tension in soil (kPa), as well as α, m, and n are parameters linked to equation adjustment in model proposed by Genuchten. The field capacity was estimated by equation $\theta_i= (\theta_s - \theta_r) \times [1+1/m]^{-m} + \theta_r$, as proposed by Dexter (2004). Where, θ_i = humidity in inflexion point of the curve ($cm^3\ cm^{-3}$), θ_s = humidity of saturation ($cm^3\ cm^{-3}$), and θ_r = humidity residual ($cm^3\ cm^{-3}$). The value of humidity calculated in field capacity of this study was 0.3458 $cm^3\ cm^{-3}$ to tension of - 40 kPa.

Irrigation depths and water volume

The irrigation was carried out based in curve of water retention linked to soil and tensiometer measurements installed in profundity of 0.15 m. The irrigation was implemented when the water tension in soil reached the value of -40 kPa, and to each irrigation depth (30, 70, 100, 130, and 160% of necessary to water reposition in this soil). All measurements were carried daily in 17:00 h, and soil moisture meters (Watermark, model 200SS-5) were installed to quantify the matric potential only in three higher tensions (30, 70, and 100 of ideal depth to soil). The water volume applied to irrigation was calculated by equation: $V = (\theta_c - \theta_{treat.}) \times V_{soil}$, where V = water volume to be applied (mL), θ_c = humidity in yield capacity ($cm^3.cm^{-3}$), θ_{treat}= humidity in treatment ($cm^3.cm^{-3}$), and V_{soil} = volume of soil (mL).

Irrigation application system and flow water

For application of depths was installed a drip irrigation system with auto compensating drippers and water flow of 4 h h^{-1}. In side lines were used flexible tubes of 80 cm of length, being initiated this lines in distribution control, and water was pressurized by gravity. The uniformity coefficient linked to flow water in this study was measured by formula: $CU = (q_{25\%}/q_{average})$ proposed by Bralts and Kesner (1978). Where, UC = uniformity coefficient, $q_{25\%}$ = average of 25% of minor flows (L h^{-1}), and $q_{average}$ = average total (L h^{-1}). In this study the value to UC was 0.93.

Leaf water potential

The leaf water potentials (Ψw) were measured in fully expanded leaves under light during period between 05:00 to 06:30 h, and 11:30 to 13:00 h corresponding to predawn and midday potentials, respectively, using an analogue plant moisture system (Skye Instruments, model SKPM 1405/50), in which is based in technical of pressure chamber (Scholander et al. 1964), according to the procedure of Turner (1988).

Data analysis

Data were subjected to variance analysis and when significant differences occurred, Scott-Knott test at 5% level of error probability was applied (Steel et al., 2006). Standard errors were calculated for all means. All statistical procedures were carried out with the SAS software (SAS, 1996).

RESULTS & DISCUSSION

Water potentials in leaf and gas exchange

The application of 100% of calcium silicate promoted increase in values of predawn and midday water potentials, being showed also that this treatment is statistically better in five irrigation depths investigated. The stomata are sensitive to leaf water potential, in which stomatal mechanism promotes stomatal closure with decreasing leaf water potential and opening of this structure with increasing water potential (Figure 1). The values of leaf water potential ranging between -0.3 and -0.5 MPa are usually considered suitable to development *Zea mays* plants, as well as values less than -0.8 MPa will cause inhibition of photosynthesis rate, lower rates linked to development and expansion leaf, and finally in minor values that -1.5 MPa frequently are found the permanent wilting points in *Zea mays* specie (Porto et al., 1998). Bergonci et al. (2000) working with *Zea mays* plants reported values of leaf water potential between -1.2 and -1.5 MPa in irrigated plants, as well as -1.6 and -2.0 MPa in non-irrigated plants.

Additionally, the silicon accumulation in stomata causes the formation of a double layer of cuticle silica, which it reduces transpiration (Datnoff et al. 2001) and makes with that the water requirement by plants is lower, being this fact of importance extreme to growing crops in soils of tropical climate and that are exposed to periods of limited water availability. Around 95% of the total water absorbed by the plant is used to maintain thermal equilibrium by transpiration. Therefore, the variation in transpiration will affect directly the plant temperature, more specifically the leaf temperature (Qiu et al. 2000).

