

SALINIZAÇÃO POR CÁLCIO NA PRODUÇÃO DE PIMENTÃO FERTIRRIGADO SOB AMBIENTE PROTEGIDO

RENAN LIMA DE SOUSA¹; JOSEANTONIO RIBEIRO DE CARVALHO²; THATIANE NEPOMUCENO ALVES³; POLIANA ROCHA D'ALMEIDA MOTA⁴ E ROBERTO LYRA VILLAS BOAS⁵

¹Departamento de Engenharia Rural e Socioeconomia, Faculdade de Ciências Agronômicas (FCA/UNESP); Brasil, renann.agro@hotmail.com; <https://orcid.org/0000-0003-2168-8249>

²Departamento de Produção Vegetal/Horticultura, Faculdade de Ciências Agronômicas (FCA/UNESP); Brasil, josercmg@gmail.com; <https://orcid.org/0000-0002-3879-4585>

³Departamento de Produção Vegetal/Horticultura, Faculdade de Ciências Agronômicas (FCA/UNESP); Brasil, thatinepomuceno@hotmail.com; <https://orcid.org/0000-0002-9077-9104>

⁴Departamento de Engenharia Agrícola e Solos, Universidade Federal do Piauí (UFPI); Brasil, poliana@ufpi.edu.br; <https://orcid.org/0000-0002-2682-0803>

⁵Departamento de Solos e Recursos Ambientais, Faculdade de Ciências Agronômicas (FCA/UNESP); Brasil, roberto.lyra@unesp.br; <https://orcid.org/0000-0001-7516-4147>

1 RESUMO

Objetivou-se avaliar doses de cálcio na produção de pimentão, cultivar ‘Gaston’, e os efeitos no extrato de solução do solo por extratores de cápsula porosa. A pesquisa foi instalada na estufa agrícola do Departamento de Solos e Recursos Ambientais da Universidade Estadual Paulista “Júlio de Mesquita Filho” - Campus de Botucatu, com plantas conduzidas em vasos. Utilizou-se delineamento em blocos casualizados, quatro repetições, testando quatro doses de Ca (98, 196, 294 e 392 kg ha⁻¹) aplicadas via fertirrigação por gotejamento. Foram avaliados: condutividade elétrica e concentração de íons específicos da solução do solo, obtidas semanalmente por extratores. Os extratores permitiram monitoramento eficiente da solução do solo, e houve diferença significativa entre os tratamentos. O aumento da concentração de sais na solução do solo reduziu a produtividade. A dose que proporcionou maior produção de frutos foi 98 kg ha⁻¹ de Ca com 46,5 t ha⁻¹, apresentando condutividade elétrica média ao longo do ciclo de 1,8 dS m⁻¹ e concentração de 397 mg L⁻¹ no extrato de solução do solo.

Palavras-chave: *Capsicum annuum* L., fertirrigação, extrator de solução, solução do solo

SOUSA, R. L.; CARVALHO, J. R.; ALVES, T. N.; MOTA, P. R. D.; VILLAS BOAS, R. L.

EFFECTS OF CALCIUM SALINIZATION IN THE PRODUCTION OF FERTIRRIGATED RED PEPPERS UNDER GREEN HOUSE

2 ABSTRACT

Pepper cultivation involves the use of several technologies, such as a protected environment to reduce the effects of environmental variability and the incidence of pests and diseases, with the goal of optimizing productivity and homogenizing supply, as well as through fertigation, which allows the nutritional demand of the crop to be met in a fractionated manner, including that of

nutrients such as calcium. The objective of this research was to evaluate the effects of different doses of calcium on the production of peppers and the cultivar 'Gaston' and on the soil solution extract using solution extractors. The research was installed in the agricultural greenhouse of the Department of Soil and Environmental Resources at the Universidade Estadual Paulista "Júlio de Mesquita Filho" - Botucatu Campus, with the plants being grown in pots. A randomized block design with four replications was used, and four doses of Ca (98 kg ha^{-1} , 196 kg ha^{-1} , 294 kg ha^{-1} and 392 kg ha^{-1}) were applied via drip fertigation. The following parameters were evaluated: electrical conductivity and specific ion concentration of the soil solution extracted weekly, plant height and production. The use of extractors allowed efficient monitoring, and there was a significant difference between treatments. An increase in the concentration of salts in the soil solution harms productivity. The dose that provided the highest fruit production was 98 kg ha^{-1} of Ca (46.5 t ha^{-1}), which presented an average electrical conductivity throughout the cycle of 1.8 dS m^{-1} and a concentration of 397 mg L^{-1} in the soil solution extract.

Keywords: *Capsicum annuum* L., fertigation, solution extractor, soil solution

3 INTRODUCTION

Bell pepper (*Capsicum*) (*annuum* L.) belongs to the Solanaceae family and is cultivated throughout the national territory. It is typically of American origin, with wild forms occurring from the southern United States to northern Chile (Souza, 2017).

The fruits contain high levels of vitamins A and C and minerals such as calcium, sodium, phosphorus, and iron. They also contain approximately 48 calories per 100 g of product; they are used in the manufacture of natural dyes, condiments, preserves, and sauces (Palangana *et al.*, 2012). The fruit is a berry and can be green, yellow, or red when it is ripe (Zhigila). *et al.*, 2014).

