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CONCENTRAÇÃO DE NUTRIENTES NA CULTURA DA ALFACE HIDROPÔNICA TRATADA COM PULSOS ELÉTRICOS DE BAIXA FREQUÊNCIA

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1 RESUMO

O consumidor de hortaliças tem se tornado cada vez mais exigente, exigindo alface de qualidade e em quantidade durante o ano todo. O sistema hidropônico oferece a vantagem de controlar as variáveis envolvidas no desenvolvimento e na nutrição das plantas. Estudos recentes sugerem que a exposição da água de irrigação a pulsos elétricos de baixa frequência pode ter efeitos positivos na produtividade, podendo ocasionar mudanças na absorção de nutrientes. Contudo, são necessários estudos mais aprofundados para confirmar esses efeitos. O objetivo deste trabalho é avaliar a concentração de nutrientes na alface hidropônica cultivada em casa de vegetação, utilizando um sistema eletrônico anti-incrustação. O estudo seguiu um delineamento inteiramente casualizado 3 x 2, com quatro repetições. Foram avaliados dois fatores: a frequência de exposição da solução nutritiva ao sistema eletrônico anti-incrustação (constante, intermitente e sem uso) e duas concentrações de solução nutritiva em dois ciclos de produção. Os resultados indicaram que o uso constante de pulsos elétricos de baixa frequência não trouxe vantagens significativas na absorção de nutrientes em comparação com a produção convencional de alface hidropônica. No entanto, a aplicação intermitente desses pulsos elétricos na solução 80 mostrou diferenças na absorção de nutrientes como nitrogênio (N), fósforo (P), potássio (K) e zinco (Zn) pela cultura.

Palavras-chave: Anti-incrustacão, sustentabilidade, tecnologia, hortaliças.

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NUTRIENT CONCENTRATION IN HYDROPONIC LETTUCE CULTURE TREATED WITH LOW FREQUENCY ELECTRICAL PULSES

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2 ABSTRACT

Consumers of leafy vegetables have become increasingly demanding, with high-quality lettuce being sought in adequate quantities throughout the year. The hydroponic system offers the advantage of controlling the variables involved in plant development and nutrition. Recent studies suggest that exposing irrigation water to low-frequency electrical pulses may have positive effects on productivity, potentially altering nutrient absorption. However, more detailed studies are needed to confirm these effects. The aim of this study was to evaluate the nutrient concentration in hydroponic lettuce grown in a greenhouse via an antiscaling electronic system. The study employed a completely randomized design of 3 × 2, with four replications. Two factors were assessed: the frequency of exposure of the nutrient solution to the antiscaling electronic system (constant, intermittent, and no use) and two concentrations of nutrient solution over two production cycles. The results indicated that the constant use of low-frequency electric pulses did not result in significant advantages in terms of nutrient absorption over conventional hydroponic lettuce production. However, intermittent application of these electric pulses in solution 80 resulted in differences in the absorption of nutrients such as nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) by the crop.

Keywords: Anti-binding, sustainability, technology, vegetables.

3 INTRODUCTION

The constant increase in population demands greater sustainable food production. Advances in irrigation techniques, pest and disease management and fertilization have contributed to increased productivity in crops of agronomic interest, such as vegetables (Instituto d e Economia Agrícola, 2020).

The production of leafy vegetables, such as lettuce (*Lactuca sativa* L.), stands out as one of the most consumed vegetables in natura and is generally cultivated by small-scale producers, with economic and social importance (Mitova *et al.*, 2017).

Vegetable consumers demand a supply of quality and quantity throughout the year (Martinez; Martins; Feiden, 2016). In this context, hydroponic production has gained relevance, showing yields equal to or greater than those of conventional production. Although this technique requires greater complexity in management, it has expanded in the vicinity of large consumer centers (Furlani *et al.*, 1999, 2009; Al-Ogaidi *et al.*, 2017; Al-Tawaha *et al.*, 2018).

