

## Original Research Article

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

### 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 doses 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 doses 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 dose of 150 Kg K<sub>2</sub>O favored the growth of sweet pepper plants in the presence of calcium silicate.

**Conclusion:** In the culture of sweet pepper in protected cultivation, the increase in the rates of potassium fertilization increases the electrical conductivity of the soil and the silicon content in the leaves. Doses up to 300 kg K<sub>2</sub>O ha<sup>-1</sup> increase the biometric factors of production. High doses of K<sub>2</sub>O reduce gas exchange and water use efficiency, and the application of calcium silicate in the soil attenuates these effects.

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

### 1. INTRODUCTION

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

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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].

29  
30 In the State of São Paulo, in 2018, about 65.800 tons of sweet pepper were produced in  
31 2.560 ha<sup>-1</sup> [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].

41  
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  
44 high 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].

47  
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].

57  
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.

64  
65 The objective of this work was to investigate the effect of calcium silicate on gaseous  
66 exchanges and production factors in the sweet pepper, cultivated under conditions of soil  
67 salinity induced by potassium fertilization, in protected cultivation.

## 68 69 **2. MATERIAL AND METHODS**

70  
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

**Comment [A3]:** Therefore, the present research was conducted to evaluate the effect of calcium silicate on gaseous exchanges and production factors in the sweet pepper under conditions of soil salinity induced by potassium fertilization, in protected cultivation .

83 doses of KCl equivalent to 150, 300, 450, 600 and 700 kg ha<sup>-1</sup> of K<sub>2</sub>O. It was applied  
84 1.62 ha<sup>-1</sup> Mg of dolomite limestone with 80 % total neutralizing power (45 % CaO and  
85 10% 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.

93  
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.

111  
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 doses of K<sub>2</sub>O.**

137

Treatments	Corrective		K <sub>2</sub> O doses 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

138

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

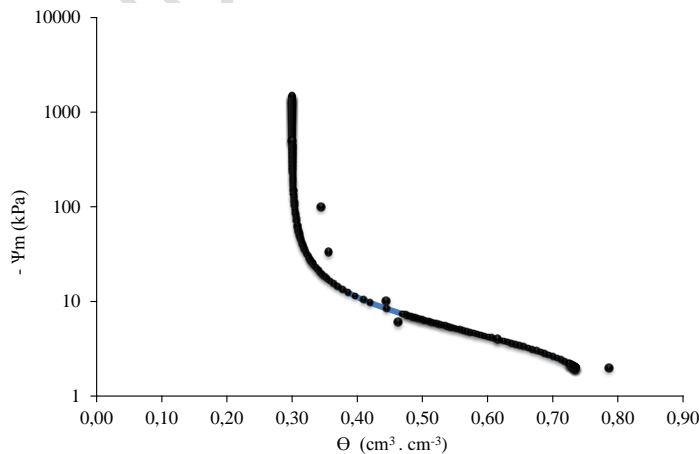
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152 The irrigation was done by drip irrigation; the self-compensating emitters being manually  
 153 inserted in polyethylene hoses. The calculation of the operating time of the irrigation  
 154 system was made based on the humidity sensors (tensiometers) 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.

157

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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**Fig. 1. Water retention characteristic curve of the Oxisol used in the experiment.**

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At the end of the experiment, the electrical conductivity (EC) was determined in the saturated paste extract [25], which is the method used as reference for EC determination and adopted in various regions of the world. To do so, the soil passed through the 2 mm sieve and allowed to stand for 24 h to air dry. Afterwards, 800 g of soil were added in plastic containers, with capacity for 1200 mL, with 500 mL of distilled water added. After the mixture turned into a paste, the container was covered with foil remaining for 24 h. After this time, the slurry was again stirred, standing for 1 h. By means of the vacuum filtration of the saturation paste, the solution of the soil was extracted, after which the EC reading was measured. The electrical conductivity of the saturated pulp was corrected considering the soil water retention characteristic using a digital conductivity meter (Lutron, model CD-4303).