Bell peppers are among the most widespread and consumed vegetable species in Brazil in their fresh form and are considered among the ten most economically important species in the vegetable market (Sediyama). *et al.*, 2014).

The macroelement calcium is of fundamental importance for all metabolic functions of plants, including its protective function against pests and pathogens. Furthermore, this nutrient, which is located in the cell wall, acts as a stabilizing agent,

directly influencing the texture, firmness, and ripening of fruits. Serious economic losses can occur annually in organs such as fruits and leaves because of physiological disorders and rot caused by inadequate calcium levels in their tissues (De Sá *et al.*, 2024).

Among the main symptoms of calcium deficiency, Flores *et al.* (2012) and Viegas *et al.* (2013) reported poorly developed plants, chlorosis, deformation and irregular shape of young leaves, necrosis of the apices and death of the shoots.

The growing demand for bell peppers in the country favors their cultivation in greenhouses because of greater production security, reduced losses, increased yield, and improved fruit quality. According to Silva, Silva, and Paggiuca (2014), protected cultivation has gained importance given its characteristics, such as reducing losses and providing predictability and consistency of production, especially during the summer period. In this way, it offers higher-quality products than those obtained in open fields do (Seabra Junior *et al.*, 2022).

Among the main factors in the cultivation and production of vegetables is mineral nutrition, as it directly affects plant

metabolism, growth, productivity and quality of the final product (Marcussi; Godoy; Villas Bôas, 2004).

Salinization means that the concentration of solutes in the soil is greater than that in the roots, and this process increases the osmotic pressure of the soil, making water less accessible to plants (Ziganshin, 2020).

Among the equipment used for its speed of response and ease of handling is the porous capsule extractor, which promotes the removal of volumes of solution from the soil in the area occupied by the plant roots (Silva; Klar; Silva, 2015).

Marcussi (2005) reported that, among the nutrients absorbed by pepper plants, calcium is the third most absorbed, a result corroborated by Oliveira *et al.* (2015), who reported the same behavior in leaf tissue.

It is still difficult to find specific recommendations for each cultivar. Most studies, such as those carried out by Oliveira *et al.* (2016) and Oliveira *et al.* (2013), are focused on the two nutrients with the greatest accumulation in the crop, N and K.

Therefore, the objective of this research was to evaluate calcium salinization in the production of 'Gaston' cultivar pepper plants in pots and protected environments and the effects on the soil solution extract obtained using extractors.

4 MATERIALS AND METHODS

The research was conducted at the Department of Soil and Environmental Resources, Faculty of Agronomic Sciences, São Paulo State University "Júlio de Mesquita Filho" - Botucatu Campus (São Paulo, Brazil), at geographic coordinates

22°50'51.6" South latitude and 48°26'06.0" West longitude, at an altitude of 830 m.

The plants were grown in an agricultural greenhouse measuring 7.0 m wide by 24.0 m long and covered with 150-micron plastic film, with upper windows and side curtains for ventilation and temperature control, white mesh sides, and misting systems.

The 'Gaston' cultivar was selected for evaluation and to verify its response to salinity, as it is the most widely used cultivar among pepper producers in the region. The seedlings were approximately 16 cm in height and had 7 to 8 leaves.

Two plants were transplanted per pot, with the less vigorous one being thinned 30 days after transplanting (DAT), thus initiating the fertigation program and application of treatments. Before 30 days, the plants received only water.

The soil used to fill the 25 L pots was sandy in texture and was properly amended after chemical analysis, increasing the base saturation to 70%. After being filled, the pots were distributed inside the greenhouse with a spacing of 0.5 m between the pots in the same block and 1.2 m between the blocks, totaling 23,529 plants per hectare.

The experiment evaluated four calcium doses distributed in randomized blocks, with four replicates and each plot with two sampling points (2 pots of 25 liters), totaling 16 plots and 32 pots.

Table 1 shows the descriptions of each treatment based on the nutrient absorption curve for the fertigated bell peppers (Trani; Tivelli; Carrijo, 2011), as shown in Table 2. For nutrients that were not investigated, 100% of the recommendation was applied. The experiment was implemented on 01/03/2016 and completed on 12/10/2016 at 225 DAT.

Table 1. Description of the treatments used in the experiment, based on the nutrient absorption curve for the cultivation of the fertigated bell peppers.

TREATMENT	DOSE (kg ha ⁻¹)
1) 70% of Ca	98
2) 140% of Ca	196
3) 210% of Ca	294
4) 280% of Ca	392

Table 2. Nutrient absorption curves used as a reference for bell pepper cultivation.

Development of pepper plants days after transplanting (DAT)	Amount of nutrients per day				
	N	P ₂ O ₅	K ₂ O	Here	Mg
	kg ha ⁻¹				
1 to 35	0.05	0.01	0.08	0.03	0.04
36 to 55	0.35	0.06	0.78	0.23	0.14
56 to 70	1.16	0.24	2.24	0.69	0.50
71 to 85	1.32	0.22	2.60	0.67	0.70
86 to 100	2.63	0.77	4.80	1.93	1.05
101 to 120	2.73	0.60	5.50	0.80	0.75
121 to 140	3.75	1.10	4.85	1.00	0.72
141 to 180	2.00	0.90	3.60	1.20	0.90
Total per hectare	295.0	90.0	514.0	139.0	103.0

Source: Trani, Tivelli and Carrijo (2011, p. 23).

