

Water stress mitigation by silicon in sweet-potato

The objective was to evaluate the effect of the reduction in the irrigation blades under silicate fertilization via soil on growth, branch emission, production of fresh phytomass of aerial part, yield of marketable tuberous roots, and agricultural water use efficiency by plants of the sweet-potato variety Campina, with purple skin. The treatments were arranged in subdivided plots, distributed into randomized blocks, using a 2x5 factorial scheme with three repetitions, totaling 30 experimental units. The plots were two irrigation blades of 100 and 50% of the crop evapotranspiration – (ETc) and the subplots corresponded to the silicon doses of 0.0, 0.5, 1.0, 1.5, and 2.0 g plant⁻¹. At the end of the experiment, the following variables were evaluated: stem diameter, branch emission, fresh phytomass of aerial part, phytomass of marketable tuberous roots, yield, and water use efficiency by plants. According to the results, the reduction from 100 to 50% of the ETc caused inhibition of growth, production of fresh phytomass of aerial part, and yield of marketable tuberous roots. The crop revealed to be more sensitive to water stress regarding yield than regarding growth or biomass formation by the aerial part and marketable tuberous roots.

Keywords: Ipomoea batatas (L.) Lam; Water availability; Silicate fertilization.

Mitigação do estresse hídrico por silício em batata-doce

Objetivou-se avaliar o efeito da redução das lâminas de irrigação sob adubação silicatada via solo sobre o crescimento, emissão de ramos, produção de fitomassa fresca da parte aérea, rendimento de raízes tuberosas comercializáveis e eficiência do uso agrícola da água por plantas da espécie adocicada. batata variedade Campina, com casca roxa. Os tratamentos foram dispostos em parcelas subdivididas, distribuídas em blocos casualizados, em esquema fatorial 2x5 com três repetições, totalizando 30 unidades experimentais. As parcelas foram duas lâminas de irrigação de 100 e 50% da evapotranspiração da cultura – (ETc) e as subparcelas corresponderam às doses de silício de 0,0, 0,5, 1,0, 1,5 e 2,0 g planta⁻¹. Ao final do experimento foram avaliadas as seguintes variáveis: diâmetro do caule, emissão de ramos, fitomassa fresca da parte aérea, fitomassa das raízes tuberosas comercializáveis, produtividade e eficiência do uso da água pelas plantas. De acordo com os resultados, a redução de 100 para 50% da ETc causou inibição do crescimento, produção de fitomassa fresca da parte aérea e rendimento de raízes tuberosas comercializáveis. A cultura mostrou-se mais sensível ao estresse hídrico quanto à produtividade do que quanto ao crescimento ou formação de biomassa pela parte aérea e raízes tuberosas comercializáveis.

Palavras-chave: Ipomoea batatas (L.) Lam; Disponibilidade de água; Fertilização silicatada.

Topic: **Desenvolvimento, Sustentabilidade e Meio Ambiente**

Received: **02/07/2021**

Approved: **28/07/2021**

Reviewed anonymously in the process of blind peer.

Evandro Franklin de Mesquita 

Universidade Estadual da Paraíba, Brasil
<http://lattes.cnpq.br/3678539134744796>
<http://orcid.org/0000-0001-5722-2235>
evandro@bol.com.br

Francisco de Oliveira Mesquita 

Instituto Nacional do Semiárido, Brasil
<http://lattes.cnpq.br/2630263044186621>
<http://orcid.org/0000-0002-8580-079X>
mesquitaagro@yahoo.com.br

Caio da Silva Sousa 

Universidade Estadual da Paraíba, Brasil
<http://lattes.cnpq.br/7062083562541883>
<http://orcid.org/0000-0002-4163-8313>
caio_silva@hotmail.com

Daniel da Silva Ferreira 

Universidade Estadual da Paraíba, Brasil
<http://lattes.cnpq.br/5927486686094961>
<http://orcid.org/0000-0003-1859-2617>
danielsilvaf@hotmail.com

Josinaldo Lopes Araujo Rocha 

Universidade Federal de Campina Grande, Brasil
<http://lattes.cnpq.br/8792518421189353>
<http://orcid.org/0000-0003-4669-6114>
josinaldo@hotmail.com

Lourival Ferreira Cavalcante 

Universidade Federal da Paraíba, Brasil
<http://lattes.cnpq.br/3065449647572057>
<http://orcid.org/0000-0002-8827-4713>
lofeca@cca.ufpb.br



DOI: 10.6008/CBPC2179-6858.2021.007.0033

Referencing this:

MESQUITA, E. F.; MESQUITA, F. O.; SOUSA, C. S.; FERREIRA, D. S.; ROCHA, J. L. A.; CAVALCANTE, L. F.. Water stress mitigation by silicon in sweet-potato. *Revista Ibero Americana de Ciências Ambientais*, v.12, n.7, p.363-376, 2021. DOI: <http://doi.org/10.6008/CBPC2179-6858.2021.007.0033>

INTRODUCTION

Although sweet potato (*Ipomoea batatas* L.) is one of the three main storage root crops of global importance, after potato (*Solanum tuberosum* L.) and cassava (*Manihot esculenta* Cratz), its sustainability depends on the efficient water use throughout the cycle in order to adapt it to climate change (YOUYONGWECH et al., 2013; GOUVEIA et al., 2019). This dependence seems to be more serious in the High Hinterland (Alto Sertao) areas of the state of Paraíba due to the volumetric reduction of water springs in response to insufficient and irregular rainfall distribution, compromising growth, development, and agricultural productivity.

Given this scenario, there is a growing concern with the availability of water resources for irrigated agriculture in semiarid lands, in annual drought periods, since in these areas the water deficit reduces the availability of water in the soil and, consequently, the agricultural water use efficiency by plants, with a negative impact on growth and crop yield (BERTINO et al., 2015; BARBOSA et al., 2016).

Among the factors that compromise the biological processes and crop yield, water deficit is highlighted since the lack of water in the soil restricts stomatal opening in the leaves, with severe damage to the photosynthetic system, especially in regions that depend on irrigation, where the water consumption of sweet potato is affected by climate change (YOUYONGWECH et al., 2016; MULOVHEDZI et al., 2020). With the reduction of photosynthesis, there is a decrease in the production of carbohydrates that would later be stored by plants to be used in other vital stages of their development (SINGELS et al., 2005; ZHANG et al., 2018).

The cultivation of sweet potatoes is one of the most important vegetable crop for family farmers in the micro-region of Catolé do Rocha-PB and your production tuberous root is negatively affected by water stress, with greater intensity in semiarid regions, according verified by Saqib et al. (2017), after irrigating the crop with water blades equivalent to 60, 80, 100, and 120% of its water requirement.

Almeida et al. (2015) and Cui et al. (2020) concluded that the water deficit inhibits crop photosynthesis, growth and production. This situation expresses the dependence of agricultural production systems on irrigation, in the semiarid world, and requires the adoption of water management strategies in order to obtain sustainable agricultural yields to guarantee food availability, given the growing global concern (SOUZA et al., 2016; DELZARI et al., 2017; EL-FOTOH et al., 2019).

