

## Fertilization With Silicon in Sweet Pepper Improved Plants Grown Under Salt Stress

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### ABSTRACT

**Aims:** The objective of this research was to investigate the effect of calcium silicate on gaseous exchanges and production factors in the sweet pepper, cultivated under conditions of soil salinity induced by potassium fertilization, in protected cultivation.

**Study design:** The experiment was arranged in a randomized complete block design in a 2 × 5 factorial scheme with five replications.

**Place and Duration of Study:** The experiment was conducted in the sector of Olericultura and Experimentation of the course of Agronomy from October 12, 2018 to February 2019.

**Methodology:** The experiment was arranged in a randomized complete block design in a 2 × 5 factorial scheme (two sources of correction: limestone and silicon and five increasing rates of KCl equivalent to 150, 300, 450, 600 and 700 kg ha<sup>-1</sup> of K<sub>2</sub>O). Ten treatments with five replicates where each experimental unit consisted of a polyethylene pot, with a volume of 19 dm<sup>3</sup>. The electrical conductivity, the determination and quantification of silicon in soil and plant, liquid photosynthesis, stomatal conductance, intercellular CO<sub>2</sub> concentration, transpiration, water use efficiency and instantaneous carboxylation efficiency were analyzed.

**Results:** With the increase of K<sub>2</sub>O in the soil there was a tendency of reduction in liquid photosynthesis, transpiration, stomatal conductance, intercellular CO<sub>2</sub> concentration, water use efficiency and instantaneous carboxylation efficiency in the presence and absence of calcium silicate. Higher rates of K<sub>2</sub>O (300, 450 and 600 kg ha<sup>-1</sup>) reduced the length and yield of sweet pepper fruits in the presence and absence of calcium silicate. The rate of 150 Kg K<sub>2</sub>O favored the growth of sweet pepper plants in the presence of calcium silicate.

**Conclusion:** It is concluded from the research that the dose of 300 kg ha<sup>-1</sup> of K<sub>2</sub>O, in the presence of calcium silicate, provided the best results for the electrical conductivity of 2.76 dS m<sup>-1</sup>, silicon content in the soil of 5.70 mg kg<sup>-1</sup>, 14% silicon leaf content, improving photosynthetic rates, transpiration, water use efficiency and fruit production. The increase in salinity reduced fruit yield, in the presence and absence of Si.

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**Keywords:** *Abiotic stress; photosynthesis; Capsicum annum; salinization; calcium silicate.*

### 1. INTRODUCTION

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Brazil is among the main sweet pepper producing countries [1]. The main sweet pepper producing states in Brazil are Minas Gerais, São Paulo, Ceará, Rio de Janeiro, Espírito Santo and Pernambuco (87% of the total) [2]. It is possible to produce sweet peppers all year round, but it develops better in the summer [3]. Currently, sweet pepper producers

26 have preferred to cultivate this crop in a protected environment, which allows a  
27 continuous supply and harvesting in periods of low supply of the product in the market,  
28 thus achieving more competitive prices [4].  
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30 In the State of São Paulo, in 2018, about 65.800 tons of sweet pepper were produced in  
31 2.560 ha [5]. In the production of vegetables in protected cultivation, it was verified that,  
32 after three years of cultivation, many producers do not obtain adequate productivities  
33 and quality of the fruits, because there are many problems related to excessive  
34 fertilization, leading the soil to an accumulation of salts. The losses suffered by the  
35 producers are generated by improper practices of the incorrect management of the  
36 fertilization in greenhouse [6]. Therefore, the symptoms of these anomalies in plants  
37 under conditions of nutritional imbalance are common, due to the saline stress of the soil  
38 solution [3]. Although irrigation water in protected crops is of good quality, the addition of  
39 fertilizers, when using the fertigation technique, makes it saline, increasing the risk of soil  
40 salinization [7].  
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42 Potassium (K) is a nutrient demanded in great quantity by the culture of the sweet  
43 pepper, being the main source used by the producers is potassium chloride that has high  
44 saline index, being one of the main sources of salinization of the soil in cultivation.  
45 Potassium sulfate has a salt content equivalent to half of the salt content of potassium  
46 chloride, which makes it more suitable for soils with tendency to salinization [8].  
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48 The exogenous application of silicon (Si) significantly improves the development of  
49 plants under conditions of salt stress [9]. Calcium silicate can be used as a corrective of  
50 soil acidity, neutralizing exchangeable aluminum, providing nutrients to the plant and  
51 increasing soil base saturation [10]. When saline stress occurs, there is a decrease in  
52 the relative water content in the leaf, indicating that the plants are exposed to osmotic  
53 stress [11]. Studies have shown that Si increases the relative water content in plants  
54 under conditions of salt stress [12], decreasing the toxicity of the salts to the plant and  
55 improving its growth [13], increasing the thickness of the leaves, due to deposition of Si,  
56 which reduces transpiration and decreases water loss [14].  
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58 Due to the condition of soil salinization, nutritional disorders may occur, inducing  
59 antagonistic relationships between nutrients in the plant, which significantly reduces crop  
60 yields [15]. Elevation of K content in soil can induce nutritional imbalance for plants [16].  
61 However, it is necessary to know the effects of the interactions between saline stress  
62 and the use of silicon in the culture of sweet pepper that has been cultivated in protected  
63 culture.  
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65 Therefore, the present research was conducted to evaluate the effect of calcium silicate  
66 on gaseous exchanges and production factors in the sweet pepper under conditions of  
67 soil salinity induced by potassium fertilization, in protected cultivation.  
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## 69 **2. MATERIAL AND METHODS**