To maximize the genetic potential of crops, complementary techniques have been tested to optimize development with lower production costs. Reports indicate that the use of electronic anti-fouling systems, which emit low-frequency electrical pulses into irrigation water, can benefit crop productivity (Surendran; Sandeep; Joseph, 2016; Chibowski; Szczes, 2018; Olaya Tellez, *et al.,* 2023).

The treatment of irrigation water, without chemicals and with low-frequency electrical pulses (3–32 kHz), alters the crystallization of calcium in hard water, causing the particles to lose their ability to adhere to the plumbing systems. This can improve the solubility of nutrients in nutrient solutions (Mercier *et al.*, 2016; Piyadasa *et al.*, 2017, 2018). This technique can help reduce microbial proliferation and algae formation, in addition to making nutrients available to roots that are insoluble, increasing productivity. However, studies detailing the production of lettuce treated with low-frequency electrical pulses are lacking (Piyadasa *et al.*, 2018; Xiao *et al.*, 2020).

The ideal conditions for lettuce development include temperatures below 25°C, with better productivity in the cold seasons of the year, when consumer demand is lower. Therefore, new cultivation techniques that provide greater efficiency in the summer are essential, such as hydroponic production in a protected environment, which allows control of environmental and cultivation conditions (Martinez; Martins; Feiden, 2016).

The ideal composition of the nutrient mixture for hydroponic production involves a balance between macro- and micronutrients, in addition to helping to control factors that influence plant development, such as production time, phenological stage and cultivar used (Furlani *et al*., 1999; Soares *et al*., 2020).

The advantages of using a hydroponic system are related to the detailed control of plant development conditions, allowing monitoring of the factors that most influence plant growth. In this sense, the present study aims to evaluate the concentration of nutrients in hydroponic lettuce in a greenhouse via an electronic anti-fouling system.

4 MATERIALS AND METHODS

The experiment was developed in the experimental area of the Department of Forestry, Soil and Environmental Science of the School of Agricultural Sciences, São Paulo State University “Júlio de Mesquita Filho” (UNESP), in the city of Botucatu-SP, located at coordinates 22° 51' 03" South latitude and 48° 25' 37" West longitude. According to the Köppen classification, the climate is a type Cfa-humid warm temperate climate, with the average temperature of the hottest month above 22°C and an average altitude of 780 m (Cunha; Martins, 2009).