One of the alternatives may be the use of silicon (Si) in agriculture (GUNTZER et al., 2012), which, although not being an essential nutrient for plants, exerts a mitigating action on abiotic stresses, such as water, salt, and nutritional stress (SAVVAS et al., 2015; BESHARAT et al., 2020).

The Catole do Rocha micro-region, located in Alto Sertão in Paraíba, presents great diversity in its production systems with environmental feasibility for the development of new agricultural activities. In this context, the arithmetic mean of the last five years of reference rainfall and evaporation was 745.3 and 1868 mm year⁻¹, respectively, obtained at the meteorological station of the State University of Paraíba, Campus IV. The reference evaporation (ET₀) was 2.5 times greater than rainfall. Thus, silicon provides protection

against water losses by plants under stress due to water deficiency and increased soil salinity. In addition to the positive action of mitigating stress, silicon also exerts a beneficial effect on plants, evidenced by the low transpiration coefficient, resulting in better water use, stimulation of leaf chlorophyll production, greater structural rigidity of tissues, increase of the mechanical resistance of cells while maintaining the leaves erect and increasing the area of photosynthetic activity, and CO₂ absorption (ETESAMI et al., 2018; ALVES et al., 2020; BESHARAT et al., 2020).

After absorption, it accumulates in the endoplasmic reticulum, in the cell walls, and intercellular spaces as hydrated silica SiO₂ · n H₂O, forming complexes with polyphenols, constituting an alternative to lignin in the reinforcement of cell walls, and improving the ability of plants to withstand stress in arid regions (TAIZ et al., 2017; HELALY et al., 2017; MAHMOUD et al., 2020).

Based on the above, the objective was to evaluate the effects of silicate fertilization on the efficiency of water use on growth, fresh biomass of the aerial part and yield of commercial sweet potato roots, in the Alto Sertão of Paraíba.

MATERIALS AND METHODS

Characterization of area

The study was conducted between July 10, 2019, and January 16, 2020, in the facilities of the Center of Human and Agricultural Sciences, belonging to the State University of Paraíba (UEPB), situated in the Mesoregion of the High Hinterland of Paraíba. located in the county of Catole do Rocha. The municipality is located in the semiarid region of the High Hinterland of Paraíba, located at the geographic coordinates: 6° 20'38" south latitude, 37° 44' 48" west longitude, and an elevation of 275 m.

The climate of the region, according to Köppen (ALVARES et al., 2013), is semiarid BSh, hot with summer rains, and according to the division of the state of Paraíba into bioclimatic regions, it presents a 4bTh bioclimate with a rainless period lasting from 5 to 7 months. The rainy season lasts from January to July, with greater frequency and intensity in the months of February, March, and May.

Soil of the experimental area

The soil of the experimental area, according to the criteria of the Brazilian Classification System, was classified as a Eutrophic FLUVIC NEOSOL (EMBRAPA, 2018). Before the installation of the experiment, soil samples were collected at the 0-20 cm layer blades for chemical characterization regarding fertility and physical attributes (Table 1) by employing the methodologies contained in the manual by EMBRAPA (2017).

Table 1: Chemical characterization regarding fertility and soil physical properties of the experimental area, Catole do Rocha-PB, 2019.

STUDIED PARAMETERS			
Chemical attributes		Physical attributes	
pH in water (1,0:2,5)	6.7	Sand (g kg ⁻¹)	661
SOM (g kg ⁻¹)	11.59	Silt (g kg ⁻¹)	213
P (mg dm ⁻³)	16.19	Clay (g kg ⁻¹)	126
Si (mg dm ⁻³)	10.00	Ada (g kg ⁻¹)	42

K ⁺ (cmol _c dm ⁻³)	1.17	Gf (%)	66.7
Ca ²⁺ (cmol _c dm ⁻³)	1.49	Id (%)	33.3
Mg ²⁺ (cmol _c dm ⁻³)	0.54	Ds (g cm ⁻³)	1.51
Na ⁺ (cmol _c dm ⁻³)	0.10	Dp (g cm ⁻³)	2.76
Ca ²⁺ /Mg ²⁺	2.8:1	Pt (%)	45.00
SB (cmol _c dm ⁻³)	4.20	M (%)	31.9
(H ⁺ +Al ³⁺) (cmol _c dm ⁻³)	0.00	m (%)	13.1
Al ³⁺ (cmol _c dm ⁻³)	0.00	Uvcc (%)	13.14
CEC (cmol _c dm ⁻³)	4.20	Uvpmp (%)	4.97
V (%)	100	Adi (%)	8.17
Classification	Eutrophic	Textural classification	FAA

SOM = Soil organic matter; SB = Sum of exchangeable bases (SB = Ca²⁺+Mg²⁺+K⁺); CEC = Cation exchange capacity [CEC = SB (Ca²⁺+Mg²⁺+K⁺)]; V = Soil saturation by exchangeable bases [V = (SB/CEC) x 100]; Ada = Clay dispersed in water; Df = Degree of flocculation {Gf = [(Clay-Ada)/Clay] x 100}; Ds and Dp = respectively the density of soil and particles; Pt, M, and m = respectively, total porosity, macro, and microporosity of the soil; Uvcc, Uvpmp = respectively, volumetric moisture at field capacity and at permanent wilting point in the -0.033 and -1.500 MPa soil tensions; Adi = Available soil water; FAA = sandy clay loam. ¹Values of laboratory analysis, in %; ²Transformed values, in g kg⁻¹.

Experimental design

The treatments were arranged in subdivided plots distributed in randomized blocks with three replications, using a 2x5 factorial scheme, totaling 30 experimental units. The plots corresponded to the irrigation blades equivalent to 100 and 50% of the crop evapotranspiration – ETc), and the subplots corresponded to the silicon doses at the levels of 0.0, 0.5, 1.0, 1.5, and 2.0 g plant⁻¹, established according to Pilon (2011). Soil preparation consisted of plowing and harrowing, and each treatment or subplot, distanced by 1.0 in the planting ridges, was formed by three manually prepared ridges, each with 4.0 m length, 0.40 m width, and 0.35 m height, with a volume of 0.56 m³. On the ridges, the branches (seeds) were planted at a distance of 0.30 m, using 11 central plants in the central ridge for the evaluations. In each subplot, 1.5 kg of bovine manure with 5% moisture was incorporated (Table 2), characterized according to EMBRAPA (2009) in order to increase the soil organic matter content from 1.1 to 2.5%, using the expression by Bertino et al. (2015).

Table 2: Chemical characterization of the bovine manure used as a source of organic matter, Catole do Rocha-PB, 2019.

N	P	K	Ca	Mg	Na	Zn	Cu	Fe	Mn	OM	OC	C/N
.....g kg ⁻¹mg kg ⁻¹g. kg ⁻¹					
14.29	2.57	16.79	15.55	4.02	5.59	60	22	8,550	325	396.0	229.7	16:1

¹Values of laboratory analysis, in %; ²Transformed values, in g kg⁻¹.