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For the quantification of the silicon in the soil, soil samples were taken from the pots grown with sweet pepper and prepared for analysis. The samples were dried at room temperature (TFSA) and subsequently sieved (<2,0 mm). The extraction procedure was performed to maintain the same soil: solution ratio, that is, for each 10 g of soil, 100 mL of extractor was added. The extractors used were: Acetic acid 0,5 mol L<sup>-1</sup> [26]: 100 mL of 0.5 mol L<sup>-1</sup> acetic acid was added to a 150 mL plastic flask containing 10 g de soil. The plastic bottle was capped and shaken horizontally for one hour. After 30 minutes, the extract was filtered (plastic funnel), using filter paper number 42; Buffer pH 4.0: 100 mL of a buffered solution at pH 4.0 acetic acid plus sodium acetate (49.2 mL of concentrated acetic acid and 14.800 g of anhydrous sodium acetate were dissolved in 1,0 liter of distilled water, and the pH adjusted to 4.0 with the addition of acetic acid) were added in a 150 mL plastic flask with 10 g soil and shaken horizontally for one hour. The vials were then held for 30 minutes and then the plastic funnel extract and filter paper number 42 filtered; Calcium chloride 0.0025 mol L<sup>-1</sup> [27]: 100 mL of a 0.0025 mol L<sup>-1</sup> calcium chloride solution was added in a plastic flask containing 10 g of soil. Thereafter, it was shaken horizontally for 15 minutes and then decanted from overnight. The following day, the extracts were filtered (plastic funnel and filter paper number 42); Water: 100 mL of distilled and demineralized water were added in 150 mL plastic bottles with 10 g of soil. Henceforth, the procedure was the same as for acetic acid.

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

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

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For the analysis of liquid photosynthesis, stomatal conductance, intercellular CO<sub>2</sub> concentration, transpiration, water use efficiency and instantaneous carboxylation efficiency, the IRGA model LI-6400XT, (Li-Cor, Lincoln, Nebraska, USA) was used. Two plants of each cultivar were chosen randomly, being defined as the sample unit the sixth

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**Comment [A6]:** were

222 leaf from top to bottom, fully expanded and mature. Because it is a species with a  
223 composite leaf, the first three leaflets of each leaf were used to measure, totaling six  
224 measurements. The value of  $850 \mu\text{mol m}^{-2} \text{s}^{-1}$  of saturation irradiance, defined by the  
225 realization of a light curve, was set using the value of radiation that induced the  
226 maximum photosynthesis. Sweet pepper is a C3 plant, where a cyclic mechanism of  
227 enzymatic reactions converts  $\text{CO}_2$  into carbohydrates through the reductive  
228 photosynthetic cycle (C3), generating the 3 phosphoglycerate. Therefore, IRGA camera  
229 temperature was controlled at  $28 \text{ }^\circ\text{C}$ , since in C3 plants the maximum rate of  
230 photosynthesis is reached at relatively low radiation intensity, causing no destruction or  
231 damage to the photosynthetic apparatus. Measurements were performed on a  $6 \text{ cm}^2$   
232 sheet area.

233  
234 The results found in the different evaluations were submitted to analysis of variance. For  
235 the evaluation of the means, the Scott-Knott or t-test were applied, according to the  
236 theories recommended by [29]. The standard deviations were calculated and the  
237 correlation estimators (Pearson or Spearman) were used, using SISVAR software [30].