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71 The experiment was conducted in the sector of Olericultura and Experimentation of the  
72 course of Agronomy from October 12, 2018 to February 2019 in greenhouse. A  
73 protective structure model was used, with 225 meters each (9 meters wide by 25 meters  
74 long) and right foot of 4 meters. The structure was covered with agrofilm, of blue color.  
75 The sweet pepper cultivar Magali R. was used. The seedlings were produced in trays  
76 with 128 cells, 6.0 to 6.2 cm high, with substrate composed of inert material and free of  
77 pathogens. Transplanting was carried out on November 20, 2018 using a seedling per  
78 pot, when they had three to four definitive leaves, which occurred around 35 days after  
79 sowing.  
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81 The experiment was arranged in a randomized complete block design in a 2 × 5 factorial  
82 scheme (two sources of correction: dolomitic limestone and silicon and five increasing  
83 rates of KCl equivalent to 150, 300, 450, 600 and 700 kg ha<sup>-1</sup> of K<sub>2</sub>O. It was applied 1.62  
84 ha<sup>-1</sup> Mg of dolomite limestone with 80 % total neutralizing power (45 % CaO and 10%  
85 MgO) corresponding to 15.39 g pot and 1.87 Mg ha<sup>-1</sup> of calcium silicate with total  
86 neutralizing power 86% (40.7% SiO<sub>2</sub> and 10% CaO) corresponding to 17.85 g by pot, the  
87 source CaSiO<sub>3</sub> used was reagent pure for analysis. Whose treatments and potency  
88 equivalence are described in Table 1. Each experimental unit consisted of a 19 dm<sup>-3</sup>  
89 polyethylene pot filled with Oxisol [17], after incubation of limestone and calcium silicate,  
90 fertilization was per-formed for the macro and micronutrients following the  
91 recommendation of [18] and [19] adapted for experiments conducted in pots and for the  
92 corn crop.

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94 The soil was classified as Oxisol [20] and samples were collected at a depth of 0-20 cm.  
95 The samples were placed to dry, crushed through a 5-mm sieve and mixed to describe  
96 the chemical and physical compositions. Chemical and physical compositions of the soil  
97 used in this study, according to [21], were: pH in water (1:2.5)= 5.2; level of organic  
98 matter (OM)= 1.42 (dag kg<sup>-1</sup>); P and K by Mehlich I extraction = 3.69 and 30.41 (mg dm<sup>-3</sup>);  
99 Mg, Ca and Al extractable by 1 M KCl solution= 7.59, 1.12 and 0.20 (cmol dm<sup>-3</sup>); Si=  
100 3.29 (mg dm<sup>-3</sup>); Zn= 1.05 (mg dm<sup>-3</sup>); Cu= 1.38 (mg dm<sup>-3</sup>); S= 13.24 (mg dm<sup>-3</sup>); B= 0.07  
101 (mg dm<sup>-3</sup>); Fe= 53.62 (mg dm<sup>-3</sup>); T = cation exchange capacity at pH 7.0 (3.62 %); t=  
102 cation exchange capacity effective (5.02 %); m = aluminum saturation index (12.50 %); V  
103 = Base saturation index (27.85 %). Soil granulometry was the soil physical composition  
104 used in this study, determined by the pipette method (sand, silt and Clay = 60 %, 11 %  
105 and 29 %). After incubation of limestone and calcium silicate, fertilization was performed  
106 for macro and micro-nutrients following the recommendation of [18] and [19] adapted for  
107 experiments conducted in pots for sweet pepper crops. The soil chemical analysis was  
108 done at the soil science laboratory of the Federal University of Lavras, Brazil. The pots  
109 had holes in the bottom where a layer of 0.30 m of folded sombrite was placed to avoid  
110 soil loss and to allow drainage of excess water, if it occurred.

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112 Before the transplanting of the crop, 300 mg dm<sup>-3</sup> of urea (45 % N), 300 mg dm<sup>-3</sup> of  
113 simple superphosphate (18 % P<sub>2</sub>O<sub>5</sub>) was applied and incorporated into the soil, pure  
114 reagent was used for analysis for both fertilizers. The calculations for soil correction were  
115 based on recommendations [18]. For N, the equivalent of 12.22 g of urea per pot was  
116 divided into three applications and, for P<sub>2</sub>O<sub>5</sub>, 72.52 g of simple superphosphate per pot  
117 applied at planting was used. Coating fertilizations started at 15 days after transplant  
118 (DAT) and were performed biweekly. The basic fertilization for K<sub>2</sub>O was made with KCl  
119 using pure reagent source for analysis (60 % K<sub>2</sub>O), as described in Table 1. After the  
120 application of the fertilizer, the soil was moistened for 35 days to favor the chemical  
121 reaction of the corrective and fertilizer. The pots were distributed at spacing of 0.63 m  
122 between plants and 1.0 m between rows.