To determine the nutritional requirements per plant, since the experiment was conducted in pots, a density of 16,667 plants per hectare was considered, obtained from the most common spacing among pepper producers in the field and cited by Trani, Tivelli and Carrijo (2011), with a spacing of 1.2 m x 0.5 m.

The fertilizers used in the nutrient solution included calcium chloride as a source of Ca (27.2% Ca), potassium chloride (white powder) as a source of K (60% K₂O), ammonium nitrate as a source of N (33% N), and purified MAP as a source of P (60% P₂O₅ and 10% N), with applications carried out

weekly. For micronutrients, periodic foliar sprays were used.

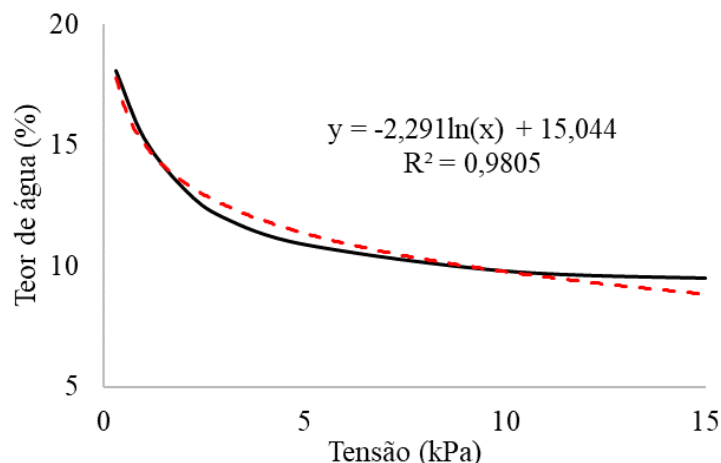
The localized irrigation system adopted was drip irrigation, which was equipped with four L h⁻¹ drip buttons arranged in four arrows for each pot. The doses were injected individually, and ball valves, properly identified, were used to switch between treatments during fertigation.

For fertilizer injection, the bypass tank was used. This system consists of a closed tank in which the concentrated nutrient solution is diluted and carried to the irrigation system as the water flow is forced through the tank.

For irrigation control, the principle of tensiometry was used on the basis of the soil water retention curve. Assuming that the more available water is, the less effort the plant will need to extract it and that pepper plants grown in a greenhouse allow for depletion of up to 30% of the soil water

without affecting production losses (Sousa *et al.*, 2019), a tension of 10 kPa (12.75% soil water) was established as an indicator of irrigation needs, using the water retention curve adjusted by the logarithmic equation shown in Figure 1.

Figure 1. Soil water retention curve.



Soil water tension was monitored by installing porous capsule tensiometers at a depth of 0.2 m, one pot per treatment in each block, allowing for daily readings with the aid of a digital tensiometer and thus verifying the need for irrigation or not.

To monitor the soil solution, solution extractors were used in triplicate for each treatment at a depth of 0.2 m, which, like the tensiometer, had a porous capsule at the end.

The solution extraction occurred 24 hours after the application of the doses via fertigation, with a standardized vacuum applied to all extractors using a 60 mL plastic syringe, allowing it to remain until at least 10 mL of solution accumulated (approximately 4 hours). Afterward, the solution was extracted and analyzed in the laboratory using portable electrical conductivity and specific ion meters. On the basis of the data from each reading, adjustments were made to the management or even the temporary suspension of fertigation when necessary.

The extracted solutions were stored in 15 mL tubes and taken to the laboratory for analysis of electrical conductivity and specific calcium ions using Horiba® portable meters. Weekly, before each reading, the instruments were calibrated with a 1.41 dS.m⁻¹ solution for the conductivity meter and with 150 mg L⁻¹ and 2000 mg L⁻¹ Ca solutions for the specific ion reader. In the interval between readings, the electrode of each portable meter was washed with distilled water and carefully dried with paper towels.

Plant height was measured once a month between 60 DAT and 200 DAT. A rigid measuring tape was used, positioning its end at the base of the plant, close to the ground, and vertically toward the top of the plant. The reading point, in centimeters, was considered to be the last leaf insertion of the tallest branch.

In terms of production, the harvest point adopted was the appearance of the first red stripe. For all the harvested fruits, the weight, commercial type (diameter), length,

quantity per plant, and presence of any defect that would be classified as noncommercial were analyzed.

The weight of each fruit was measured in the laboratory using a digital scale with two decimal places of precision and properly leveled. To identify the type, the fruit classifier developed by GREENPACK® was used, with standard CEAGESP sizes for fruits and vegetables ranging from type 4 to type 11, according to the maximum circumference diameter. For the length of the fruits, a digital caliper with one decimal place was used. Fruits with a diameter smaller than 49 mm, sunburn, or blossom-end rot were classified as noncommercial.

All the results from the analyses were subjected to analysis of variance and

subsequently to regression analysis using the SISVAR 5.6 program.