The branches of the sweet potato variety Campina, with reddish-purple skin, were standardized to a size of 0.35 m, 10 internodes, and a diameter of 3.8 mm, aiming at greater planting homogeneity.

$$QEB (g) = (25 \text{ g kg}^{-1} - \text{TMOSP}) \times VL \times ds \times UE / \text{TMOEB}$$

In which:

QEB = Mass of bovine manure minus the moisture (g);

TMOSP = Content of organic matter that the soil possesses (g kg⁻¹);

VL = Ridge volume (dm³);

ds = Soil density (kg dm⁻³);

UE = Mass unit of bovine manure (%);

TMOEB = Content of organic matter in the bovine manure (g kg⁻¹).

Forms of application of Silicon

Silicon was supplied in the form of synthetic amorphous silicon dioxide (910 g kg⁻¹ of SiO₂), composed of nanoparticles of SiO₂ with high surface activity due to the high density of the radical silanol (SiO₂.nH₂O), in three equal applications, one at the preparation of the ridges, and other two at 30 and 60 days after planting the branches of the sweet potato variety Campina (*Ipomea batatas* L.), with purple skin. Mineral fertilization with NPK was common to all treatments: nitrogen was provided via urea (45%), phosphorus came from single superphosphate (21% P₂O₅, 18% Ca₂₊, 12% S), and potassium was provided in the form of potassium sulfate (53% K₂O), 40-60-40 of kg ha⁻¹ of N-P₂O₅-K₂O by applying a 20-30-20 kg ha⁻¹ ratio at planting, respectively, and the remaining 20-30-20 kg ha⁻¹ afterward, in two equal applications at 30 and 45 days after planting, respectively, as suggested by the Agronomic Institute of Pernambuco (CAVALCANTI, 2008). The plants were irrigated daily with water of moderate restriction to agriculture (AYERS et al., 1999), characterized according to Richards (1954) (Table 3).

Table 3: Chemical characterization of the water used in the experiment, Catole do Rocha-PB, 2019.

pH	CEai	SO ₄ ⁻²	Mg ⁺²	Na ⁺	K ⁺	Ca ⁺²	CO ₃ ⁻²	HCO ₃	Cl ⁻	RAR	class
.....mmolc L ⁻¹											
(mmol L ⁻¹) ^{1/2}											
6.9	1.01	0.18	1.48	6.45	1.21	2.50	0.00	2.75	8.11	4.57	C ₂ S ₁

CEai = Electrical conductivity of the irrigation water; RAS = Sodium adsorption rate [RAR= Na⁺/(Ca²⁺+Mg²⁺/2)1/2];

Irrigation and its application were performed using drip tapes with emitters spaced 0.3 m at a flow rate of 1.6 L h⁻¹, working at a 0.1 MPA service pressure. Crop evapotranspiration – ET_c was obtained by the product between the reference evaporation (ET_o, mm day⁻¹), estimated based on the evaporation data of a class A evaporation pan adjusted by the K_t of the device (0.75), and the crop coefficient – k_c in the different ages of the plants (ET_c = ET_o x k_c). To obtain the consumptive water use by the plants (U_c), a percentage of wet area (P) = 100% was considered. In this manner, the calculation of the daily net water blades (LLD) included the 6/7 irrigation fraction of referring to Sunday, for LLD = U_c x P/100 (mm d⁻¹); from this value, the water blades provided corresponding to 50 and 100% LLD were determined.

Distribution of blades

In the plots referring to the water blades of 100% ET_c, two drip tapes were distributed, whereas only one tape was distributed per ridge in the water blades of 50% ET_c. The variables attributed in the experiment were: Coefficient of the class A evaporation pan (k_p) = 0.75; Crop coefficient (k_c), equivalent to 0.4; 0.8 and 1.0 and 1.4 in the first 30 days after planting (DAP), from 30 to 60 DAP, from 60 to 90 DAP, and from 90 to 130 DAP (DOORENBOS et al., 1994; DOORENBOS et al., 1997). The blades referring to the percentages of 100 and 50% of the ET_c were equivalent to 940 and 470 mm/cycle, respectively. The irrigation blade referring Sunday was distributed in the week.

Meteorological data

In the place of the experiment, the data of rainfall, as well as the daily evaporation values of the class

A evaporation pan, temperature, and relative humidity were registered. The hydrothermal variables were obtained at 60-minute intervals, using a thermo hygrometer data logger (Table 4).

Table 4: Mean monthly data of air temperature, relative air humidity, reference evaporation, and rainfall, Catole do Rocha-PB, 2019.

Months	Air temperature (°C)		Air relative humidity (%)		Reference evaporation (mm month ⁻¹)	Rainfall (mm month ⁻¹)
	Day	Night	Day	Night		
July	29.33	23.86	56.00	77.50	4.67	1.09
August	30.94	23.60	46.50	71.00	6.87	0.60
September	37.40	24.41	31.00	68.00	8.60	0.00
October	35.75	25.00	36.50	62.50	9.08	0.00
November	36.00	26.00	33.00	62.00	8.36	0.00
December	35.50	23.60	30.00	54.50	8.82	0.00
January	33.50	27.70	33.00	48.59	5.61	4.46

¹ Researcher data observed in the field;

At harvest, which was performed at 141 DAP, the following variables were evaluated in the 11 central plants of the central ridge of each subplot or treatment: stem diameter at the base of the plant, measured with a digital pachymeter; number of branches per plant; fresh phytomass of aerial part per plant per area; mean mass of marketable tuberous roots, that is, those with mass above 80 g (EMBRAPA, 1995); and yield. The decision to evaluate the fresh phytomass of aerial part is justified by the fact that sweet potato producers use this part of the plant as a diet supplementation for flocks in the property.

The agricultural water use efficiency (WUE) was obtained by the ratio between the production (P) and the water volume applied (L), according to Mantovani et al. (2013), using the following equation:

$$WUE = P/mm$$

In which:

$$WUE = \text{Agricultural water use efficiency (kg mm}^{-1}\text{); } P = \text{Production (kg); mm = Irrigation blade.}$$

Statistical analysis

The data were subjected to analysis of variance by the F-test ($p > 0.01$ and $p > 0.05$). The means referring to the irrigation blades were compared by the F-test, which is conclusive for a unitary degree of freedom, and the values referring to the silicon doses were analyzed by regression, using the SISVAR statistical software (FERREIRA, 2011) to process the data.

RESULTS

Except for the mass of marketable tuberous roots (MRC) and the agricultural water use efficiency by plants (WUE), which responded, respectively, to the isolated effects of the irrigation blades ($p > 0.05$) and doses of silicon ($p > 0.05$) - MRC and to the silicon doses - WUE ($p > 0.01$), the interaction between water blades and silicon doses exerted significant effects on the remaining variables evaluated, as seen in Table 5.

The statistical behavior of the data, as a function of silicon, is in accordance with Alves et al. (2020), when they concluded that the combination of silicon and nitrogen, applied via soil, exerted significant effects on growth and gas changes of field pumpkin (*Cucurbita pepo* L.).