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135 **Table 1. Treatments and equivalence in pots based on the two correctives**  
136 **(calcium silicate and dolomitic limestone) and rates of K<sub>2</sub>O.**

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Treatments	Corrective		K <sub>2</sub> O rates kg ha <sup>-1</sup> of K <sub>2</sub> O	
T1	Calcium silicate	-	150	-
T2	Calcium silicate	-	300	-
T3	Calcium silicate	-	450	-
T4	Calcium silicate	-	600	-
T5	Calcium silicate	-	700	-
T6	-	Calcário	-	150
T7	-	Calcário	-	300
T8	-	Calcário	-	450
T9	-	Calcário	-	600
T10	-	Calcário	-	700

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139 The water characterization of the soil was determined by its water retention  
140 characteristic curve (Fig.1). The parameters of the soil water retention curve used in  
141 irrigation and irrigation management were obtained based on the model proposed by  
142 [22], with the aid of the Solver application of Microsoft Office Excel<sup>®</sup> software ( $\theta = 0.4215$   
143  $\times [1 + (0.2040 \times |\Psi_m|)^{1.8757}]^{-0.4669} + 0.2670$ ), where:  $\theta$  = current moisture cm<sup>3</sup>.cm<sup>-3</sup> and  
144  $\Psi_m$  = stress, kPa. The field capacity was estimated to be equivalent to the voltage and  
145 humidity at the inflection point of the retention curve, as proposed by [23]:  $\Psi_m = 1 / \alpha [1 /$   
146  $m]^{1/n}$ , where:  $\Psi_m$  = tension at the inflection point of the curve, kPa;  $\alpha$ ,  $m$  and  $n$  =  
147 adjustment parameters of the model equation proposed by [22]. The moisture value in  
148 the field capacity found was 0.3458 cm<sup>3</sup>.cm<sup>-3</sup> for a voltage of 4.25. Soil moisture was  
149 determined through tensiometers, using the water potential of -35 kPa, considered as  
150 adequate for the development of the crop [24].

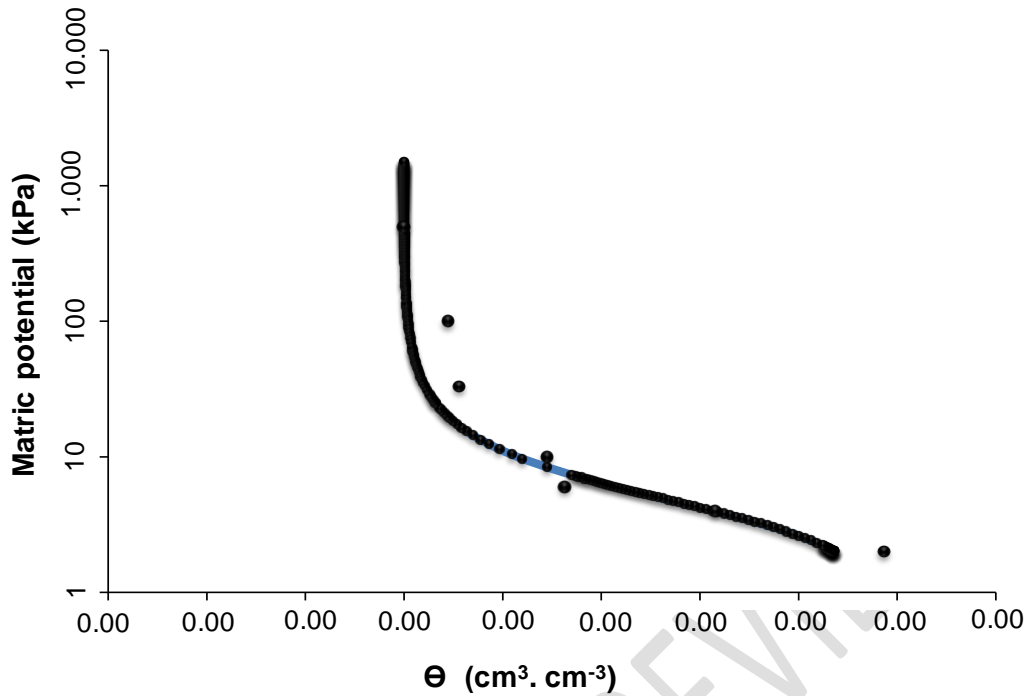
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152 The irrigation was done by drip irrigation; the self-compensating emitters being manually  
153 inserted in polyethylene hoses. The calculation of the operating time of the irrigation  
154 system was made based on the humidity sensors (tensiometers) installed in the depth of  
155 0.15 m. With the observed stresses, the corresponding moisture values were estimated  
156 from the water retention curve in the soil.

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158 With these moistures and the one corresponding to -30 kPa [19] and, considering the  
159 effective depth of the root system (0.15 m), the net and gross replacement slides were  
160 calculated for the treatments. Aiming at the replacement of soil water, two readings were  
161 performed daily in the tensiometers, one in the morning (8:00 am) and one in the  
162 afternoon (14:00 pm).