5 RESULTS AND DISCUSSION

5.1 Soil solution analysis: electrical conductivity (EC)

With the exception of the reading corresponding to day 92 (DAT), all the other readings differed significantly between treatments. The treatment with the lowest dose resulted in the lowest CE value, with a linear increase observed in the other treatments. Tables 3, 4, and 5 show the results of the analysis throughout the cycle as a function of the treatments.

Table 3. Electrical conductivity of the soil solution from 43 DAT to 99 DAT

Treatments	43 DAT	50 DAT	57 DAT	65 DAT	71 DAT	78 DAT	85 DAT	92 DAT	99 DAT
Electrical conductivity (dS m ⁻¹)									
Ca 70%	1.1	0.8	0.9	1.3	1.4	1.2	1.6	2.2	2.8
Ca 140%	1.3	1.0	1.1	1.7	1.5	1.3	1.8	2.4	3.1
Ca 210%	1.5	1.0	1.3	1.8	1.8	1.6	2.1	2.5	3.3
Ca 280%	1.9	1.4	1.6	2.0	2.0	1.8	2.5	2.9	3.5
CV (%)	10.0	6.5	10.0	8.4	10.6	12.8	8.53	12.4	6.3
Regression	L *	L *	L *	L *	L *	L *	L *	Ns	L *
R2 (%)	97.4	89.3	99.7	95.1	94.7	96.1	97.5	-	99.8

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

Table 4. Electrical conductivity of the soil solution from 106 DAT to 162 DAT.

Treatments	106 DAT	113 DAT	120 DAT	127 DAT	134 DAT	141 DAT	148 DAT	155 DAT	162 DAT
Electrical conductivity (dS m ⁻¹)									
Ca 70%	2.4	3.0	3.4	1.8	2.3	1.3	1.4	1.6	2.4
Ca 140%	2.6	3.2	3.8	2.3	2.3	1.9	2.0	1.9	2.8
Ca 210%	2.7	3.4	4.2	2.7	2.8	2.4	2.3	2.3	3.1
Ca 280%	3.0	3.9	4.6	3.0	3.2	2.9	2.8	2.7	3.4
CV (%)	4.2	3.2	4.8	6.6	8.0	10.2	7.5	11.1	6.1
Regression	L *	L *	L *	L *	L *	L *	L *	L *	L *
R2 (%)	96.7	97.3	99.9	97.9	88.7	99.9	98.8	99.6	99.8

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

Table 5. Electrical conductivity of the soil solution from 169 DAT to 225 DAT.

Treatments	169 DAT	176 DAT	183 DAT	190 DAT	197 DAT	204 DAT	211 DAT	218 DAT	225 DAT
Electrical conductivity (dS m ⁻¹)									
Ca 70%	3.2	3.1	1.5	0.8	1.1	1.4	1.5	1.3	1.1
Ca 140%	3.6	3.6	1.9	1.0	1.4	2.1	2.1	1.8	1.5
Ca 210%	3.7	3.9	2.0	1.1	1.5	2.5	2.6	2.1	1.7
Ca 280%	4.1	4.6	2.4	1.3	1.9	2.8	2.9	2.6	2.1
CV (%)	6.4	11.1	7.0	16.0	13.3	3.1	3.3	11.7	11.9
Regression	L *	L *	L *	L *	L *	L *	L *	L *	L *
R2 (%)	95.3	96.8	97.8	98.6	98.5	96.5	96.4	98.3	97.2

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

The average of 27 readings taken throughout the crop cycle was 1.8 dS m⁻¹ (70% Ca), 2.1 dS m⁻¹ (140% Ca), 2.4 dS m⁻¹ (210% Ca) and 2.7 dS m⁻¹ (280% Ca), with the 70% dose being the one that most closely approximated the EC threshold in the soil solution extract and where the highest productivity was obtained (Table 10).

To meet the recommended parameters, as soon as the 70% treatment reached values equal to or higher than those in the literature, fertigation was suspended or, in more critical cases, leaching was carried out, for example, at 120 and 176 DAT (days after transplanting).

Under cultivation conditions, the fruits of the 'Gaston' pepper plant reached the harvest point 60 to 70 days after

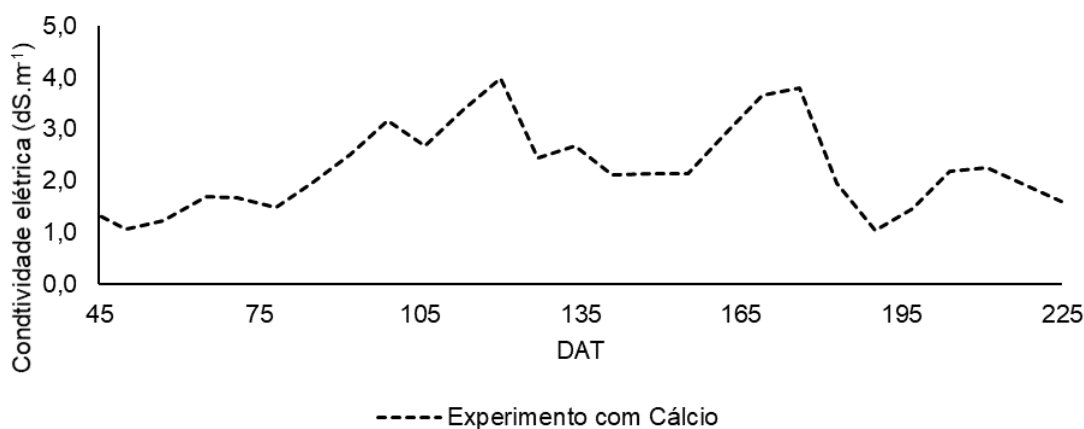
emergence (3 cm in size). Marti and Mills (1991) reported that as hanging fruits approached maturity, nutrient absorption decreased, and consequently, the EC of the soil solution increased because of the accumulation of salts in the soil, as occurred, for example, at 65, 120, and 176 DAT in this experiment.