The increase in silicon, from 0.0 to the maximum estimated doses of 1.4 and 1.2 g plant⁻¹, stimulated

plant growth in stem diameter, from 14.68 and 13.26 mm to 23.75 and 23.25 mm, with gains of 61.8 and 75.3% among the plants grown in soil without and with each maximum dose estimated, under a water blade corresponding to 100 and 50% of the crop evapotranspiration – ET_c. However, there was a 2.1 % decline among the plants irrigated with the lowest and highest irrigation blades (Figure 1).

Table 5: Summary of the analyses of variance for stem diameter (SD), number of branches (NB), fresh matter of the aerial part (FMAP), biomass of tuberous roots (BTR), yield of marketable tuberous roots (P), and agricultural water use efficiency (WUE) by sweet potato plants under irrigation blades and silicate fertilization. Catole do Rocha-PB, 2019.

Fontes de variação	GL	Significance of the mean squares					
		SD	NB	FMAP	BTR	P	WUA
Block	3	ns	ns	ns	ns	ns	ns
Blades (BLA)	1	ns	ns	ns	*	**	ns
Erro I	3	23.94	16.17	0.017	1574.86	15134113.51	30.58
Silicon (Si)	4	**	**	**	*	**	**
Interaction BLA x Si	4	**	*	**	ns	*	ns
Erro II	36	40.72	5.23	0.04	1890.12	11705487.49	34.22
CV (%) - Plot	-	14.06	15.16	10.82	14.80	26.72	26.08
CV (B) (%) - Suplot	-	6.48	9.09	5.55	16.21	23.50	27.60

** , * Significant at the level of 0.01 and 0.05 of probability by the test F. CV (coefficient of variation).

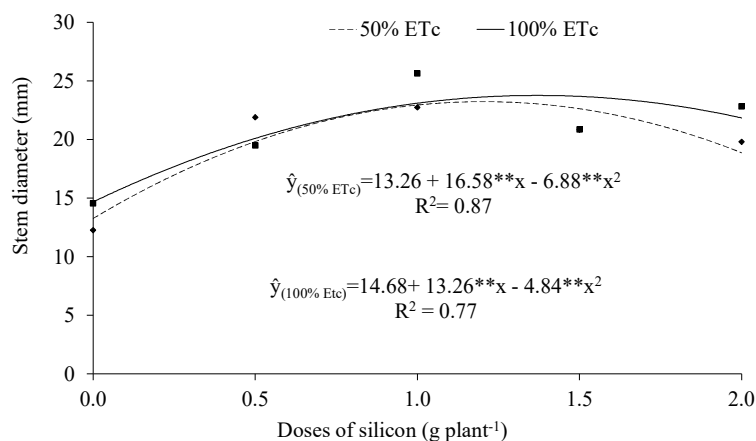


Figure 1: Stem diameter (SD) of sweet potato plants under silicon doses and irrigation blades, Catole do Rocha-PB, 2019. **: Significant at 1% probability by the F test.

Silicon doses above 1.4 and 1.2 g plant⁻¹, regardless of the irrigation blade, inhibited plant development in stem diameter. The similarity between the stem diameters of the sweet potato plants subjected to 50% and 100% of the ET_c, at the maximum estimated doses of Si, and the percentage superiority of the plants irrigated with the lowest blade (50% ET_c) may be a response of the beneficial action of Si to the plants in reducing the transpiration rate, acting in the control of stomatal closure and opening (GAO et al., 2006; YOUYONGWECH et al., 2016; GUO-CHAO et al., 2018).

In a similar way to stem diameter, the increase in Si increased the emission and formation of branches from 23.94 and 20.95 to 32.12 and 25.27 branches plant⁻¹, with increments of 34.2 and 20.6% in the plants grown in soil with the maximum estimated doses of 0.9 and 1.0 g plant⁻¹ of silicon, irrigated with water blade equivalent to 100 and 50% of the ET_c (Figure 2). When relating the values 25.27 and 32.12, it is verified that the reduction in the irrigation blade from 100 to 50% of the ET_c caused a 21.3% loss in branch formation by sweet potato plants. In spite of the water stress (50% of the ET_c), the number of branches was not expressively reduced, as previously commented by (MANTOVANI et al., 2017) for sweet potato grown under

drip irrigation, in Minas Gerais.

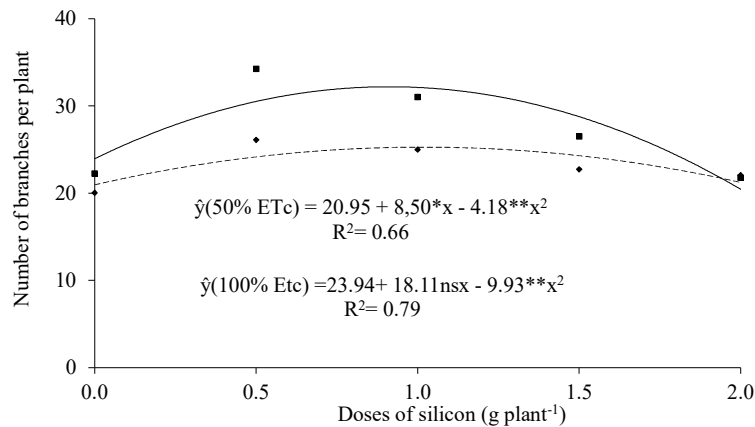


Figure 2: Number of branches (NB) per sweet potato plant under silicon doses and irrigation blade, Catole do Rocha-PB, 2019. **: Significant at 1 and 5% probability by the F test.

The increase in silicon increased fresh matter production from 1.0 to 1.42 and 1.24 g plant⁻¹, at the same estimated dose of the element, 1.1 g plant⁻¹, resulting in gains of 42 and 24% for the plants grown in soil without and with the highest estimated dose of Si, under irrigation with the water blades of 100 and 50% of the ETc (Figure 3).

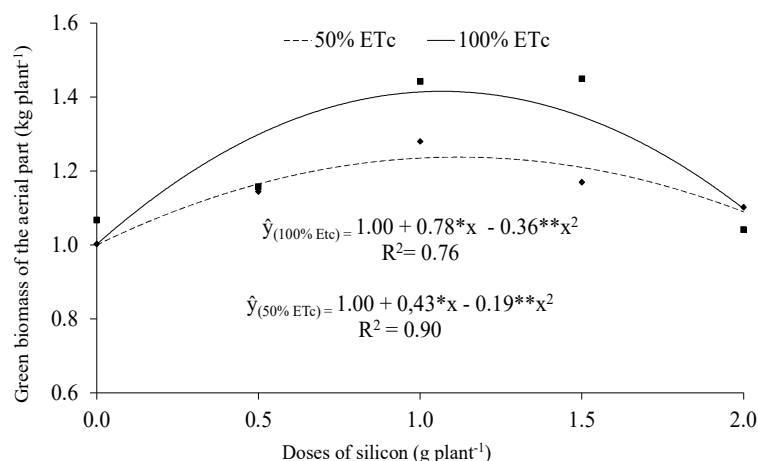


Figure 3: Fresh matter of the aerial part (FMAP) of sweet potato plants grown under silicon doses and irrigation blades, Catole do Rocha-PB, 2019. Significant at 1 and 5% probability by the F test.

