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Growth of sweet pepper plants submitted to water tensions in soil and potassium silicate doses

Alexandre Igor A Pereira[1]; João de Jesus Guimarães[1]; João Victor Costa[1]; Fernando S de Cantuário[1]; Leandro C Salomão[1]; Roberta C de Oliveira[2]; José Magno Q Luz[2]

[1]Instituto Federal Goiano (IF Goiano), Urutaí-GO, Brazil; j-jesus.guimaraes15@hotmail.com; joaovictor0796@hotmail.com; aiapereira@yahoo.com.br (correspondence author); fernandoscantuario@hotmail.com; leandro.salomao@ifgoiano.edu.br; [2]Universidade Federal de Uberlândia (UFU), Uberlândia-MG, Brazil; robertacamargoss@gmail.com; jmagno@ufu.br

ABSTRACT

Water stress compromises plant growth. Resistance inducers, such as potassium silicate (K_2SiO_3), can reduce negative effects of this stress on Solanaceae, *Capsicum annuum*. Plant height, stem diameter and leaf area may indicate the efficiency of potassium silicate foliarsprayagainst water stress. The aim of this study was to evaluate the growth of sweet pepper plants under water stress and K_2SiO_3 doses. The experiment was conducted in randomized blocks in a split-plot scheme in space. The treatments consisted of four soil water stresses: 15 kPa (field capacity), 25 (intermediate value), 35 and 45 kPa (water stress) and three doses of potassium silicate (0, 0.4 and 0.8 L 100 L^{-1} water), acting as resistance inducers to water stress. The resistance inducer maintained greater heights of the sweet pepper plants, under water stress (35 and 45 kPa) at the initial stage [(20 days after transplanting (DAT)]. Smaller plant diameters were observed at 80 and 100 DAT at 35 and 45 kPa. Sprays using K_2SiO_3 maintained sweet pepper leaf area with higher values, even under stress condition. The soil water tension from 35 kPa limited, in general, the plant growth. Growth responses in *Capsicum annuum* to K_2SiO_3, via foliar spraying, varied according to plant age, as well as the growth parameter considered in this experiment.

Keywords: *Capsicum annuum*, Solanaceae, water stress, silicon.

RESUMO

Crescimento de plantas de pimentão submetidas a tensões de água no solo e doses de silicato de potássio

O estresse hídrico compromete o crescimento vegetal. Indutores de resistência, como o silicato de potássio (K_2SiO_3) podem amenizar efeitos negativos desse estresse em Solanaceae, *Capsicum annuum*. A altura das plantas, diâmetro do caule e área foliar podem servir como indicadores da eficiência de pulverizações foliares com K_2SiO_3 contra o estresse hídrico. O objetivo foi avaliar o crescimento do pimentão submetido ao estresse hídrico e doses de K_2SiO_3. O experimento foi conduzido em blocos casualizados em esquema de parcelas subdivididas no espaço. Os tratamentos consistiram em quatro tensões de água no solo: 15 kPa (capacidade de campo), 25 (valor intermediário), 35 e 45 kPa (estresse hídrico) e três doses de silicato de potássio (0, 0,4 e 0,8 L 100 L^{-1} água) que age como indutor de resistência ao estresse hídrico. O indutor de resistência manteve maiores alturas da planta de pimentão, sob estresse hídrico (35 e 45 kPa) no estádio inicial [20 dias após o transplantio (DAT)]. Menores diâmetros foram observados aos 80 e 100 DAT com 35 e 45 kPa. Pulverizações com K_2SiO_3 mantiveram a área foliar das plantas de pimentão com maiores valores, mesmo sob condição de estresse. A tensão de água no solo, a partir de 35 kPa, limitou o crescimento das plantas de forma geral. As respostas de crescimento em *Capsicum annuum* ao K_2SiO_3, via pulverização foliar, variaram de acordo com a idade da planta, bem como do parâmetro de crescimento considerado.

Palavras-chave: *Capsicum annuum*, Solanaceae, estresse hídrico, silício.

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Sweet pepper (*Capsicum annuum*) has carotenoids in its composition which act as antioxidants in prevention and relief of various diseases (Agostini-Costa *et al.*, 2017). Pungency, nutrition and pigment also created new market demands (Tian *et al.*, 2014), which requires more modern strategies to manage this plant production.