238

### 239 **3. RESULTS AND DISCUSSION**

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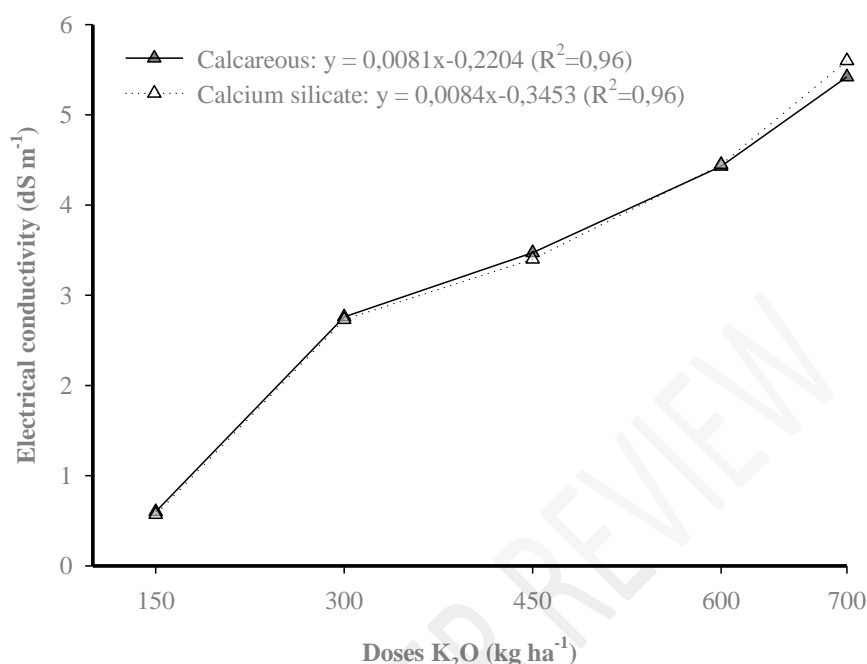
241 The electrical conductivity (EC) of the soil (Fig. 2) increased with increasing doses of  
242  $\text{K}_2\text{O}$  in both correctives (calcium silicate and dolomitic limestone). The EC of 2.76 and  
243  $2.16 \text{ dS m}^{-1}$  were the ones that provided the greatest vegetative development and  
244 production, these results agree with those found by [31], who studied the influence of EC  
245 on eggplant concluded that the EC of  $2.36 \text{ dS m}^{-1}$  provided the greatest development  
246 and fruiting. The higher dry matter yield of roots, stems, leaves and fruits in eggplant  
247 plants was obtained with EC of nutrient solution of  $2.10 \text{ dS m}^{-1}$  [32]. The use of a dose  
248 greater than  $60 \text{ kg ha}^{-1}$  of  $\text{K}_2\text{O}$  may cause some damage to the legumes due to its saline  
249 effect, which may have occurred in this experiment with doses greater than  $100 \text{ kg ha}^{-1}$  of  
250  $\text{K}_2\text{O}$  [33]. The electrical conductivity increased linearly with the increase of the KCl dose  
251 applied in two sources of potassium fertilization, due to the increase of the electrolytic  
252 concentration of the soil solution, which is proportional to the increase in the  
253 concentration of ions in the solution [34].

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

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262  
263 The concentration of Si in the soil did not vary in the different doses of K<sub>2</sub>O studied when  
264 calcium or calcium silicate was applied (Table 2). However, in the interaction between  
265 the doses of K<sub>2</sub>O x sources of correctives it was observed that the silicon concentration  
266 was higher for the treatment using calcium silicate, due to the fact that it is a soluble  
267 source of Si.

268  
269 **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 doses and**  
270 **corrective sources (dolomitic limestone and calcium silicate).**

271

K <sub>2</sub> O doses (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

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

274  
275 For the silicon content in the sweet pepper leaf (Table 3) differences were observed  
276 between the doses of K<sub>2</sub>O. When the calcium silicate was applied, the highest levels  
277 were found with 600 and 700 kg ha<sup>-1</sup> K<sub>2</sub>O. As for the interaction between the correctives  
278 (calcium silicate x dolomitic limestone), independent of the K<sub>2</sub>O dose, the higher silicon  
279 contents were found when calcium silicate was applied.