The effects and importance of leaching are more evident (at 120 and 176 DAT) (Figure 2). Additionally, as a control measure for EC, fertigation was suspended at 99, 120, 134, 169, 176, and 211 DAT. This need for leaching or suspension of fertilizer application was associated with management, since the nutrient absorption curve is a reference according to the plant's development stage, but the needs of the crop

are not always equal to the amount applied, as nutrient demand can vary because of

several factors (Trani; Tivelli; Carrijo, 2011).

Figure 2. Average EC of the soil solution as a function of Ca dose throughout the cycle.



5.2 Soil solution analysis: concentration of specific ions

nutrient for bell pepper crops, and the results of the analysis of this ion in the soil solution are presented in Tables 6, 7, and 8.

Calcium, which is not very mobile within the plant, is the third most in-demand

Table 6. Calcium ions in the soil solution from 43 DAT to 99 DAT

Treatments	43 DAT	50 DAT	57 DAT	65 DAT	71 DAT	78 DAT	85 DAT	92 DAT	99 DAT
Concentration (mg L ⁻¹)									
Ca 70%	173	203	270	393	480	433	393	440	493
Ca 140%	180	290	363	453	633	600	580	633	743
Ca 210%	243	353	477	630	703	687	680	747	920
Ca 280%	263	450	580	757	817	790	760	907	1200
CV (%)	8.1	9.8	4.4	4.1	2.8	2.2	7.6	3.1	5.6
Regression	L *	L *	L *	L *	L *	L *	L *	L *	L *
R2 (%)	91.0	99.4	99.8	96.9	97.9	97.8	95.9	99.0	99.3

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

Table 7. Calcium ions in the soil solution from 106 DAT to 162 DAT

Treatments	106 DAT	113 DAT	120 DAT	127 DAT	134 DAT	141 DAT	148 DAT	155 DAT	162 DAT
Concentration (mg L ⁻¹)									
Ca 70%	477	557	697	423	443	413	443	470	503
Ca 140%	727	850	1067	610	687	667	723	763	817
Ca 210%	897	1100	1500	910	693	937	983	1067	1133
Ca 280%	1133	1533	1933	1203	1233	1167	1233	1333	1400
CV (%)	4.7	6.7	8.7	8.3	35.1	4.6	4.7	5.2	7.1
Regression	L *	L *	L *	L *	L *	L *	L *	L *	L *
R2 (%)	99.5	98.5	99.8	98.9	84.5	99.9	99.9	99.9	99.8

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

Table 8. Calcium ions in the soil solution from 169 DAT to 225 DAT

Treatments	169 DAT	176 DAT	183 DAT	190 DAT	197 DAT	204 DAT	211 DAT	218 DAT	225 DAT
Concentration (mg L ⁻¹)									
Ca 70%	553	637	350	187	210	257	290	277	267
Ca 140%	897	1033	570	280	303	363	410	387	373
Ca 210%	1233	1433	783	460	500	597	667	640	607
Ca 280%	1567	1800	977	530	573	680	763	733	693
CV (%)	4.8	5.9	4.8	7.7	7.1	6.7	6.7	6.7	6.3
Regression	L *	L *	L *	L *	L *	L *	L *	L *	L *
R2 (%)	99.8	99.9	99.9	97.2	96.8	96.6	96.8	96.5	96.7

DAT: days after transplantation; L: linear regression; *: significant at 5% according to the F test.

The dose influenced the concentration of Ca ions in the soil solution throughout the cycle, following a linear trend with increasing dose. On the basis of the data obtained, a calcium concentration of 397 mg L⁻¹ in the soil solution is adequate for pepper plants, since the average calcium content throughout the cycle (397 mg L⁻¹ at 70% Ca, 593 mg L⁻¹ at 140% Ca, 799 mg L⁻¹ at 210% Ca, and 1000 mg L⁻¹ at 280% Ca) was evaluated, and the 70% dose resulted in the highest productivity (Table 10).

No information was found in the literature regarding the ideal concentration

of this nutrient in the soil solution, and the values available in the literature do not consider the same conditions as those used in this research. An important factor when evaluating this nutrient is the depth at which the solution extractor is installed. Because it is highly soluble, calcium chloride is distributed rapidly in water and can be easily leached to the bottom of the container. The vertical “section” of the soil at the end of the experiment is shown in Figure 3, with the porous capsule at a depth of 20 cm, which may explain the high concentrations observed in the readings.

Figure 3. Depth of the solution extractor capsule in the vessel.



The high concentration of Ca in the soil solution may also be related to the increase in EC (due to the doses), which reduced water consumption by the plant and, therefore, Ca absorption, keeping it retained in the soil solution. Another possibility is that the absorption curve used shows values above those required by the 'Gaston' pepper cultivar in a protected environment; thus, even with the suspension of fertigation, it still showed high values in the subsequent reading.