One of the greatest challenges of the vegetable production these days is to meet quantitative demand and, on the other hand, use natural resources increasingly efficient and sustainable. In the last decades, water has been suffering a tendency of scarcity around the world, which evidences the search for better management practices of this resource through the adoption of techniques to reduce its spending (Egea *et al.*, 2017). This is especially important due to uncertainties in weather events, an increase in environmental, populational and industrial needs (Jonge *et al.*, 2015).

Public policies have considered drip irrigation as a strategy to deal with water scarcity (Ortega-Reig *et al.*, 2017), because it rationalizes the use of water and provides an increase in plant production (Dai *et al.*, 2016). However, the generation of technical knowledge about the water requirement of plants of economic importance, combined with a better understanding of how environmental conditions interfere with the agricultural system, contributes to expand the possibilities of irrigation management. Regulated water deficit with reduction of water supply in order to improve its efficiency (without compromising plant and productivity development, though) is a recently explored enhancement (Yang *et al.*, 2017).

The improvement in irrigation efficiency can reach up to 80%, with only a slight increase in the water deficit, according to simulations performed in the Mediterranean region (García-Garizábal *et al.*, 2017). However, despite being considered as a promising strategy in water use, using deficit irrigation presents as a challenge meeting plant physiological requirements (Mancosu *et al.*, 2015). Thus, Contreras *et al.* (2017) highlighted the need to monitor plant growth parameters to diagnose the effect of induced rationalization of water.

An option to mitigate the risk of losses in quality and quantity of sweet pepper plants submitted to higher soil water tensions, would be to associate their cultivation with the use of resistance inducers against abiotic stress (Pereira *et al.*, 2013). Leaf applications used as exogenous silicon sources (Si) have been used as promising mechanisms of resistance in *Solanaceae* family against water stress (Crusciol *et al.*, 2009). The use of resistance inductors, such as potassium silicate (K_2SiO_3), has been reported as a component for phytossanitary management in sweet pepper (Pereira *et al.*, 2015). Growth, physiological and production parameters have been satisfactory in sweet pepper (and other Solanaceae) with high soil water tensions and sprayed with exogenous Si sources (Manivannan *et al.*, 2016). In Brazil, this kind of irrigation management is still underexplored, though.

Water deficit can act as a precursor of the abiotic stress in Solanaceae (Oliveira *et al.*, 2013), but little is known about the effect of resistance inducers against stress, such as potassium silicate, used in plants of Solanaceae family. Thus, this study aimed to evaluate growth of sweet pepper plants, cv. Magali R, submitted to soil water tensions, using K_2SiO_3 as foliar spray.

MATERIAL AND METHODS

The experiment was carried out at the Experimental Olericulture Sector of Instituto Federal Goiano (IF Goiano), Campus Urutaí, southeast of the state of Goiás, Brazil (17º29’10”S, 48º12’38”W, 697 m altitude). An arch-type greenhouse with a metallic structure, facing East-West, 30 m length, 7 m width, 4.0 m ceiling height and 1.2 m height was used. The greenhouse was covered with low density polyethylene opaque film, 0.15 mm thick, with sides closed with aphid-proof screen.

The local climate was classified as tropical altitude, dry winter and rainy summer, Cwb according to Köppen. The soil in the experimental area is classified as Typic Hapludox, loam sandy texture (Santos *et al.*, 2013). Soil was prepared using mechanic plowing with a mini tractor model TC 14 with 14 cv (Yanmar Agritech Lavrale S/A, Indaiatuba-SP) with rotary hoes adapted for operation. Fertilization using 40 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5, 100 kg ha^{-1}of K_2O and 2 kg ha^{-1} of B (boron) in the form of urea, superphosphate, potassium chloride and borax (respectively) was performed 15 days before seedling transplant to the definitive place.

The experimental design was a randomized block design, arranged in split plot scheme in space; with four soil water tensions (15, 25, 35 and 45 kPa) and three potassium silicate doses (0, 0.4 and 0.8 L 100 L^{-1} water) with four replications. The soil water tensions were arranged in plots, whereas the potassium silicate doses were arranged in split plots. Four useful seedbeds (blocks) in two planting lines per seedbed were used.