Grain production and matter of 100 seeds

The grain production (Figure 2 A) revealed an increase tendency, proportional to the irrigation depth. For the irrigation of 30%, the higher productions were occurred to proportions of 50, 75 and 100% of calcium silicate, respectively. While at 70% of the irrigation depth, the higher grain production was found in the proportions of 50 and 75% of calcium silicate. These results indicate that silicon attenuated the negative effects provoked by water deficit in maize plants. For applications of 100, 130 and 160% of irrigation depth, there was no significant difference in maize production at different ratios of calcium silicate. Figure 2 B shows the results for the matter of 100 seeds. The interaction between the irrigation and proportion of calcium silicate does not significantly affect the matter of 100 seeds. It was observed that the matter of 100 seeds responds positively to increased irrigation depth in all proportions of calcium silicate. Additionally, responded positively to increase of irrigation depth, in turn, aiming to increase the production. The grain production and matter of 100 seeds (Figure 2 A and B) were influenced by increase in irrigation depths, but the application of calcium silicate not promoted significant increases in these parameters. The performance of *Zea mays* plants under conditions of water restriction is much lower, when compared to cultivation in adequate condition, and it can be explained by the low tolerance of this species to water deficit (Silva et al., 1984). The Si absorption promotes benefits in several crops and also in *Zea mays* plants (Lima et al., 2011), such as increased resistance to lodging and photosynthesis rate (Ali et al., 2013). Silicon is a chemical element involved in physical functions of evapotranspiration regulation, as well as it can form a mechanical barrier against pathogen invasion to internal part of the plant, besides it to work preventing the attack of insects (Romero et al., 2011). Study conducted by Faria (2000) revealed than lower the value linked to field capacity of the soil, higher was the plant response to silicon.

Despite calcium silicate to promote significant increase in photosynthesis rate this increment was not transferred to grain production. In addition, photosynthesis plays an important role in crop production (Wullschleger and Oosterhuis, 1990), because the yield is directly influenced by the intensity of the accumulation rate of carbohydrates (Crafts-Brandner and Poneleit, 1992). Results described by Pimentel (1999) revealed that water deficit can affect the transport and utilization of carbon skeletons, because these molecules are redirected and/or maintained in other regions of the plant as leaf and stem, and of this form to reach not the grain (Oliveira Neto et al., 2009). Drought causes changes in the partition of carbohydrates into plant, such as sucrose and starch, which it can perform key roles in the mechanisms of adaptation and tolerance of the plant in water deficit conditions (Villadsen et al., 2005).

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Figure e Table

Table 1 - Amounts of $CaSiO_3$, $CaCO_3$, and $CaCl_2$ used in different associations.

Association	**$CaSiO_3$**	**$CaCO_3$**	**$CaCl_2$**
(%)		**(g pot^{-1})**	
100	12.20	0.00	0.00
75	9.15	2.63	1.03
50	6.10	5.25	2.06
25	3.05	7.88	3.09
0	0.00	10.50	4.12