The lowest concentrations were detected in the treatments with 70% (98 kg ha⁻¹ of Ca), and the highest was observed with 280% (392 kg ha⁻¹ of Ca). The concentration peaks at 65, 120, and 176 DAT, as already mentioned in the EC data, are due to the presence of fruits in the final stage of maturation and lower absorption by

the plant and therefore an increase in Ca in the soil solution.

When applied equally across treatments aimed at meeting the nutritional requirements of the plant, K ions did not significantly differ at 5% according to the F test; however, K may have interfered with the accumulation of Ca in the soil solution and EC since the administered dose corresponded to 100% of the absorption curve. On average, the concentration was approximately 207 mg L⁻¹ and followed the trend of the curve.

5.3 Plant height

The results of the plant height analysis as a function of the treatments are shown in Table 9.

Table 9. Average plant height as a function of calcium treatment.

Treatments	62 DAT	93 DAT	123 DAT	154 DAT	185 DAT
Plant height (cm)					
Ca 70%	72.6	76.0	79.5	85.5	90.5
Ca 140%	76.4	79.4	83.0	83.1	88.1
Ca 210%	73.3	77.1	80.3	82.4	87.4
Ca 280%	72.4	76.1	80.3	81.8	86.6
CV (%)	4.3	6.0	6.1	6.2	6.2
Regression	Ns	Ns	Ns	Ns	Ns

DAT - days after transplantation; ns - not significant.

Although no statistically significant difference was observed, it is possible to see that plants subjected to the 140% dose (196 kg ha⁻¹ of Ca) grew more than those in the other treatments did up to 123 DAT (days after transplanting). At 154 DAT and 185 DAT, the greatest increase occurred in the treatment with the 70% dose (98 kg ha⁻¹ of Ca). This behavior may be associated with the accumulation of Ca salts in the soil and an increase in electrical conductivity (EC). Dias and Blanco (2010) reported that this accumulation of salts hinders water absorption by reducing the osmotic potential and directly interferes with plant growth and development.

Similar results were observed by Sousa *et al.* (2019) in an experiment with potassium, where from 123 DAT onward, there was statistical differentiation as a function of the dose, with inversely proportional growth between the 70% (363 kg ha⁻¹ of K₂O) and 280% (1,451 kg ha⁻¹ K₂O) treatments.

5.4 Fruit Production

Among the yield assessments conducted, we highlight the number of fruits per plant and the yield in kg plant⁻¹ and t ha⁻¹. Table 10 presents the yield data according to the application rates.

Table 10. Analysis of the quantity and quality of fruits as a function of the treatments. FPP: fruits per plant; PMF: average fruit weight; PP: production per plant; PH: production in tons per hectare; CMF: average fruit length; L: linear regression;

Treatments	FPP	PMF	PP	pH	TYPE	CMF
	Items.	(g)	(kg)	t ha ⁻¹	-	(mm)
Ca 70%	13.0	147.6	2.0	46.5	6.9	110.7
Ca 140%	12.0	142.1	1.6	38.6	6.9	105.7
Ca 210%	11.0	131.0	1.5	34.1	6.7	101.6
Ca 280%	9.0	127.9	1.1	25.9	6.7	106.1
CV (%)	12.2	13.5	3.5	3.9	5.4	5.6
Regression	L *	ns	L *	L *	Ns	Ns
R2 (%)	89.9	-	99.0	98.7	-	-

*: Significant at the 5% confidence level according to the F test; ns: not significant.

The number of fruits best expressed the plant's response to the variation factors, with the lowest dose showing approximately 13 fruits per plant. The literature shows great variability in bell pepper cultivation (Albuquerque *et al.*, 2011).

Although not statistically significant, a decreasing linear trend in the average fruit weight was observed with increasing Ca dose. With respect to the productivity data per plant and per hectare, the significant difference strongly confirmed the distinction between treatments, with plants subjected to the 70% dose (98 kg ha^{-1} of Ca) being more

productive as predicted by the other analyses.

To evaluate the effects of salinity from fertilizers on pepper plants, Leonardo *et al.* (2007) correlated lower fruit set and average fruit weight with increased EC, with losses between 55% and 58%. A comparison of the production data from the lowest dose revealed that in t ha^{-1} , the losses varied from 30% to 44% with increasing amount of fertilizer and were more severe at the highest dose. The correlation of productivity is easily illustrated in Figures 4 and 5. (t ha^{-1}) as a function of the concentration of Ca and CE ions in the soil.

Figure 4. Correlation of production with the concentration of calcium ions in the soil solution.