In borders on the left and right sides of the greenhouse, only one planting line was used. Each planting line consisted of irrigation lateral line, with drippers spaced 40 cm. A total of 8 useful lateral lines, and one line for the left and one line for the right border were used. Potassium silicate was applied weekly, via foliar spraying, following the treatment methodology, using a 20-L manual costal sprayer (Jacto Agricultural Machines S/A, Pompéia-SP). The doses of K_2SiO_3 followed technical recommendation (Solo Fértil SP Comercial Agrícola Ltda, São José do Rio Preto, São Paulo). A total of 18 applications was performed during the experimental period (about 150 days), starting 15 days after transplant (DAT) and finishing 120 DAT.

The parthenocarpics of cultivar, Magali R hybrid (Sakata Seed Sudamerica Ltda, Bragança Paulista-SP), green, cone-shaped, resistant to Potato Virus Y (PVY) and to Tomato MosaicVirus (ToMV) was used. Seeds were sown in polystyrene trays with 200 cells. The cells were filled with substrate for seedling production (Bioplant Agrícola Ltda, Ponte Nova-MG) containing, as main raw material, *Pinus* sp. bark, as well as coconut fiber, vermiculite and rice hull as aggregates. Seedlings were kept under appropriate conditions in nurseries and, 50 days after sowing, seedlings were transplanted, showing approximately 8 cm height and 4 to 5 definitive leaves.

Plants were irrigated using a dripping irrigation system, each lateral row consisted of one irrigation lateral line, 16 mm thickness and drippers with 1.4 L h^{-1} nominal flow and10 mca operating pressure. Irrigation water pumping system consisted of 1 cv motor pump, a Venturi type fertilizer injector (Plasnova Tubos Louveira Industria e Comércio Ltda, Louveira-SP), a 120 mesh screen filter, valves and manometers for measuring the irrigation system pressure. Fertilization was splitted into five fertigations throughout experiment.

Two puncture tensiometers Son da Terra Equipamentos Agronômicos, Piracicaba-SP) were installed in each experimental plot, totalizing 32 units. The tensiometers were installed at 10 cm from sweet pepper plants and 10 cm depth, to control the irrigation quantity in the soil layer from 0 to 20 cm in the first 50 DAT (days after transplant). From 50 DAT on, tensiometers installed at 20 cm depth were used to control irrigation quantity in soil layer from 20 to 40 cm depth. Soil water tension was measured using a digital tensiometer (Hidrosense Comércio de Sistemas para Irrigação Ltda, Jundiaí-SP).

During the first 15 DAT, the authors used the same irrigation management for all treatments. The aim was to ensure seedling establishment. Thus, all experimental plots received, in the first two days after transplant, 25 mm water depth and, from the second day on, 2 mm daily water depths. This procedure followed responses of soil water retention curve in order to keep soil close to an average water matric potential of -10 kPa.

During sweet pepper plant growth, required cultural practices were done. Bamboo canes (1.0 m height) were crisscrossed, tied using strings, for vertical plant support. The elimination of the lateral shoots below the first bifurcation was performed. Weed control was carried out throughout the experiment through manual hoeing every three days. Pests were controlled with fungicide and acaricide applications, when necessary.

Plant height (cm), stem diameter (mm) and leaf area (cm^2) were quantified in seven time intervals after transplant (20, 40, 60, 80, 100, 120 and 140 DAT) for each treatment. Plant height was quantified using a metallic measuring tape graduated in centimeter (0.1 cm), with measures taken from the soil surface to the apical bud. A digital caliper (0.05 mm) was used to quantify stem diameter of sweet pepper plants at a height of 50% of the total stem size. The authors used length and width of three leaves of the plants, obtained randomly, in order to estimate the leaf area. The first leaf was taken from the superior part, the second in the middle part and the third from bottom of the plant canopy. Using average values of leaf length and width, the authors used the equation proposed by Rezende *et al.* (2002). Plant leaf area was determined by multiplying leaf area by total number of leaves per plant.