It is also verified that the decrease from 100 to 50% in the irrigation blade, which represents significant water stress, reduced the fresh matter of the aerial part in production by the plants in 12.7%, with yield values of 47.3 and 41.3 kg ha⁻¹ in a 1.0 m x 0.3 m spacing and 50% of the crop evapotranspiration. When considering the planting spacing of 1.0 x 0.3 m, the values of 1.42 and 1.24 g plant⁻¹ represent yield values of 47.3 and 41.3 of sweet potato fresh matter.

Although the silicon x irrigation interaction does not interfere significantly with the mass of marketable roots, the variable responded in an isolated manner to the effects of each source of variation (Figure 4A). The mean mass of marketable sweet potato roots, under irrigation with water blade of 100 and 50% of the ETc, was increased from 244.98 to 294.75 g plant⁻¹, promoting a gain of 20.3 among the plants grown in soil without and with the dose of maximum physical efficiency of 1.0 g plant⁻¹ of silicon. Silicon doses

above this value inhibited the formation of marketable roots to the down to lowest value of 238.12 g plant⁻¹, resulting in a 19.2% loss among the plants grown in soil without (0.0) and with 1.0 g plant⁻¹ of the element, and of 2.8% among the plants grown in soil without (0.0) and with 2.0 g plant⁻¹ of silicon.

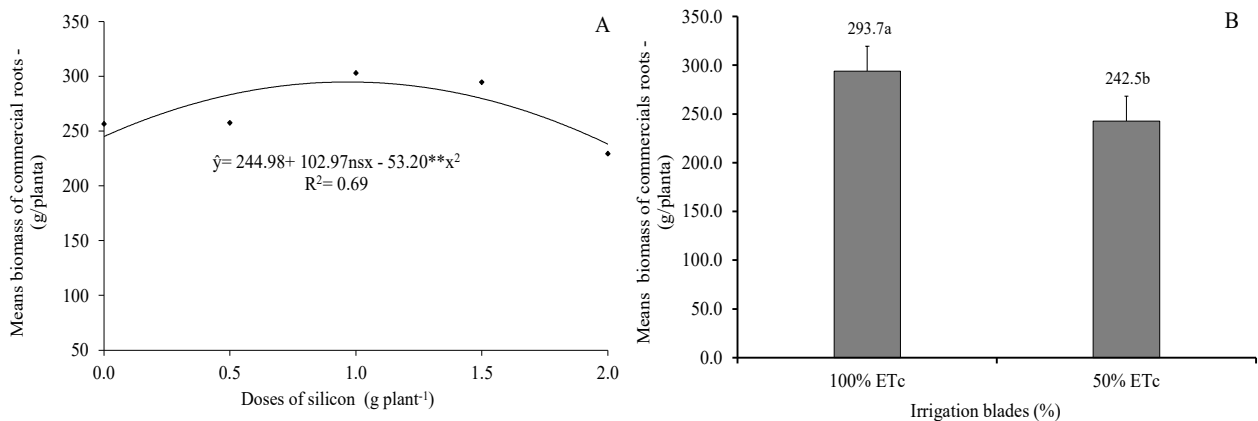


Figure 4: Mean mass of marketable (BTR) of sweet potato roots under silicate fertilization (A) and irrigation blades (B), Catole do Rocha-PB, 2019. Significant at 1% probability by the F test.

The reduction in water blade from 100 to 50% of the crop evapotranspiration inhibited by 17.4% the mean mass of marketable sweet potato roots (Figure 4B). In spite of this loss, the values, regardless of the irrigation blade, overcome by 267.1 and 203.1% the 80 g considered adequate to roots for the consumer market of marketable sweet potato.

The yield of marketable sweet potato roots was increased from 13,982 and 8,702 kg ha⁻¹ to the highest values of 23,615 and 13,252 kg ha⁻¹. In spite of the increment of 68.9 and 52.2% among the plants grow in soil without (0,0) and with the same dose of maximum physical efficiency of 1.0 g plant⁻¹ of Si irrigated with 100 and 50% of the crop evapotranspiration, the 50% reduction in the irrigation blade led to an expressive loss of 43.9% among the highest yield values (Figure 5).

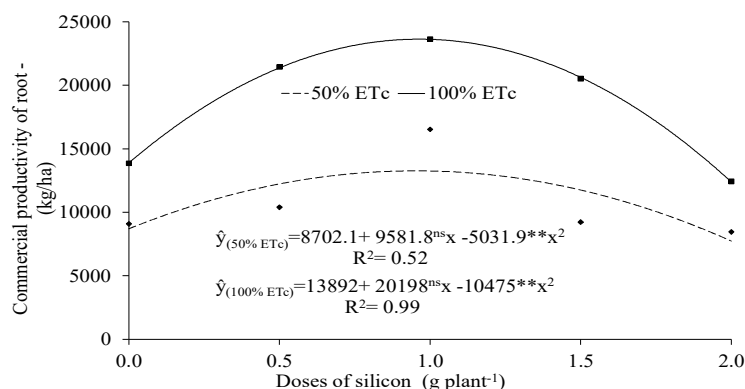


Figure 5: Yield of marketable roots (P) (kg/ha) of sweet potato grown under silicate fertilization and irrigation blade, Catole do Rocha-PB, 2019. Significant at 1% probability by the F test.

Such as verified for the marketable roots (Figure 5), silicon doses above 1 g plant⁻¹ compromised the yields down to the lowest values of 12,300 and 7,738 kg ha⁻¹, with respective losses of 47.9 and 41.6% due to the increase in the doses of 1.0 and 2.0 g plant⁻¹ of silicon in the plants irrigated with the water blade of 100 and 50% of the ETc. In spite of the high losses, with the reduction in the irrigation from 100 to 50% of the crop evapotranspiration - ETc, the yields referring to the dose of maximum physical efficiency of 1 g plant⁻¹

¹ expressively overcome the 7,800 and 14,800 kg ha⁻¹ referring to the mean yields of the states of Paraíba and of Brazil, respectively (IBGE, 2015). This was the greatest loss among all the evaluated in this study and suggests that water stress compromises more the yield than the development of plants by branch emission and diameter, formation of fresh matter of the aerial part, and marketable roots.

The silicon increase stimulated the mean agronomical water use efficiency among the plants grown under irrigation blade corresponding to 100 and 50% of the ET_c, from 16.65 to 26.68 kg mm⁻¹, promoting an absolute gain of 60.2% among the plants grown in soil without (0.0) and with 1.0 g plant⁻¹ of the element (Figure 6). In the remaining production components, the silicon doses above 1.0 g plant⁻¹ also damaged the water use efficiency by plants, from 26.68 to 14.85 kg mm⁻¹.