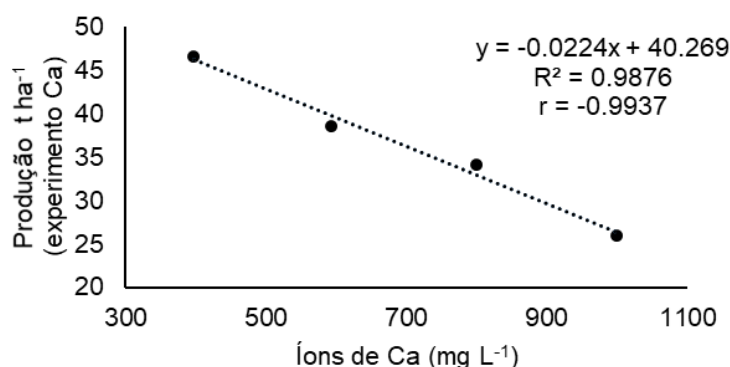
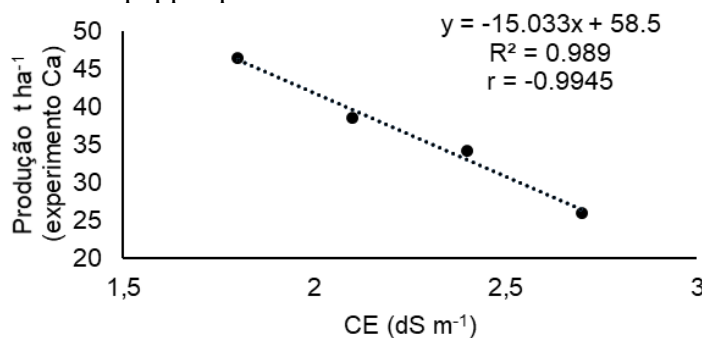


Figure 5. Correlation of bell pepper production with the EC of the soil solution.



According to Silva Júnior *et al.* (2024), in terms of monitoring the concentration of N and K ions and electrical conductivity, fertigation management, together with doses of 75% (1.5 mS cm^{-1}) and 100% (416 mg L^{-1}) N and K (110 mg L^{-1}) in nutrient solution, resulted in the best performance for all the variables analyzed.

There was an almost perfect negative correlation between electrical conductivity and production according to Hopkins' classification (2000); that is, productivity decreases when the EC or the concentration of Ca in mg L^{-1} in the soil solution increases.

This information demonstrates the productive response of the 'Gaston' pepper plant as a function of the EC and Ca ion

concentration and highlights the importance of efficiently monitoring these parameters to achieve success in terms of fertigation in a protected environment.

By combining the production data, it is possible to verify that when a pepper plant is subjected to salinity in the soil solution due to fertilizer, its productive response is affected in terms of the number of fruits per plant and the average fruit weight. In terms of nutritional stress conditions, the maximum productivity was 46.5 t ha^{-1} , which is within the range of 25 t ha^{-1} to 50 t ha^{-1} obtained by Nunes Júnior (2013).

6 CONCLUSIONS

Increased salinity, above the level tolerated by the crop, causes significant production losses.

Monitoring fertigation using soil solution extractors is a viable alternative for pepper cultivation in a protected environment.

The dose that provided the highest fruit production was 98 kg ha^{-1} of Ca, with a value of 46.5 t ha^{-1} , indicating an average electrical conductivity throughout the cycle of 1.8 dS m^{-1} and a concentration of 397 mg L^{-1} in the soil solution extract.

7 ACKNOWLEDGEMENTS

This work is part of the first author's master's thesis (SOUSA, RL), presented to the Postgraduate Program in Agronomy (Irrigation and Drainage) of the Faculty of Agronomic Sciences—São Paulo State University “Júlio de Mesquita Filho”, Botucatu Campus, available at: <http://hdl.handle.net/11449/151566>.

The authors thank the National Council for Scientific and Technological Development (CNPq) for its financial support.

8 REFERENCES

- ALBUQUERQUE, FS; SILVA, EFF; ALBUQUERQUE FILHO, JAC; NUNES, MFFN. Growth and yield of fertigated bell pepper under different irrigation depths and potassium doses. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 15, n. 7, p. 686-694, 2011.
- DE SÁ, AAS; OLIVEIRA, GH de; SILVA, RP da ; ASSIS, VCSS de; OLIVEIRA, C. DA S. de; OLIVEIRA, JA de; BERTI, MP da S. The importance of calcium for plant nutrition: a review. **Scientific Electronic Archives**, Sinop, v. 17, no. 2, p. 30, 2024.
- DIAS, NS; BLANCO, FF. Effect of salts on soil and plants. *In* : GHEYI, HR; DIAS, NS; LACERDA, CF (ed.). **Salinity management in agriculture: basic and applied studies**. Fortaleza: National Institute of Science and Technology in Salinity, 2010. p. 43-61.
- FLORES, RA; ALMEIDA, BF; POLITI, LS; PRADO, RM; BARBOSA, JC. Growth and nutritional disorder in malagueta pepper cultivated in nutrient solutions deprived of macronutrients. **Revista Brasileira de Ciências Agrárias**, Recife, v. 7, n. 1, p. 104-110, 2012.
- HOPKINS, WG **A new view of Statistics : Correlation coefficient**. Auckland: Will G. Hopkins, 2000. Available at: <http://www.sportsci.org/resource/stats/corre1.html>. Accessed on: June 15, 2017.
- LEONARDO, M.; BROETTO, F.; VILLAS BÔAS, RL; ALMEIDA, RS; MARCHESE, JA. Production of bell pepper fruits under different saline concentrations. **Irriga**, Botucatu, v. 12, n. 1, p. 73-82, 2007.