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166 **Fig. 1. Water retention characteristic curve of the Oxisol used in the experiment**  
167 **(-  $\Psi_m$  = matric potential).**  
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169 At the end of the experiment (120 days after plant transplantation), the electrical  
170 conductivity (EC) was determined in the saturated paste extract [25], which is the  
171 method used as reference for EC determination and adopted in various regions of the  
172 world. To do so, the soil passed through the 2 mm sieve and allowed to stand for 24 h to  
173 air dry. Afterwards, 800 g of soil were added in plastic containers, with capacity for 1200  
174 mL, with 500 mL of distilled water added. After the mixture turned into a paste, the  
175 container was covered with foil remaining for 24 h. After this time, the slurry was again  
176 stirred, standing for 1 h. By means of the vacuum filtration of the saturation paste, the  
177 solution of the soil was extracted, after which the EC reading was measured. The  
178 electrical conductivity of the saturated pulp was corrected considering the soil water  
179 retention characteristic using a digital conductivity meter (Lutron, model CD-4303).  
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181 For the quantification of the silicon in the soil, soil samples were taken from the pots  
182 grown with sweet pepper and prepared for analysis. The samples were dried at room  
183 temperature (TFSA) and subsequently sieved (<2,0 mm). The extraction procedure was  
184 performed to maintain the same soil: solution ratio, that is, for each 10 g of soil, 100 mL  
185 of extractor was added. The extractors used were: Acetic acid 0,5 mol L<sup>-1</sup> [26]: 100 mL of  
186 0.5 mol L<sup>-1</sup> acetic acid was added to a 150 mL plastic flask containing 10 g de soil. The  
187 plastic bottle was capped and shaken horizontally for one hour. After 30 minutes, the  
188 extract was filtered (plastic funnel), using filter paper number 42; Buffer pH 4.0: 100 mL  
189 of a buffered solution at pH 4.0 acetic acid plus sodium acetate (49.2 mL of concentrated  
190 acetic acid and 14.800 g of anhydrous sodium acetate were dissolved in 1,0 liter of  
191 distilled water, and the pH adjusted to 4.0 with the addition of acetic acid) were added in  
192 a 150 mL plastic flask with 10 g soil and shaken horizontally for one hour. The vials were  
193 then held for 30 minutes and then the plastic funnel extract and filter paper number 42  
194 filtered; Calcium chloride 0.0025 mol L<sup>-1</sup> [27]: 100 mL of a 0.0025 mol L<sup>-1</sup> calcium  
195 chloride solution was added in a plastic flask containing 10 g of soil. Thereafter, it was  
196 shaken horizontally for 15 minutes and then decanted from overnight. The following day,  
197 the extracts were filtered (plastic funnel and filter paper number 42); Water: 100 mL of

198 distilled and demineralized water were added in 150 mL plastic bottles with 10 g of soil.  
199 Henceforth, the procedure was the same as for acetic acid.

200  
201 The determination of Si in the extract was made by mixing 10 mL of the extract (filtrate /  
202 decanting) in 1 mL of sulfo-molybdenum 7.5% solution (7.5 g ammonium molybdate in  
203 10 mL + ac. sulfuric 9 mol L<sup>-1</sup> in 100 mL). After 10 minutes 2 mL of the 20% tartaric acid  
204 solution was added and after 5 minutes 10 mL of the 0.3% ascorbic acid solution was  
205 added. After one hour, the Si was read in a spectrophotometer and at the wavelength of  
206 660nm. The quantification of silicon in the leaves was performed by the colorimetric  
207 method of molybdenum blue in the laboratory of mineral nutrition of plants in the  
208 Laboratory of Mineral Nutrition of Plants of the Federal University of Uberlandia, Brazil  
209 [28].

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211 The shoot dry matter (leaves + stem) was collected at 120 days after transplanting  
212 (DAT), to determine dry shoot mass (MMSPA). To dry the material an oven was used at  
213 70 °C with forced ventilation until constant mass was reached. The shoot + stem were  
214 processed together. The heights of the plants (m) were evaluated with the help of a  
215 scale, measuring the distance between the base of the plant collar to the end of the main  
216 stem, the production, which was determined throughout the reproductive stage of the  
217 plants, and also the diameter, length, weight and diameter of commercial fruits.

218  
219 For the analysis of liquid photosynthesis, stomatal conductance, intercellular CO<sub>2</sub>  
220 concentration, transpiration, water use efficiency and instantaneous carboxylation  
221 efficiency, the IRGA model LI-6400XT, (Li-Cor, Lincoln, Nebraska, USA) was used. Two  
222 plants of each cultivar were chosen randomly, being defined as the sample unit the sixth  
223 leaf from top to bottom, fully expanded and mature. Because it is a species with a  
224 composite leaf, the first three leaflets of each leaf were used to measure, totaling six  
225 measurements. The value of 850 μmol m<sup>-2</sup> s<sup>-1</sup> of saturation irradiance, defined by the  
226 realization of a light curve, was set using the value of radiation that induced the  
227 maximum photosynthesis. Sweet pepper is a C3 plant, where a cyclic mechanism of  
228 enzymatic reactions converts CO<sub>2</sub> into carbohydrates through the reductive  
229 photosynthetic cycle (C3), generating the 3 phosphoglycerate. Therefore, IRGA camera  
230 temperature was controlled at 28 °C, since in C3 plants the maximum rate of  
231 photosynthesis is reached at relatively low radiation intensity, causing no destruction or  
232 damage to the photosynthetic apparatus. Measurements were performed on a 6 cm<sup>2</sup>  
233 sheet area.