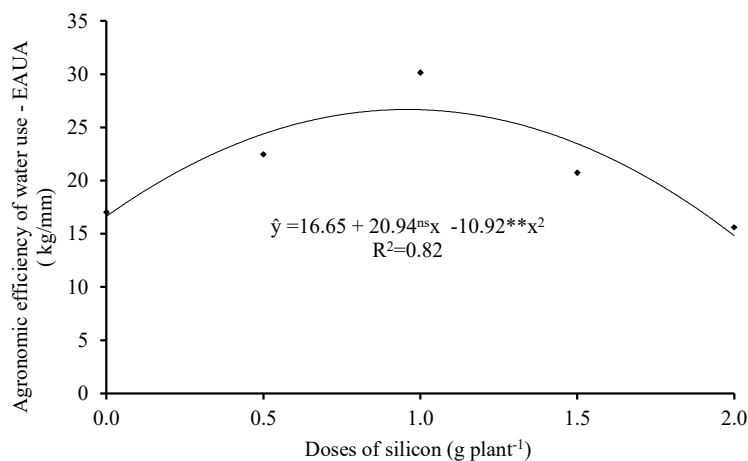


Figure 6: Agronomical water use efficiency (WUE) of sweet potato as a function of silicon doses applied in the soil, Catole do Rocha-PB, 2019. Significant at 1% probability by the F test.

These results demonstrate a 44.3% loss as a function of the increase in Si from 1.0 to 2.0 g plant⁻¹ in the increase of water use efficiency until reaching a maximum value of 26.68 kg mm⁻¹ with the application of 0.96 gram per plant, decreasing above the estimated dose due to the excess of the nutrient in the root zone or due to the action of another liming factor, such as nutritional imbalance.

DISCUSSION

A similar situation was verified by Sonobe et al. (2010), when concluding that silicon decreased the water potential of roots, contributing to the osmotic adjustment and promoting water absorption by sorghum plants (*Sorghum bicolor*).

For Zhang et al. (2018), this situation evidences the positive effect of silicon on plants, modulating some photosynthesis-related genes, and regulating the photochemical process. Ahmed et al. (2013) affirm that the action of silicon is associated to the adjustment of the water potential, arguing that with the maintenance of the adequate water content in the plants, there is an improvement in photosynthetic efficiency even when the plants are subjected to water stress. In this perspective, Camargo et al. (2016) affirms that silicon absorption by plants reduces the effect of water stress since this element avoids the compression of vessels under high transpiration rates.

The fresh matter of the aerial part superiority expresses the response of greater water content in the

soil, and, therefore, the greater state of water energy in the leaves and turgor of the guard cells, with a positive reflection in biomass production by plants, in general (TAIZ et al., 2017), including sweet potato (DELZARI et al., 2017).

The highest production was fresh matter of the aerial part $1.24 \text{ kg plant}^{-1}$ in the plants subjected to the water stress of 50% of the ET_c , overcoming the mean of 590 g plant^{-1} in clones of sweet potato obtained by Andrade Junior et al. (2012). The results demonstrate the beneficial action of silicon in mitigating the deleterious effects of water deficiency in the soil to plants, maintaining the productive capacity.

According to Marschner (2012) and Taiz et al. (2017), with the increase in the availability of a specific element in the soil, upon reaching the proper absorption to the demands of the plants, further additions are no longer required and may even compromise the growth and productive capacity of the crops, including, based on the results of the present work, the sweet potato crop as well.

For Zi-chuan et al. (2018), studies on the interaction between silicon and essential nutrients available for plants are still scarce in the literature, although the respective authors already confirmed that silicon can stimulate the absorption of essential nutrients by plants.

The yield of the plants irrigated with the irrigation blade corresponding to 100% of the ET_c also overcomes the $20,590 \text{ kg ha}^{-1}$ harvested by Soratto et al. (2012) in sweet potato grown without and with the leaf application at the dose of 2 L ha^{-1} of a commercial fertilizer with 0.8% of soluble Si in the form of a stabilized concentrate of silicic acid, which forms the orthosilicic $[\text{Si}(\text{OH})_4]$ disilicic acids when diluted in water.

Regarding the plants under water stress, that is, irrigated with the water blade corresponding to 50% of the crop evapotranspiration, the yields of $9,078.46$ and $13,252.00 \text{ kg ha}^{-1}$ among the plants grown in soil without (0.0) and with 1.0 g plant^{-1} of silicon overcome the mean of the $7,800 \text{ kg ha}^{-1}$ of the state of Paraíba. These results agree with Shi et al. (2016) when verifying that Si mitigated the aggressivity of water stress in tomato plants (*Solanum lycopersicum* L.) due to the improvement that it exerts in the hydraulic conductance of roots for water and nutrient absorption.

The water use efficiency (WUE) is often considered an important determinant of production under stress, indicating that plant production can be increased per unit of water used by the plants for transpiration, which also involves reduced non-stomatal transpiration and minimal water loss by soil evaporation (BLUM, 2009). The highest value of 26.68 kg mm^{-1} , which is equivalent to $2,668 \text{ kg m}^{-3}$, overcomes the water use efficiency values of 16.1 and 20.0 kg mm^{-1} of the sweet potato cultivars Amanda and Duda, with values of 1.61 and 2.0 kg m^{-3} (MANTOVANI et al., 2013).

CONCLUSIONS

The efficient silicon dose in the soil, regardless of the irrigation blades, for root emission, formation of fresh matter of the aerial part, mass and yield of marketable roots, and agronomical water use efficiency by plants of the sweet potato var. Campina varied from 0.9 and 1.0 g plant^{-1} .

The reduction from 100% to 50% of the irrigation blades promoted losses of 2.1, 21.3, 12.7, and 43.9%, respectively in stem diameter, number of branches emitted, production of fresh matter of the aerial

part, and mass and yield of marketable roots.

The sweet potato var. Campina was more sensitive to water stress on productivity than any growth variable and biomass formation.

ACKNOWLEDGMENTS: To the National Council for Scientific and Technological Development (CNPq) and to the Person Coordination of higher Education (CAPES), respectively for the project financing and for the concessions of the scholarships. The authors thank the Diatom company for the donation of the silicon to perform this research. Mogi das Cruzes - São Paulo - Brasil - CEP: 08772-010.