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

K <sub>2</sub> O doses (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

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

285

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

300 The increase in CO<sub>2</sub> concentration inside leaves promotes the closure of stomata, which  
 301 may occur in response to abiotic stress [38]. This CO<sub>2</sub> concentration may be directly  
 302 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>  
 303 (Fig. 3B). According to [39], the increase in resistance to gas diffusion can be a limiting  
 304 factor in the CO<sub>2</sub> assimilation rate. The increase in transpiration by plants is mainly due  
 305 to the inability of some plants to absorb enough water to replenish that consumed in the  
 306 transpiration process [40], and the loss of water by plants is regulated by the activity of  
 307 the guard cells [41]. As temperature rises, relative air humidity decreases and responses  
 308 of metabolic processes in plants will reflect the interaction between transpiration and  
 309 guard cell activities [42].  
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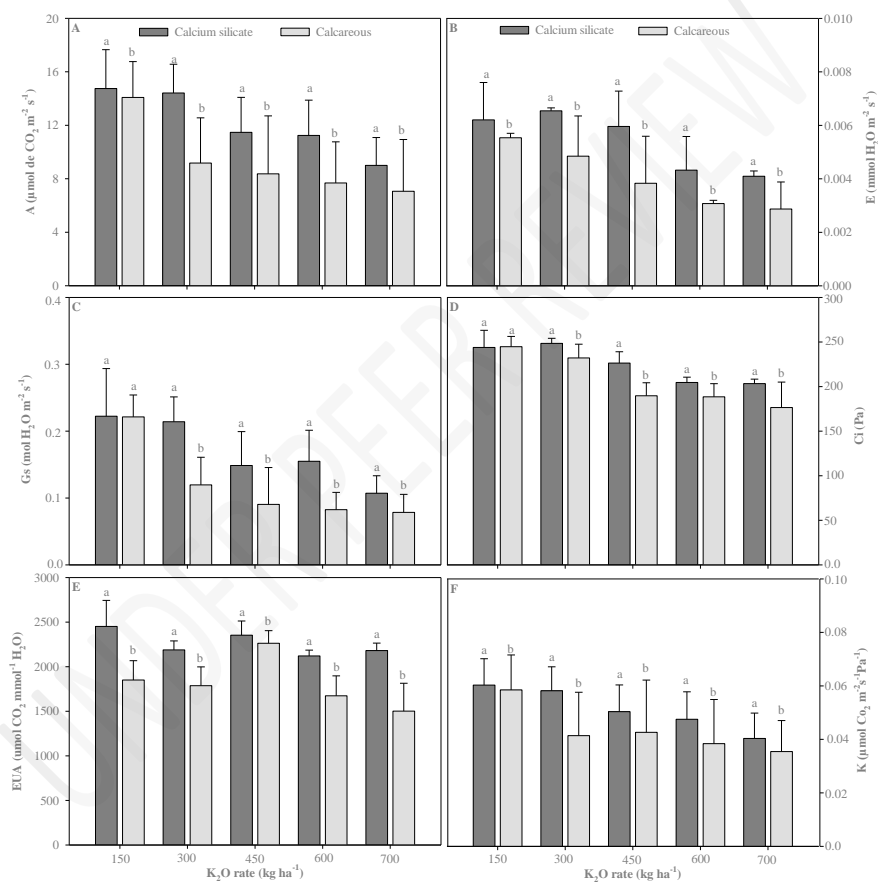
311 The efficiency in the use of water by sweet pepper plants demonstrates a relationship  
 312 between photosynthesis and transpiration in which the observed values are directly  
 313 related to the amount of carbon that the plant fixes for each unit of water it loses [43]. In  
 314 this sense, decreases observed in water use efficiency (Fig. 3E) are reflective of  
 315 increases in the rate of carbon dioxide assimilation and transpiration of plants. As for the  
 316 instantaneous efficiency of carboxylation (Fig. 3F).  
 317