All quantified data were verified in relation to assumptions of the analysis of variance. Normality was verified by the Lilliefors adherence test and, in a complementary way, by the histogram obtained in the SAEG statistical program. According to this procedure, the variables plant height, stem diameter and leaf area did not follow normal distribution and therefore were transformed into log (x+1). In this case, standard deviations of the samples were proportional to their mean (Feng *et al.*, 2014). In addition, the coefficient of variation (CV) was used as an indicator to diagnose the correct transformation of the real data to log (x+1). The transformation was considered valid when CV of the transformed data was smaller than CV of the actual data (Reed *et al.*, 2002).

Variance analysis and comparison between averages of treatments were done in transformed scale, the results shown in figures remained in original scale, though. After significance verification (or not) of factors in interaction or isolated considered, using ANOVA with split plot scheme, averages were compared using Tukey test, at 5% probability. All figures were generated using program SigmaPlot®, version 11 (Systat Software Inc).

RESULTS AND DISCUSSION

Soil water tension, as an isolated factor, significantly influenced sweet pepper plant height only in the intervals of 40 (P= 0.00), 80 (P= 0.01) and 100 DAT (P= 0.02) (Figure 1A). The lowest evaluated tensions (15 and 25 kPa) generated higher sweet pepper plants at 40 DAT (P> 0.05) and 100 DAT (P= 0.02) (Figure 1B). Tension of 25 kPa generated higher plants in comparison to tensions of 15, 35 and 45 kPa, in the interval of 80 DAT (Figure 1B). Considering the effect of soil water tension, independent of time intervals, the tensions of 35 and 45 kPa generated smaller sweet pepper plants (Figure 1B). Potassium silicate doses, as an isolated factor, influenced in sweet pepper plant height, only at 120 DAT (P= 0.00) (Figure 1C). In this case, leaf applications for both doses of 0.4 and 0.8 L of K_2SiO_3, generated higher sweet pepper plants in comparison to plants without K_2SiO_3 (P= 0.02) (Figure 1C). Significant interaction between soil water tensions and potassium silicate doses in sweet pepper plants was noticed only at 20 DAT (Figure 1A). In this case, the sweet pepper plants without potassium silicate application were smaller, under water stress (35 and 45 kPa) (Figure 1D). Potassium silicate application, independent of the dose, provided higher sweet pepper plants when submitted (at 20 DAT) to tensions of 35 and 45 kPa (Figure 1D).

Sweet pepper plants showed to be responsive to soil water deficiency, considering height a sensitive parameter to water stress condition (Schlichting, 2012). Soil water tensions between 35 and 45 kPa also hindered the growth of other Solanaceae as it was observed by Viol *et al.* (2017). The authors verified that up to 40-45% of water withdrawal and 30-35% of soil moisture content interferes in an appropriate C*apsicum* species' physiological functioning, with greater losses in vegetative stage comparing with fruiting or flowering stages (Okunlola *et al.*, 2017). Thus, irrigation tutoring only during fruit production stage can be risky, since the remediation change in a particular type of management may be irrelevant. This study highlights that monitoring growth parameters of *C. annuum* can indicate the plant behavior in relation to water stress and exposure to resistance inductors, such as K_2SiO_3.

The reduction in photosynthetic activity is a hindrance to plants under high soil water tensions (Costa *et al.*, 2011). However, potassium silicate acts in this scenery as an important resistant inductor against water stress, being able to minimize negative effects, especially on young sweet pepper plants, as observed at 20 DAT. Silicate compounds protect the membrane integrity of chloroplasts (Cao *et al.*, 2015), increasing antioxidant capacity and decreasing lipid peroxidation, which determines the maintenance or increase of biomass under water stress (Kang *et al.,* 2016). In addition, Si acts on the modulation of gene expression and signaling through phytohormones, decreasing ethylene levels, which delay leaf senescence under dry conditions (Kang *et al.*, 2016). Thus, the results obtained in this study showed that leaf sprayings with Si can provide better resistance for sweet pepper plants, against water stress effects, during seedling establishment, when sensitivity is higher (Katerji *et al.*, 1993).