REFERENCES

- ALVES, J. M.; LIMA, A. S.; FIGUEIREDO, F. R. A.; SILVA, T. I.; CAVALCANTE, L. F.; MESQUITA, F. O.; MESQUITA, E. F.; SUASSUNA, C. F.. Chlorophyll a fluorescence and development of zucchini plants under nitrogen and silicon fertilization. *Agronomía Colombiana*, v.38, n.1, p.57-65, 2020. DOI: <https://doi.org/10.15446/agron.colomb.v38n1.79172>
- AHMED, M.; KAMARAN, A.; ASIF, M.; QADEER, U.; AHMED, Z. I.; GOYAL, A.. Silicon priming: a potential source to impart abiotic stress tolerance in wheat. *Australian Journal of Crop Science*, v.4, p.484-491, 2013.
- ALMEIDA, D. J.; CAVALCANTE, L. F.; SILVA, R. A. R.; ARAÚJO, R. C.; SILVA, V. B.; MALTA, A. O.. Irrigação de salvação e cobertura do solo no rendimento de gravioleira 'morada' em safras consecutivas. *Pesquisa Agropecuária Pernambucana*, v.20, n.1, p.11-16, 2015. DOI: <http://doi.org/10.12661/pap.2015.002>
- ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C. GONÇALVES, J. L. M.; SPAROVEK, G.. Köppen's climate classification map for Brasil. *Meteorologisch*, v.22, n.6, p.711-728, 2013. DOI: <http://doi.org/10.1127/0941-2948/2013/0507>
- ANDRADE JÚNIOR, V. C.; VIANA, D. J. S.; PINTO, N. A.; RIBEIRO, K. G.; PEREIRA, R. C.; NEIVA, I. P.; AZEVEDO, A. M.; ANDRADE, P. C. R.. Características produtivas e qualitativas de ramas e raízes de batata-doce. *Horticultura Brasileira*, v.30, n.4, 2012. DOI: <http://dx.doi.org/10.1590/S0102-05362012000400004>
- AYERS, R. S.; WESTCOT, D. W.. **A qualidade da água na agricultura**. Campina Grande: UFPB, 1999.
- BARBOSA, M. A.; FERREIRA, N. M.; BERTINO, A. M. P.; MESQUITA, E. F.; CHAVES, L. H. G.; CAVALCANTE, L. F.; RIGOBELLO, E. C.. Effect of organic matter, irrigation and soil mulching on the nutritional status and productivity of okra (*Abelmoschus esculentus* L.) in the semiarid region of Brazil. *African Journal of Biotechnology*, v.15, p.2720-2728, 2016.
- BERTINO, A. M. P.; MESQUITA, E. F.; SÁ, F. V. S.; CAVALCANTE, L. F.; FERREIRA, N. M.; PAIVA, E. P.; BRITO, M. E. B.; BERTINO, A. M. P.. Growth and gas Exchange of okra under irrigation, organic fertilization and cover of soil. *African Journal of Agricultural Research*, v.10, n.40, p.3832-3839, 2015. DOI: <http://doi.org/10.5897/AJAR2015.9844>
- BESHARAT, S. B.; BARÃO, L.; CRUZ, C.. New strategies to overcome water limitation in cultivated maize: Results from sub-surface irrigation and silicon fertilization. *Journal of Environmental Management*, v.263, p.1-9, 2020. DOI: <http://doi.org/10.1016/j.jenvman.2020.110398>
- BLUM, A.. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Research*, v.112, n.26, p.119-123, 2009. DOI: <http://doi.org/10.1016/j.fcr.2009.03.009>
- SAQIB, M.; KHALID, M. F.; HUSSAIN, S.; ANJUM, M. A.. Effect of water stress and planting system on growth, yield and quality of sweet potato. *Acta Sci. Pol. Hortorum Cultus*, v.16, n.6, p.201-210, 2017.
- CAMARGO, D. C.; MONTOYA, F.; ORTEGA, J. F.; CÓRCOLES, J. I.. O rendimento da batata e a eficiência no uso da água respondem à irrigação em condições semiáridas. *Agronomy Journal*, p.2120-2131, 2015.
- CAVALCANTI, J. A.. **Recomendações de adubação para o estado de Pernambuco: 2o aproximação**. 3 ed. Recife: IPA, 2008.
- CUI, J.; SHAO, G.; LU, J.; KEABETSWE, L.; HOOGENBOOM, G.. Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. *Scientia Agricola*, v.77, n.2, p.1-9, 2020. DOI: <https://doi.org/10.1590/1678-992x-2018-0390>
- DELZARI, F. T.; FERREIRA, M. G.; SILVA, G. H.; DARIVA, F. D. D.; FREITAS, D. S.; NICK, C.. Eficiência no uso da água e acúmulo de matéria na batata-doce em função de lâminas de irrigação. *Irriga*, v.22, n.1, p.115-128, 2017.
- DONAGEMA, G. K.; CAMPOS, D. V. B.; CALDERANO, S. B.; TEIXEIRA, W. G.; VIANA J. H. M.. **Manual de Métodos de Análise de Solos**. 2 ed. Embrapa Solos, 2011.
- DOORENBOS, J.; KASSAM, A. H.. **Efeito da água no rendimento das culturas**. Campina Grande: UFPB, 1994.
- DOORENBOS, J.; PRUITT, J.. **Necessidades hídricas das culturas**. Campina Grande: UFPB, 1997.
- EL-FOTOH, M. A.; EL-KADER, A. S.; MANSSUR, F. Y. O.. Effect of irrigation intervals, antitranspirants, compost and humic

acid on growth and yield of sweet potato. **Zagazig Journal of Agricultural Research**, v.46, n.3, p.640-660, 2019. DOI: <http://doi.org/10.21608/ZJAR.2019.40949>

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Manual de Métodos de Análise de Solos**. 3 ed. Brasília: Embrapa Solos, 2017.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Manual de análises químicas de solos, plantas e fertilizantes**. Embrapa Informação Tecnológica, 2009.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Centro Nacional de Pesquisa de Hortaliças**. Cultivo da batata-doce (*Ipomoea batatas* (L.) Lam). 3 ed. Brasília: Ministério da Agricultura, do Abastecimento e Reforma Agrária, 1995.

ETESAMI, H.; JEONG, R.. Silicon (Si): Review and future prospects on the action mechanisms in alleviating biotic and abiotic stresses in plant. **Ecotoxicology and Environmental Safety**, v.147, p.881-896, 2018. DOI: <http://doi.org/10.1016/j.ecoenv.2017.09.063>

FERREIRA, D. F.. Sisvar: a computer statistical analysis system. **Ciência & Agrotecnologia**, v.35, n.6, p.1039-1042, 2011. DOI: <http://doi.org/10.1590/S1413-70542011000600001>

GAO, X.; ZOU, C.; WANG, L.; ZHANG, F.. Silicon Improves Water Use Efficiency in Maize Plants. **Journal of Plant Nutrition**, v.27, p.1457-1470, 2006. DOI: <http://doi.org/10.1081/PLN-200025865>

GOUVEIA, C. S. S.; GANANÇA, F. T.; SLASKI, J.; LEBOT, V.; CARVALHO, A. A. P.. Variation of carbon and isotope natural abundances ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) of whole-plant sweet potato (*Ipomoea batatas* L.) subjected to prolonged water stress. **Journal of Plant Physiology**, v.243, p.1-13, 2019. DOI: <http://doi.org/10.1016/j.jplph.2019.153052>

GUNTZER, F.; KELLER, C.; MEUNIER, J. D.. Benefits of plant silicon for crops: a review. **Agronomy for Sustainable Development**, v.32, p.201-213, 2012. DOI: <http://doi.org/10.1016/j.jplph.2019.153052>

GUO-CHAO, Y.; NIKOLIC, M.; UM-JUN, Y.; ZHUO-XI, X.; YONG-CHAO, L.. Silicon acquisition and accumulation in plant and its significance for agriculture. **Journal of Integrative Agriculture**, v.17, n.10, p.2138-2150, 2018. DOI: [http://doi.org/10.1016/S2095-3119\(18\)62037-4](http://doi.org/10.1016/S2095-3119(18)62037-4)

HELALY, M. N.; EL-HOSEINY, H.; EL-SHEERY, N. I. RASTOGI, A.; KALAJI, H. M.. Regulation and physiological role of silicon in alleviating drought stress of mango. **Plant Physiology and Biochemistry**, v.118, p.31-44, 2017. DOI: <http://doi.org/10.1016/j.plaphy.2017.05.021>

IBGE. Instituto Brasileiro de Geografia e Estatística. **Produção Agrícola Municipal 2015**. Rio de Janeiro: IBGE, 2015.