318 The results obtained in this work indicate that the increase in the instantaneous  
 319 efficiency of carboxylation is related to the increase in the concentration of CO<sub>2</sub> and to  
 320 the gains related to the rate of assimilation of CO<sub>2</sub>. [44] point out that this efficiency is  
 321 related to the intercellular CO<sub>2</sub> concentration and the rate of assimilation of CO<sub>2</sub>. The  
 322 CO<sub>2</sub> assimilation from the external environment promotes water loss, which restricts CO<sub>2</sub>  
 323 entry [41]. The gas exchanges, according to [45], are influenced by climatic conditions,  
 324 so the reduction in the efficiency of water use may be related to the increase of solar  
 325 radiation, temperature and relative humidity. [46], found a mean value of 0.28 mol of H<sub>2</sub>O  
 326 m<sup>-2</sup>s<sup>-1</sup> for stomatal conductance in sweet pepper plants cultivated in protected  
 327 environment, which is in agreement with the observed in this work (Fig. 3C).  
 328

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329 It is noteworthy that the stomatal behavior determines the transpiratory requirement of  
 330 the plants, thus controlling the loss of water in the form of vapor [47]. Although Si is not  
 331 considered an essential element for plants, studies show that its application to the soil  
 332 contributes to the growth and increase of productivity [48], as can be observed in this  
 333 work (Table 3). In saline stress conditions, the plant growth is compromised due to the  
 334 reduction of the osmotic potential of the soil solution, which reduces the water potential  
 335 of the plants [49]. According to [50], this reduction of the water potential of the plants can  
 336 be mitigated by the application of Si, which reduces the toxicity caused by excess  
 337 sodium chloride in the soil solution.

339 The use of calcium silicates in the soil provides significant responses of the crops in the  
 340 increase of the contents and P and in the reduction of the heavy metal content, resulting  
 341 in a greater productive stability [51].



342 **Fig. 3. Liquid photosynthesis (A), transpiration (B), stomatal conductance (C),**  
 343 **intercellular CO<sub>2</sub> concentration (D), water use efficiency (E) and instantaneous**  
 344 **efficiency of carboxylation (F) as a function of presence and absence of calcium**  
 345 **silicate and doses of K<sub>2</sub>O.**  
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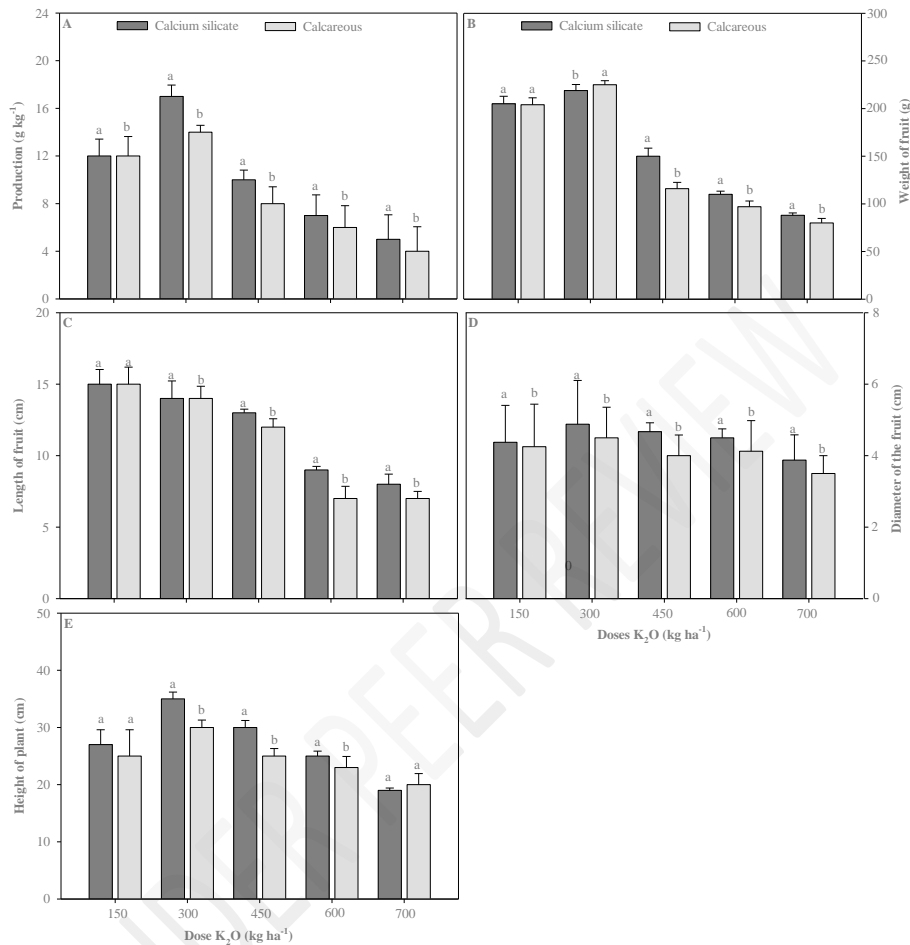
347  
 348 The production and weight of sweet pepper fruits were higher when the 150 kg K<sub>2</sub>O dose  
 349 was applied in the presence and absence of calcium silicate (Fig. 4A and 4B). Higher  
 350 doses of K<sub>2</sub>O reduced chilli fruit production (Fig. 4A) and caused a significant decrease  
 351 in plant height (Fig. 4E). There was a reduction in the length of the chilli fruits when the