Sweet pepper stem diameter was influenced only by soil water tensions at 80 and 100 DAT (P> 0.05) (Figure

2A). In both intervals, tensions of 35 and 45 kPa provided lower stem diameter values in comparison to lower tensions (15 and 25 kPa) (Figure 2B). Significance of isolated factor of potassium silicate doses (*P*< 0.05), as well as the interaction of this factor with soil water tension (P< 0.05) was not observed for sweet pepper stem diameter (Figure 2A).

Sweet pepper plants at 80 and 100 DAT, under higher soil water tensions, showed lower stem diameter values. This parameter was less influenced by the evaluated treatments. The stem of Solanaceae allows passage of energy sources, nutrients and water that stimulate plant growth and reproduction (Longui *et al*., 2016). Trade off between shoot growth (like stem) in detriment to root growth in sweet pepper plants has been observed in water stress situations (Ezzo *et al*., 2010). This proves that, for sweet pepper, flow direction of elements via stem to shoot or root part of the plant seems to be mediated by the water state of the medium in which the plant is located (Blom-Zandstra *et al.*, 1998). The obtained results in this study showed evidences that the plant stem diameter is more sensitive to water stress at 80 and 100 DAT. This fact can be an important reference to observe plant quality, according to the adopted irrigation management.

Leaf area was influenced by a significant interaction between the two studied factors in intervals of 60, 80 and 100 DAT (*P*= 0.03) (Figure 3A). For intervals of 60 (Figure 3B), 80 (Figure 3C) and 100 DAT (Figure 3D) sweet pepper leaf area was smaller in tensions of 35 and 45 kPa, without potassium silicate application, though. However, sweet pepper seedlings maintained leaf area greater when kept under the two higher soil water tensions and leaf applications with potassium silicate dose-independent, when compared to its area without potassium silicate applications and showed similar values when compared to the plants submitted to tensions of 15 and 25 kPa (Figures 3B, C and D).

Sweet pepper leaf area showed significant interaction between soil water tensions and potassium silicate doses evaluated in this study. In this case, the authors suggest that sprayings with Si on leaves under water stress conditions is beneficial. The benefits of silicon for leaves are important and notorious, for various purposes, such as improvement of plant architecture, regulation of water loss through transpiration and greater rigidity of external morphology. Such changes may provide some resistance in sweet pepper leaves against herbivory (Guntzer *et al.*, 2012) and this fact should be conveniently explored in further studies.

The reduction in leaf area indicates degree of stress since foliar growth interferes directly on productivity capacity (Buczkowska *et al*., 2016). The