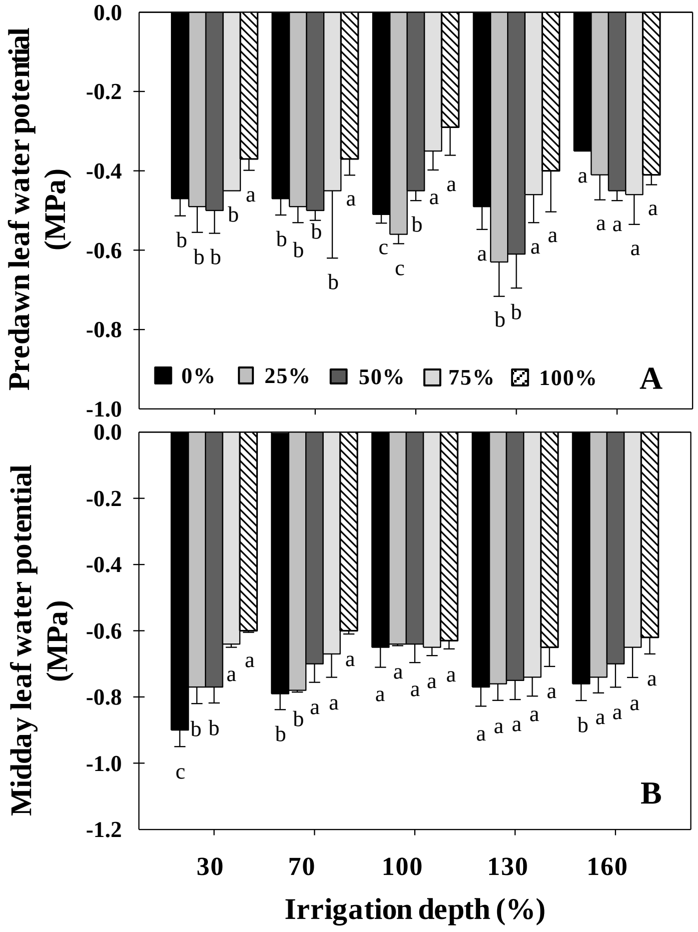

Figure 3 - Predawn leaf water potential (A) and midday leaf water potential (B) in *Zea mays* plants (cv. BR 106) exposed to five corrective associations (0, 25, 50, 75, and 100% of calcium silicate indicated to liming of this soil) and five irrigation depths (30, 70, 100, 130, and 160% of necessary to water reposition in this soil). Means followed by the same letter to each irrigation depth are not significantly different by the Scott-Knott test at 5% of probability (P > 0.05). The bars represent the mean standard error.

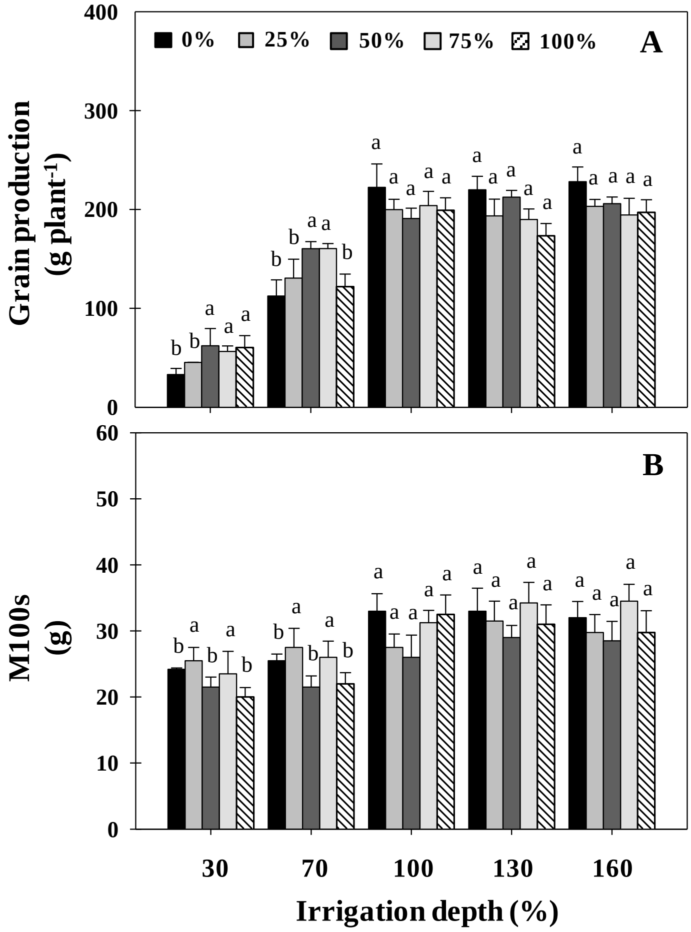

Figure 2 - Grain production (A), and matter of 100 seeds (B) in *Zea mays* plants (cv. BR 106) exposed to five corrective associations (0, 25, 50, 75, and 100% of calcium silicate indicated to liming of this soil) and five irrigation depths (30, 70, 100, 130, and 160% of necessary to water reposition in this soil). Means followed by the same letter to each irrigation depth are not significantly different by the Scott-Knott test at 5% of probability (*P* > 0.05). The bars represent the mean standard error.