MARCUSSI, FFN; GODOY, LJG; VILLAS BÔAS, RL. Nitrogen and potassium fertigation in bell pepper cultivation based on the accumulation of N and K by the plant. **Irriga**, Botucatu, v. 9, n. 1, p. 41-51, Jan./Apr. 2004.

MARCUSSI, FFN. Use of fertigation and macronutrient levels in bell pepper plants. **Agricultural Engineering**, Jaboticabal, v. 25, n. 3, p. 642-650, Sept./Dec. 2005.

MARTI, HR; MILLS, HA Nutrient uptake and yield of sweet pepper as affected by stage of development and N form. **Journal of Plant Nutrition**, Philadelphia, vol. 14, no. 11, p. 1165-1175, 1991.

NUNES JÚNIOR, ES **Nitrogen and potassium fertigation in bell pepper cultivation in a protected environment**. 2013. Thesis (Doctorate in Agronomy/Phytotechnics) – Federal Rural University of the Semi-Arid Region, Mossoró, 2013.

OLIVEIRA, FA; DUARTE, SN; MEDEIROS, JF; DIAS, NS; SILVA, RCP; LIMA, CJGS. Fertigation management and N and K doses in bell pepper cultivation in a protected environment. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 17, n. 11, p. 1152-1159, Nov. 2013.

OLIVEIRA, FA; DUARTE, SN; MEDEIROS, JF; OLIVEIRA, MKT; SILVA, RCP; SOUZA, MS. Efficiency of nitrogen and potassium fertigation in the production of bell pepper grown in a protected environment. **Revista de Ciências Agrárias**, Belém, v. 59, n. 3, p. 293-301, 2016.

OLIVEIRA, FA; DUARTE, SN; MEDEIROS, JF; DIAS, NS; OLIVEIRA, MKT; SILVA, RCP; LIMA, KS. Mineral nutrition of plants subjected to different

fertigation management. **Revista Horticultura Brasileira**, Brasília, DF, v. 33, n. 2, p. 216-223, 2015.

PALANGANA, FC; SILVA, ES; GOTO, R.; ONO, EO. Joint action of cytokinin, gibberellin and auxin in grafted and nongrafted bell pepper under protected cultivation. **Revista Horticultura Brasileira**, Brasília, DF, v. 30, n. 4, p. 751-755, Oct./Dec. 2012.

SEABRA JUNIOR, S.; CASAGRANDE, JG; TOLEDO, CAL; PONCE, FS; FERREIRA, FS; ZANUZO, MR; DIAMANTE, MS; LIMA, GPP Selection of Thermotolerant Italian tomato cultivars with high fruit yield and nutritional quality for the consumer taste grown under protected cultivation. **Scientia Horticulturae**, Amsterdam, vol. 291, art. 110559, 2022.

SEDIYAMA, MAN; SANTOS, MR; VIDIGAL, SM; PINTO, CLO; JACOB, LL. Nutrition and productivity of colored bell pepper plants fertilized with swine biofertilizer. **Brazilian Journal of Agricultural and Environmental Engineering**, Campina Grande, v. 18, n. 6, p. 588-594, 2014.

SILVA, AO; KLAR, AE; SILVA, EFF. Management of fertigation and soil salinity in the growth of beet crops. **Revista Engenharia Agrícola**, Jaboticabal, v. 35, n. 2, p. 230-241, Mar./Apr. 2015.

SILVA, BA; SILVA, AR da; PAGIUCA, LG Protected cultivation: in search of greater productive efficiency. **Hortifruti Brasil**, Piracicaba, v. 1, p. 10-18, 2014.

SILVA JUNIOR, JJ; SALES, MA de L.; SANT'ANA, JA do V.; VALE, BSC. Use of different fertigation management methods in bell pepper cultivation in a protected environment. **Contributions to**

Las Ciencias Sociales , São José dos Pinhais, v. 17, n. 7, p. 1-19, 2024.

SOUSA, RL; VILLAS BÔAS, RL; MOTA, PRD; MATEUS, CMD; MENDONÇA, RB. Potassium salinization in fertigated bell pepper production under a protected environment. **Irriga** , Botucatu, v. 24, n. 1, p. 177-191, 2019.

TRANI, PE; TIVELLI, SW; CARRIJO, OA. **Fertigation in vegetables** . 2nd ed. rev. updated. Campinas: Instituto Agrônômico, 2011. (APTA Technology Series. IAC Technical Bulletin, 196).

VIEGAS, I de JM; SOUSA, GO; SILVA, AF; CARVALHO, JG de.; LIMA, MM. Mineral composition and visual symptoms of nutrient deficiencies in long pepper

plants (*Piper hispidinervum*) . **Acta Amazônica**, Manaus, vol. 43, no. 1, p. 43-50, 2013.

ZHIGILA, DA; ABDULRAHAMAN, AA; KOLAWOLE, OS; OLADELE, FA Fruit morphology as taxonomic features in five varieties of *Capsicum annuum* L. Solanaceae . **Journal of Botany** , New York, vol. 2014, art. 540868, 2014.

ZIGANSHIN, B.; GALIEV, I.; KHUSAINOV, R.; ABDELFAHATTAH, A. The effect of fertigation on salinization and stability of soil aggregates , taking into account the effectiveness of precipitation on their natural desalination in central Europe . **BIOWeb of Conferences** , Kazan, vol. 27, art. 00119, 2020.