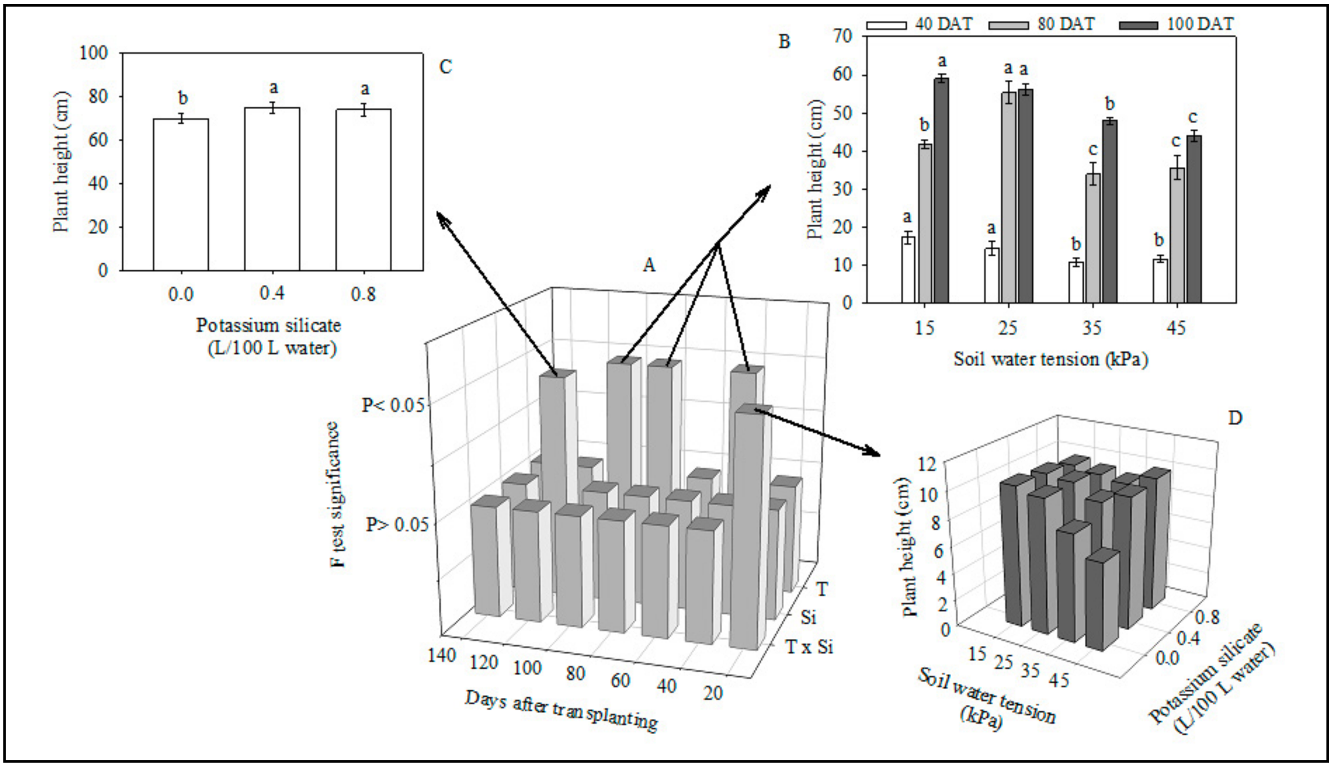

Figure 1. Graphical representation of variance analysis under split plot scheme considering only significant effects of soil water tension (T) (15, 25, 35 and 45 kPa) and potassium silicate doses (Si) (0, 0.4 and 0.8 L of K_2SiO_3/100 L water), isolated or under interaction (T x Si), for sweet pepper height (*Capsicum annuum*) (1A). Unfolding of significant effects of soil water tension (T), isolated, for plant height (average ± EP[1]), only at 40, 80 and 100 DAT (1B). Unfolding of significant effects of potassium silicate doses (Si), isolated, for plant height (average ± EP[1]), only at 120 DAT (1C). Unfolding of significant effects of investigated factors, under interaction, for plant height (average ± EP[1]), at 20 DAT (1D). Averages followed by same letters do not differ from each other, Tukey test at 5% probablility in figures 1B, C and D. Urutaí, IF Goiano, 2015.