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235 The results found in the different evaluations were submitted to analysis of variance. For  
236 the evaluation of the means, the Scott-Knott or t-test were applied, according to the  
237 theories recommended by [29]. The standard deviations were calculated and the  
238 correlation estimators (Pearson or Spearman) were used, using SISVAR software [30].

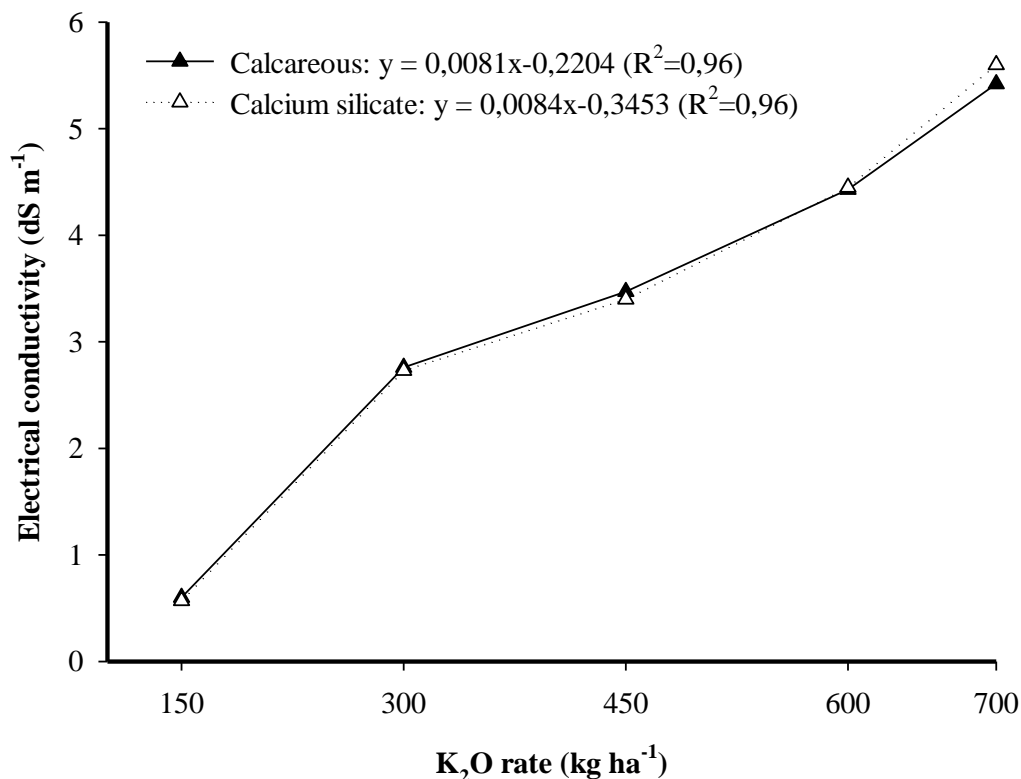
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### 240 3. RESULTS AND DISCUSSION

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242 The electrical conductivity (EC) of the soil (Fig. 2) increased with increasing rates of K<sub>2</sub>O  
243 in both correctives (calcium silicate and dolomitic limestone). The EC of 2.76 and 2.16  
244 dS m<sup>-1</sup> were the ones that provided the greatest vegetative development and production,  
245 these results agree with those found by [31], who studied the influence of EC on  
246 eggplant concluded that the EC of 2.36 dS m<sup>-1</sup> provided the greatest development and  
247 fruiting. The higher dry matter yield of roots, stems, leaves and fruits in eggplant plants  
248 was obtained with EC of nutrient solution of 2.10 dS m<sup>-1</sup> [32]. The use of a rate greater  
249 than 60 kg ha<sup>-1</sup> of K<sub>2</sub>O may cause some damage to the legumes due to its saline effect,  
250 which may have occurred in this experiment with rates greater than 100 kg ha<sup>-1</sup> of K<sub>2</sub>O  
251 [33]. The electrical conductivity increased linearly with the increase of the KCl rate  
252 applied in two sources of potassium fertilization, due to the increase of the electrolytic  
253 concentration of the soil solution, which is proportional to the increase in the  
254 concentration of ions in the solution [34].

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**Fig. 2. Electrical conductivity of the soil as a function of the K<sub>2</sub>O rates and sources of correctives (calcium silicate and dolomitic limestone).**

The concentration of Si in the soil did not vary in the different rates of K<sub>2</sub>O studied when calcium or calcium silicate was applied (Table 2). However, in the interaction between the rates of K<sub>2</sub>O x sources of correctives it was observed that the silicon concentration was higher for the treatment using calcium silicate, due to the fact that it is a soluble source of Si.