MAHMOUD, L. M.; DUTT, M.; SHALAN, A. M.; EL-KADY, M. E.; EL-BORAY, M. S.; SHABANA, Y. M.; GROSSER, J. W.. Silicon nanoparticles mitigate oxidative stress of in vitro-derived banana (*Musa acuminata* 'Grand Nain') under simulated water deficit or salinity stress. **South African Journal of**

Botany, v.132, p.155-163, 2020. DOI: <http://doi.org/10.1016/j.sajb.2020.04.027>

MANTOVANI, E. C.; DELAZARI, F. T.; DIAS, L. E.; ASSIS, I. R.; VIEIRA, G. H. S.; LANDIM F. M.. Eficácia no uso da água de duas cultivares de batata-doce em resposta a diferentes lâminas de irrigação. **Horticultura Brasileira**, v.31, p.602-606, 2013. DOI: <http://dx.doi.org/10.1590/S0102-05362013000400015>

MARSCHNER, H.. **Mineral nutrition of higher plants**. 6 ed. London, Academic Press, 2012.

MULOVHEDZI, N. E.; ARAYA, N. A.; MENGISTU, M. G.; FESSEHAZION, M. K.; POOY, C. P.; ARAYA, H. T.; LAAN, M. V.. Estimating evapotranspiration and determining crop coefficients of irrigated sweet potato (*Ipomoea batatas*) grown in a semi-arid climate. **Agricultural Water Management**, v.233, p.1-9, 2020. DOI: <http://doi.org/10.1016/j.agwat.2020.106099>

PILON, C.. **Aplicação de silício solúvel via solo e foliar na cultura da batata (*Solanum tuberosum* L.) sob deficiência hídrica**. Dissertação (Mestrado em Agronomia – Agricultura) - Universidade Estadual Paulista “Julio de Mesquita Filho”. Botucatu, São Paulo, 2011.

RICHARDS, L. A.. **Diagnostico y rehabilitación de suelos salinos y sódicos**. Ciudad el México: Departamento de Agricultura de los Estados Unidos de América, 1954.

SAVVAS, D.; NTATSI, G.. Biostimulant activity of silicon in horticulture. **Scientia Horticulturae**, v.196, p.66-81, 2015. DOI: <http://doi.org/10.1016/j.scienta.2015.09.010>

SHI, Y.; ZHANG, Y.; HAN, W.; FENG, R.; YANHONG, H.; GOA, J. G.; GONG, H.. Silicon Enhances Water Stress Tolerance by Improving Root Hydraulic Conductance in *Solanum lycopersicum* L. **Original Research Article**, v.7, n.193, p.01-15, 2016. DOI: <http://doi.org/10.3389/fpls.2016.00196>

SINGELS, A.; DONALDSON, R. A.; SMIT, M. A.. Improving biomass production and partitioning in sugarcane: theory and practice. **Field Crops Research**, v.92, p.291-303, 2005. DOI: <http://doi.org/10.1016/j.fcr.2005.01.022>

SONOBE, K.; HATTORI, T.; WATARU, P. A.; ENEJI, A. E.; KOBAYASHI, S.. Effect of silicon application on sorghum root responses to water stress. **Journal of Plant Nutrition**, v.34, p.71-82, 2010. DOI: <http://doi.org/10.1080/01904167.2011.531360>

SORATTO, R. P.; FERNANDES, A. M.; CRUSCIOL, C. A. C.; SCHLICK, G. D. S.. Produtividade, qualidade de tubérculos e incidência de doenças em batata, influenciados pela aplicação foliar de silício. **Pesquisa Agropecuária Brasileira**, v.47, n.7, p.1000-1006, 2012. DOI: <http://dx.doi.org/10.1590/S0100-204X2012000700017>

SOUZA, S. F.; RIBEIRO, V. G.. Yellow passion-fruit irrigated in different cropping systems. **Revista Brasileira Fruticultura**, v.38, n.3, p.1-11, 2016. DOI: <http://dx.doi.org/10.1590/0100-29452016512>

TAIZ, L.; ZEIGER, E.; MOLLER, I. M.; MURPHY, A.. **Fisiologia e desenvolvimento vegetal**. 6 ed. Porto Alegre: Artmed, 2017.

YOUYONGWECH, C. T.; THEERAWITAVA, C.; SAMPHUPHUANG, T.; CHA-UM, S.. Water-deficit tolerant identification in sweet potato genotypes (*Ipomoea batatas* (L.) Lam.) in vegetative developmental stage using multivariate physiological indices. *Scientia Horticulturae*, v.162, p.242-251, 2013. DOI: <http://doi.org/10.1016/j.scienta.2013.07.041>

YOUYONGWECH, S.; SAMPHUMPHUANG, T.; TISARUM, R.; T.; WITAYA, C. T.; CHA-UM, S.. Arbuscular mycorrhizal fungi (AMF) improved water deficit tolerance in two different sweet potato genotypes involves osmotic adjustments via soluble sugar and free proline. *Scientia Horticulturae*, v.198, p.107-117, 2016. DOI:

<http://doi.org/10.1016/j.scienta.2015.11.002>

ZHANG, Y.; SHI, Y.; GONG, H.; ZHAO, H.; HU, Y.; WANG, Y.. Beneficial effects of silicon on photosynthesis of tomato seedlings under water stress. *Journal of Integrative Agriculture*, v.17, p.2151-2159, 2018. DOI: [http://doi.org/10.1016/S2095-3119\(18\)62038-6](http://doi.org/10.1016/S2095-3119(18)62038-6)

ZI-CHUAN, L.; SONG, Z.; YANG A.; YU, C.; VSONG, Y.; WANG, T.; XIA, S.; LIANG, C.. Impacts of silicon on biogeochemical cycles of carbon and nutrients in croplands. *Journal of Integrative Agriculture*, v.17, p.2182-2195, 2018. DOI: [http://doi.org/10.1016/S2095-3119\(18\)62018-0](http://doi.org/10.1016/S2095-3119(18)62018-0)

A CBPC – Companhia Brasileira de Produção Científica (CNPJ: 11.221.422/0001-03) detém os direitos materiais desta publicação. Os direitos referem-se à publicação do trabalho em qualquer parte do mundo, incluindo os direitos às renovações, expansões e disseminações da contribuição, bem como outros direitos subsidiários. Todos os trabalhos publicados eletronicamente poderão posteriormente ser publicados em coletâneas impressas sob coordenação da **Sustenere Publishing**, da Companhia Brasileira de Produção Científica e seus parceiros autorizados. Os (as) autores (as) preservam os direitos autorais, mas não têm permissão para a publicação da contribuição em outro meio, impresso ou digital, em português ou em tradução.