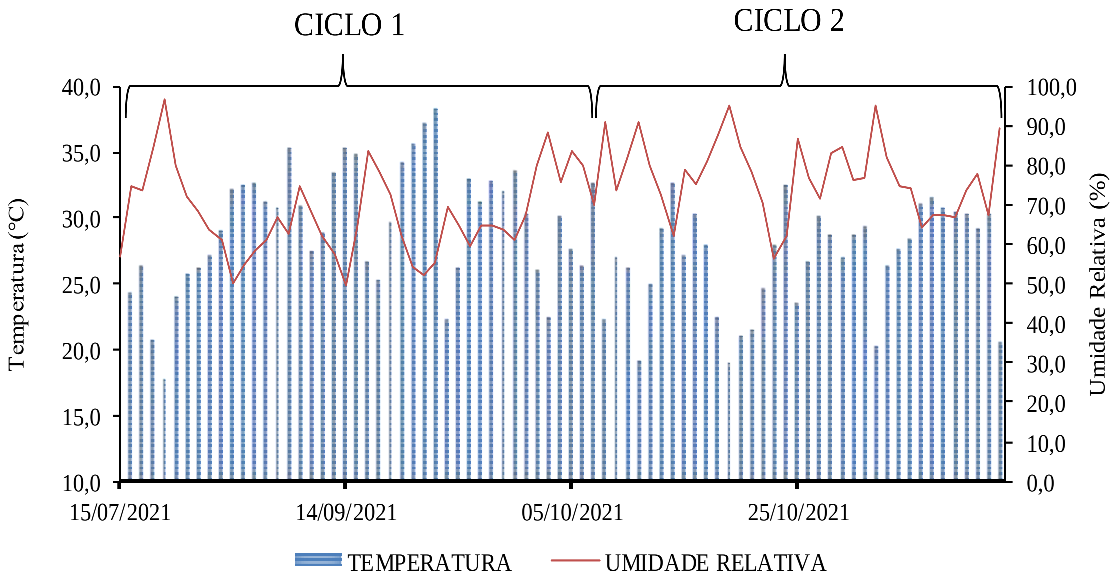
4.1 Experimental design

A completely randomized 3 × 2 design with four replicates was used. The factors evaluated were the frequency of exposure of irrigation water to the electronic anti-scaling system (constant, intermittent and without use) and two levels of nutrient solution (100% and 80% of the recommendation in Furlani *et al*.). (1999)), applied in two production cycles.

4.2 Hydroponic system

The system was installed in a greenhouse measuring 24 × 7 meters in length and width and 3.8 meters at its highest point, covered with 150-micron plastic film. Temperature control was performed by opening two windows when the internal temperature exceeded 25°C. Luminosity was regulated with an Aluminet 50% screen installed 2 m above the hydroponic system benches. The temperature and relative humidity conditions inside the greenhouse are shown in Figure 1.

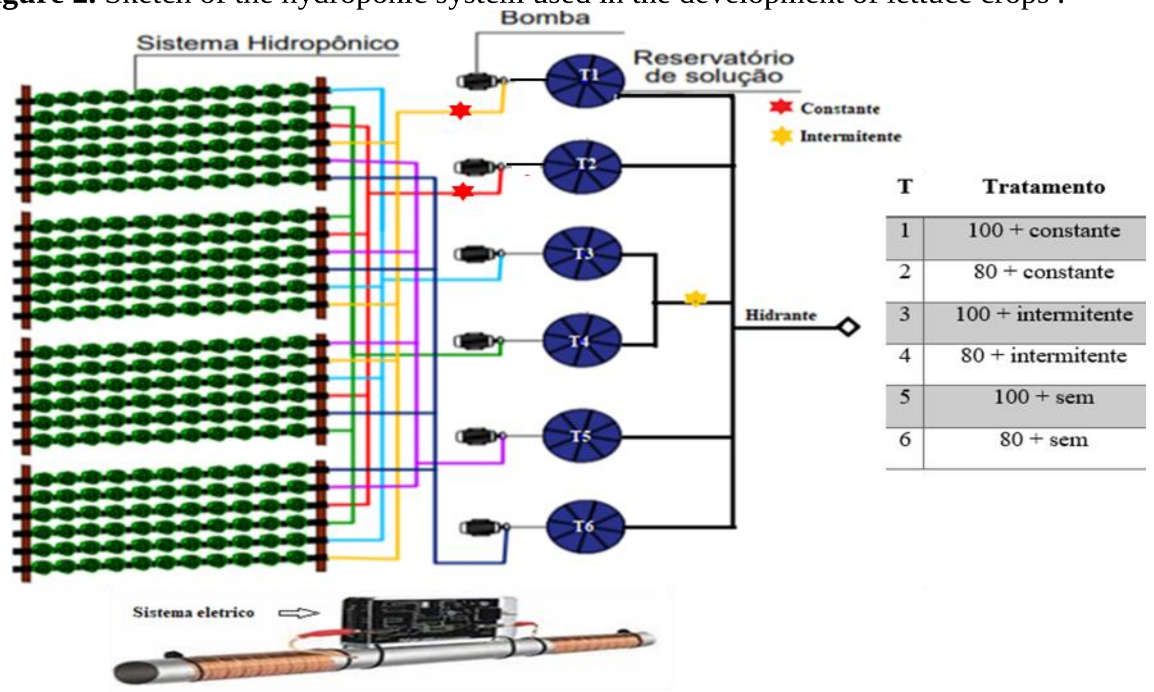
Figure 1. Temperature and relative humidity conditions inside the greenhouse throughout the experiment.