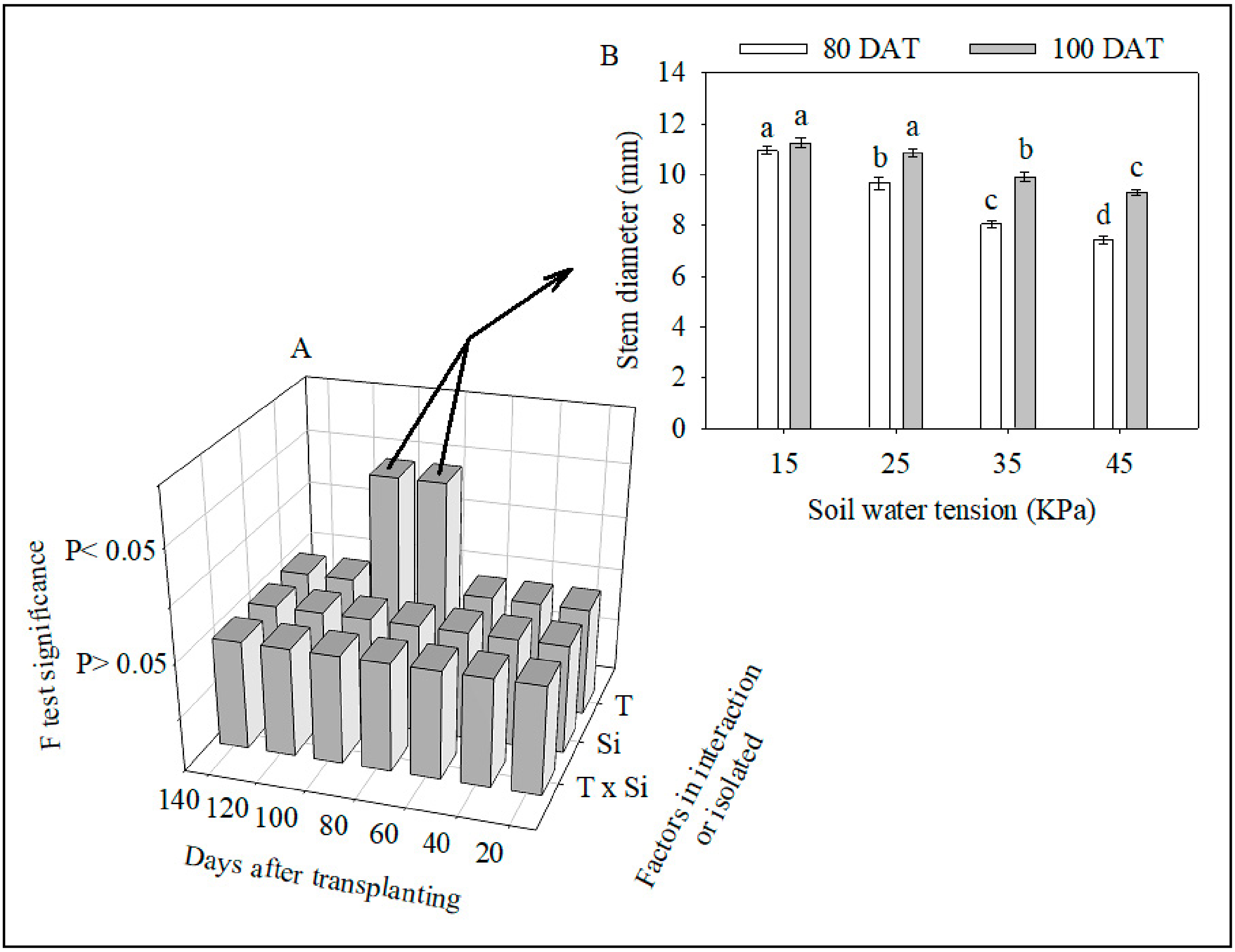

Figure 2. Graphical representation of variance analysis under split plot scheme considering only significant effects of soil water tension (T) (15, 25, 35 and 45 kPa) and potassium silicate doses (Si) (0, 0.4 and 0.8 L of K_2SiO_3/100 L water), isolated or under interaction (T x Si), for sweet pepper stem diameter (*Capsicum annuum*) (2A). Unfolding of significant effects of soil water tension (T), isolated, for plant stem diameter (average ± EP[1]), only at 80 and 100 DAT (2B). Averages followed by same letters do not differ from each other, Tukey test at 5% probability in figure 2B. Urutaí, IF Goiano, 2015.

leaf area was smaller in two higher soil water tensions (35 and 45 kPa) at 60, 80 and 100 DAT, showing that greater susceptibility to stress in this plant may be dependent on its phenological age, as previously commented (Delfine *et al.*, 2015).

Inhibition of leaf expansion, due to reduced rate of cell division, results in a smaller plant canopy (Chaves *et al.*, 2003). This may be an important adaptive indicative to prevent water loss by perspiration. Sweet pepper plants showed higher values of leaf area when kept under two greater soil water tensions with sprayings of resistance inductor on their leaves (independent of the dose). Plants differ, a great deal, from each other when it comes to capacity of absorption and deposition of Si (Mitani & Ma, 2005). Most of Si absorbed by the plant is deposited in the leaf, in the tissues of the epidermis and, more precisely, in the cell walls (Agarie *et al.*, 1998) which may explain the most prominent responses of the leaf area in sweet pepper plants with presence of Si.

Lastly, we highlight that using soil water tensions, from 35 kPa, may limit sweet pepper plant growth. The responses of this plant to potassium silicate via leaf spraying depended on plant age and growth parameter to be considered. Sweet pepper plants reacted to Si use in critical phonological phases, such as seedling establishment, flowering and fructification.The authors suggest that K_2SiO_3 is important when it comes to protect sweet pepper plants and highlight that the growth parameter of this plant can be used as indicative of the beneficial action of abiotic resistance inducers, such as the ones against water stress.