**Table 2. Soil silicon content in CaCl<sub>2</sub> 0.01 mol L<sup>-1</sup> as a function of K<sub>2</sub>O rates and corrective sources (dolomitic limestone and calcium silicate).**

K <sub>2</sub> O rates (kg ha <sup>-1</sup> )	Calcium silicate	Dolomitic limestone
	Content tho Si (mg kg <sup>-1</sup> )	
150	6.00 Aa	5.00 Ab
300	5.70 Aa	5.00 Ab
450	5.80 Aa	4.80 Ab
600	5.75 Aa	5.00 Ab
700	6.00 Aa	5.20 Ab

273 *Capital letters equal in the column, do not differ at the level of significance of 5%; Minor letter in*  
274 *the same line, do not differ at the level of significance of 5%.*

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For the silicon content in the sweet pepper leaf (Table 3) differences were observed between the rates of K<sub>2</sub>O. When the calcium silicate was applied, the highest levels were

278 found with 600 and 700 kg ha<sup>-1</sup> K<sub>2</sub>O. As for the interaction between the correctives  
 279 (calcium silicate x dolomitic limestone), independent of the K<sub>2</sub>O rate, the higher silicon  
 280 contents were found when calcium silicate was applied.

281 **Table 3. Silicon content in the leaf (%) as a function of K<sub>2</sub>O rates and corrective**  
 282 **sources (dolomitic limestone and calcium silicate).**

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K <sub>2</sub> O rates (kg ha <sup>-1</sup> )	Calcium silicate Content tho Si (%)	Dolomitic limestone
150	13 Ca	12 Ab
300	14 Ca	12 Ab
450	18 Ba	13 Ab
600	20 Aa	13 Ab
700	20 Aa	14 Ab

284 *Capital letters equal in the column, do not differ at the level of significance of 5%; Minor letter in*  
 285 *the same line, do not differ at the level of significance of 5%.*

286

287 With increasing rates of K<sub>2</sub>O in the soil there was a tendency of reduction in the liquid  
 288 photosynthesis (total photosynthesis) ( Fig. 3A), transpiration (Fig. 3B), stomatal  
 289 conductance (Fig. 3C), intercellular CO<sub>2</sub> concentration (Fig. 3D), water use efficiency  
 290 (Fig. 3E) and instantaneous carboxylation efficiency (Fig. 3F), in the presence and  
 291 absence of calcium silicate. However, it was observed that with the application of  
 292 calcium silicate all these variables presented higher values. The deposition of silicon in  
 293 plant tissues improves the interception of light and decreases transpiration [35].  
 294 Increased availability of Si favors increased productivity, since Si can act indirectly in  
 295 photosynthetic and biochemical processes, especially when the plant is subjected to  
 296 some type of stress [36]. The translocation of silicon from the roots to the aerial part of  
 297 plants may be related to the increase in photosynthetic capacity, greater resistance to  
 298 possible damage and reduction in the evapotranspiration process, which, consequently,  
 299 improves the use of available water in the soil [37].

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301 The increase in CO<sub>2</sub> concentration inside leaves promotes the closure of stomata, which  
 302 may occur in response to a biotic stress [38]. This CO<sub>2</sub> concentration may be directly  
 303 related to the increase in transpiration, which was greater than 0,006 mmol H<sub>2</sub>O m<sup>-2</sup>s<sup>-1</sup>  
 304 (Fig. 3B). According to [39], the increase in resistance to gas diffusion can be a limiting  
 305 factor in the CO<sub>2</sub> assimilation rate. The increase in transpiration by plants is mainly due  
 306 to the inability of some plants to absorb enough water to replenish that consumed in the  
 307 transpiration process [40], and the loss of water by plants is regulated by the activity of  
 308 the guard cells [41]. As temperature rises, relative air humidity decreases and responses  
 309 of metabolic processes in plants will reflect the interaction between transpiration and  
 310 guard cell activities [42].

311

312 The efficiency in the use of water by sweet pepper plants demonstrates a relationship  
 313 between photosynthesis and transpiration in which the observed values are directly  
 314 related to the amount of carbon that the plant fixes for each unit of water it loses [43]. In  
 315 this sense, decreases observed in water use efficiency (Fig. 3E) are reflective of  
 316 increases in the rate of carbon dioxide assimilation and transpiration of plants. As for the  
 317 instantaneous efficiency of carboxylation (Fig. 3F).