352 K<sub>2</sub>O doses increased, in the presence and absence of calcium silicate (Fig. 4C). The  
353 application of calcium silicate favored the increase of the diameter of the fruits in the  
354 doses of K<sub>2</sub>O studied (Fig. 4D). The beneficial effects of Si on the growth have been  
355 reported in a wide of plant species, which are characterized by protecting the plant from  
356 various biotic and abiotic stresses [52]. Transporters responsible for Si unloading from  
357 xylem in leaves also have been identified in many plant species [53]. The aerial plant  
358 parts accumulate more Si than roots [54]. Deposition of Si takes place in different parts  
359 of plant such as epidermis of shoots but can also occur in the cell wall of root  
360 endodermis [14]. However, phytoliths formation, composition, and localization vary  
361 among plant species [55].

362  
363 The dose of 150 Kg K<sub>2</sub>O favored the growth of sweet pepper plants in the presence of  
364 calcium silicate. In Fig. 4C it is observed that, as increasing doses of K<sub>2</sub>O were applied,  
365 there was reduction in fruit length, as observed by [56]. Under conditions of higher  
366 salinity and osmotic pressure of the soil solution the absorption of water from the root  
367 cells decreases, allowing the occurrence of ionic toxicity. The addition of 16.6 g KCl m<sup>-2</sup>  
368 reduced root yield and P uptake by sweet pepper plants cultivated on an Oxisol with 24.0  
369 g dm<sup>-3</sup> of organic matter [6] in addition, [57] reported that high salinity promotes changes  
370 in photosynthesis (CO<sub>2</sub> assimilation, stomatal conductance and leaf transpiration), thus  
371 inhibiting plant growth and reducing its height, as shown in Fig. 4E.  
372

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373  
374 **Fig. 4. Production (A), fruit weight (B), fruit length (C), fruit diameter (D) and plant**  
375 **height (E) as a function of the presence and absence of calcium silicate and  $K_2O$**   
376 **doses.**

377  
378 **4. CONCLUSION**

379  
380 It is concluded that, in the culture of sweet pepper in protected cultivation, the increase in  
381 the rates of potassium fertilization increases the electrical conductivity of the soil and the  
382 silicon content in the leaves. Doses up to 300  $kg\ K_2O\ ha^{-1}$  increase the biometric factors  
383 of production. High doses of  $K_2O$  reduce gas exchange and water use efficiency, and the  
384 application of calcium silicate in the soil attenuates these effects.

385  
386 **COMPETING INTERESTS**

387  
388 We declared that no competing interests exist.  
389  
390  
391

**Comment [A9]:** The conclusion is already mentioned

392 **CONSENT**

393

394 It is not applicable.

395

396 **ETHICAL APPROVAL**

397

398 It is not applicable.

399

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