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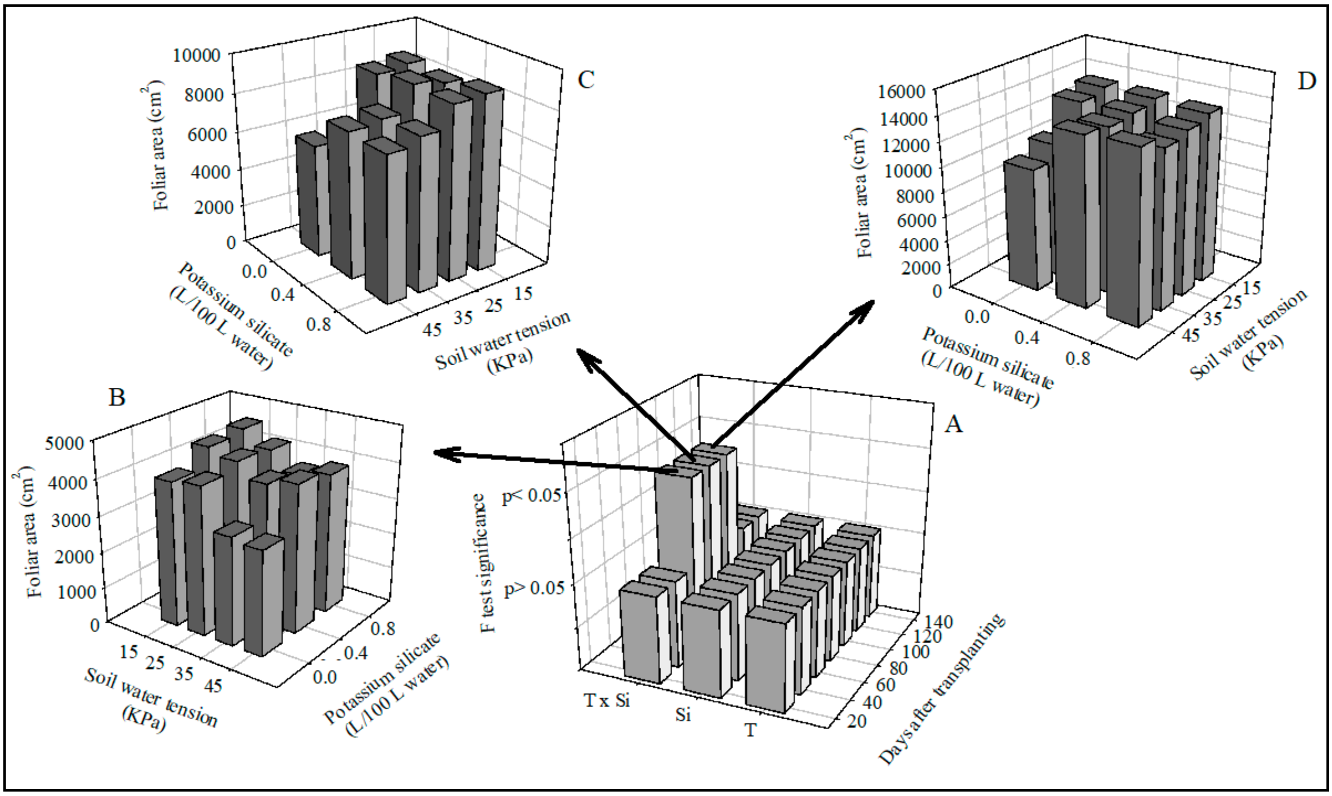

Figure 3. Graphical representation of variance analysis under split plot scheme considering only significant effects of soil water tension (T) (15, 25, 35 and 45 kPa) and potassium silicate doses (Si) (0, 0.4 and 0.8 L of K_2SiO_3/100 L water), isolated or under interaction (T x Si), for sweet pepper leaf area (*Capsicum annuum*) (3A). Unfolding of significant effects for interaction (T x Si) in leaf area at 60 DAT (3B), 80 DAT (3C) and 100 DAT (3D).Urutaí, IF Goiano, 2015

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