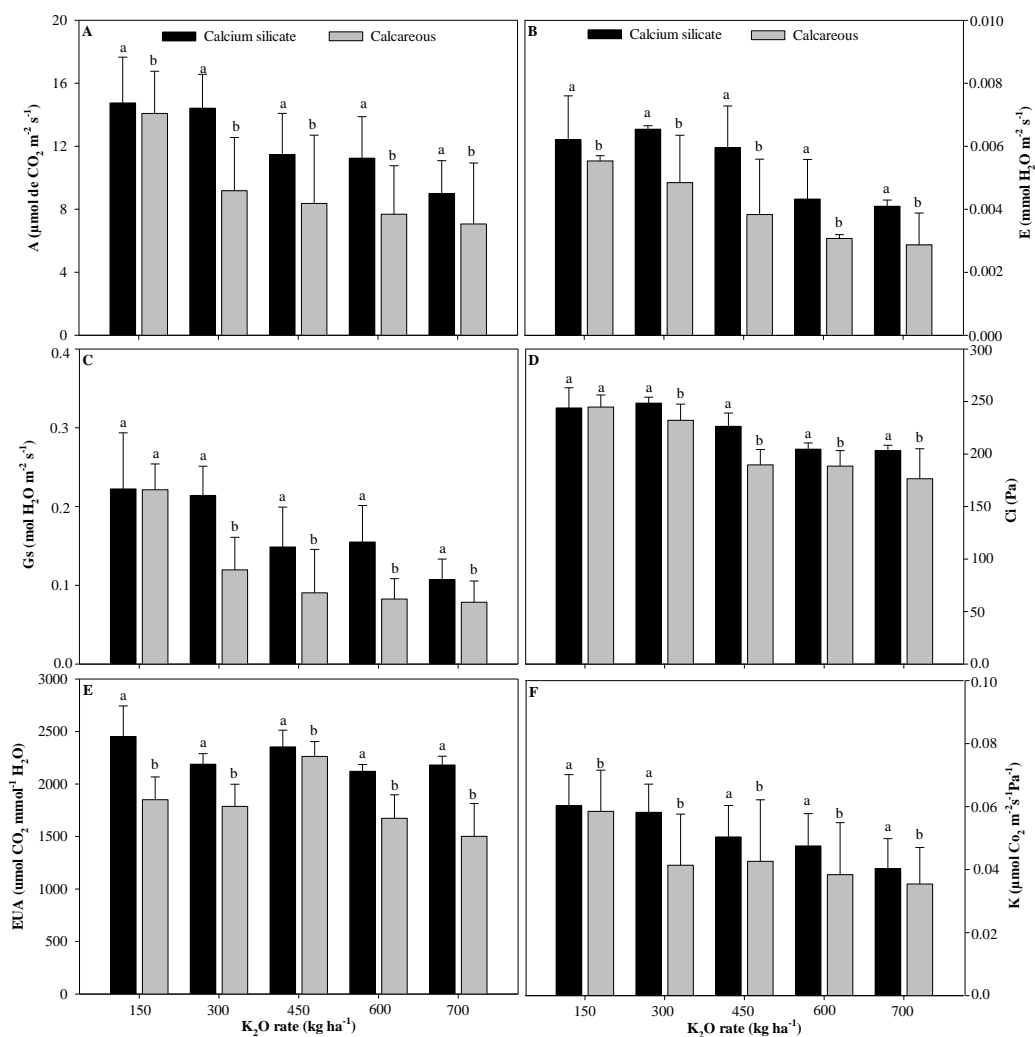
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319 The results obtained in this work indicate that the increase in the instantaneous  
 320 efficiency of carboxylation is related to the increase in the concentration of CO<sub>2</sub> and to  
 321 the gains related to the rate of assimilation of CO<sub>2</sub> [44]. Point out that this efficiency is  
 322 related to the intercellular CO<sub>2</sub> concentration and the rate of assimilation of CO<sub>2</sub>. The  
 323 CO<sub>2</sub> assimilation from the external environment promotes water loss, which restricts CO<sub>2</sub>  
 324 entry [41]. The gas exchanges, according to [45], are influenced by climatic conditions,  
 325 so the reduction in the efficiency of water use may be related to the increase of solar  
 326 radiation, temperature and relative humidity. [46], found a mean value of 0.28 mol of H<sub>2</sub>O

327  $\text{m}^2\text{s}^{-1}$  for stomatal conductance in sweet pepper plants cultivated in protected  
 328 environment, which is in agreement with the observed in this work (Fig. 3C).  
 329

330 It is noteworthy that the stomatal behavior determines the transpiratory requirement of  
 331 the plants, thus controlling the loss of water in the form of vapor [47]. Although Si is not  
 332 considered an essential element for plants, studies show that its application to the soil  
 333 contributes to the growth and increase of productivity [48], as can be observed in this  
 334 work (Table 3). In saline stress conditions, the plant growth is compromised due to the  
 335 reduction of the osmotic potential of the soil solution, which reduces the water potential  
 336 of the plants [49]. According to [50], this reduction of the water potential of the plants can  
 337 be mitigated by the application of Si, which reduces the toxicity caused by excess  
 338 sodium chloride in the soil solution.  
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340 The use of calcium silicates in the soil provides significant responses of the crops in the  
 341 increase of the contents and P and in the reduction of the heavy metal content, resulting  
 342 in a greater productive stability [51].



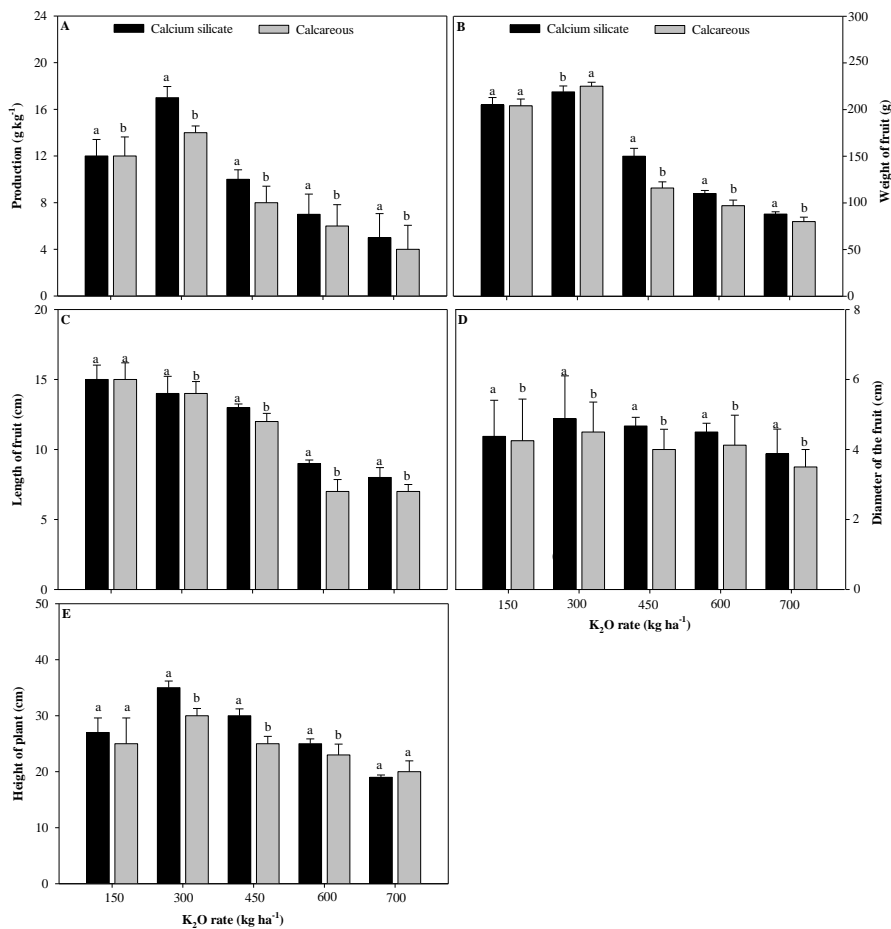
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 344 **Fig. 3. Liquid photosynthesis (A), transpiration (B), stomatal conductance (C),**  
 345 **intercellular  $\text{CO}_2$  concentration (D), water use efficiency (E) and instantaneous**  
 346 **efficiency of carboxylation (F) as a function of presence and absence of calcium**  
 347 **silicate and rate of  $\text{K}_2\text{O}$ .**  
 348

349 The production and weight of sweet pepper fruits were higher when the 150 kg K<sub>2</sub>O rate  
 350 was applied in the presence and absence of calcium silicate (Fig. 4A and 4B). Higher  
 351 rates of K<sub>2</sub>O reduced sweet pepper production (Fig. 4A) and caused a significant  
 352 decrease in plant height (Fig. 4E). There was a reduction in the length of the chili fruits  
 353 when the K<sub>2</sub>O rates increased, in the presence and absence of calcium silicate (Fig. 4C).  
 354 The application of calcium silicate favored the increase of the diameter of the fruits in the  
 355 rates of K<sub>2</sub>O studied (Fig. 4D). The beneficial effects of Si on the growth have been  
 356 reported in a wide of plant species, which are characterized by protecting the plant from  
 357 various biotic and a biotic stresses [52]. Transporters responsible for Si unloading from  
 358 xylem in leaves also have been identified in many plant species [53]. The aerial plant  
 359 parts accumulate more Si than roots [54]. Deposition of Si takes place in different parts  
 360 of plant such as epidermis of shoots but can also occur in the cell wall of root  
 361 endodermis [14]. However, phytoliths formation, composition, and localization vary  
 362 among plant species [55].

364 The rate of 150 Kg K<sub>2</sub>O favored the growth of sweet pepper plants in the presence of  
 365 calcium silicate. In Fig. 4C it is observed that, as increasing rates of K<sub>2</sub>O were applied,  
 366 there was reduction in fruit length, as observed by [56]. Under conditions of higher  
 367 salinity and osmotic pressure of the soil solution the absorption of water from the root  
 368 cells decreases, allowing the occurrence of ionic toxicity. The addition of 16.6 g KCl m<sup>-2</sup>  
 369 reduced root yield and P uptake by sweet pepper plants cultivated on an Oxisol with 24.0  
 370 g dm<sup>-3</sup> of organic matter [6] in addition, [57] reported that high salinity promotes changes  
 371 in photosynthesis (CO<sub>2</sub> assimilation, stomatal conductance and leaf transpiration), thus  
 372 inhibiting plant growth and reducing its height, as shown in Fig. 4E.

373

300



374

375 **Fig. 4. Production (A), fruit weight (B), fruit length (C), fruit diameter (D) and plant**  
376 **height (E) as a function of the presence and absence of calcium silicate and K<sub>2</sub>O**  
377 **rates.**

378

#### 379 **4. CONCLUSION**

380

381 It is concluded from the research that the dose of 300 kg ha<sup>-1</sup> of K<sub>2</sub>O, in the presence of  
382 calcium silicate, provided the best results for the electrical conductivity of 2.76 dS m<sup>-1</sup>,  
383 silicon content in the soil of 5.70 mg kg<sup>-1</sup>, 14% silicon leaf content, improving  
384 photosynthetic rates, transpiration, water use efficiency and fruit production. The  
385 increase in salinity reduced fruit yield, in the presence and absence of Si.

386

#### 387 **COMPETING INTERESTS**

388

389 We declared that no competing interests exist.

390

391

392

#### 393 **CONSENT**

394

395 It is not applicable.

396

#### 397 **ETHICAL APPROVAL**

398

399 It is not applicable.

400

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