Source: Authors (2024)

The laminar nutrient flow (NFT) technique was used in the hydroponic system, which had four benches with a 5% slope (Figure 2). Each bench had an initial height of 1.10 m and a final height of 0.80 m, was 1.2 m wide and was spaced 0.70 m apart. They were composed of six 6 m PVC profiles each (treatments), with a spacing of 0.20 m between them and 24 openings 0.05 m in diameter for transplanting seedlings.

Figure 2. Sketch of the hydroponic system used in the development of lettuce crops .



Source: Olaya Tellez *et al.* (2023)

The nutrient solution was stored in 500-liter tanks for each treatment, with individuals returning through a closed system. The solution was pumped with a 0.5 hp Ferrari peripheral motor pump for each tank. An electromechanical *timer was* used to activate the pump every 15 minutes from 6:00 a.m. to 6:00 p.m. and for 15 minutes every hour from 6:00 p.m. to 6:00 a.m., with a flow rate ranging from 1.5 to 2.0 l/min.

The nutrient mixture used followed the recommendations of Furlani *et al*. (1999), which indicates the use of 187 mg/L N, 72 mg/L P, 220 mg/L K, 143 mg/L Ca, 38 mg/L Mg, 52 mg/L S, 0.45 mg/L B, 0.45 mg/L Cu, 1.81 mg/L Fe, 0.45 mg/L Mn, 0.18 mg/L Zn and 0.09 mg/L Mo. These recommendations were adjusted to dosages of 80% and 100% of the recommended value in the treatments, referred to as solution 80 and solution 100, respectively. When the temperature exceeded 25°C, the solutions were diluted by 20%, and the proportions were maintained.

The treatments of the nutrient solution with the electronic antiscaling system, which emits low-frequency electrical pulses, were divided into two categories: constant and intermittent. In the constant treatment, the water in the nutrient solution was constantly exposed to low-frequency electrical pulses, whereas in the intermittent treatment, the water in the nutrient solution was exposed only during the filling of the reservoirs, when the solution was changed, which occurred every 8 days. The other treatments involved no exposure, and the same concentrations of nutrient mixture were maintained.

The initial development of lettuce seedlings occurred in phenolic foam in a protected environment for 30 days. When the seedlings had 5 to 7 leaves and good uniformity, they were transplanted to the hydroponic system.

4.3 Reviews

In each cycle, 24 days after transplanting (DAT), four plants per treatment were collected, duly identified and processed in the Laboratory of the Faculty of Agricultural Sciences of UNESP. Each plant was washed three times individually with distilled water and dried in a manual food centrifuge to eliminate residues and impurities on the surface of the leaves.

The material was placed in individual paper bags and dried in a forced air circulation oven at 65°C until it reached a constant weight within approximately 72 hours. The dry mass was subsequently ground in a Willey-type mill and taken to the laboratory of the Department of Soils and Environmental Resources, FCA/UNESP, Botucatu, SP, for determination of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese and zinc contents, according to the methodology of Malavolta, Vitti and Oliveira. (1997).

4.4 Statistical analysis

The data were subjected to the Anderson–Darling normality test and homoscedasticity (homogeneity of variances) via the Hartley test, in addition to analysis of variance, with a significance level of 5% probability of error. When significant, the means were compared via the Tukey test at 5% significance, with the aid of the statistical program R (version 4.1.2). The graphs were prepared via the SigmaPlot program (version 14.0).

5 RESULTS AND DISCUSSION

5.1 Chemical analysis

The nutrients calcium, boron and manganese responded differently to frequency and solution factors. In contrast, the nutrients nitrogen, phosphorus, potassium, sulfur, copper and zinc significantly affected the interaction between frequency and solution. The levels of magnesium and iron were not different. The average concentrations of macro- and micronutrients used in the production of lettuce in a hydroponic system, which was fed water treated with low-frequency electrical pulses in two nutrient solutions, are presented in Table 1.

Table 1. Summary of analysis of variance, mean values and standard deviations of macro- and micronutrient concentrations in lettuce crops in a hydroponic system fed water treated with low-frequency electrical pulses

Source of variation		N	P	K	Here	Mg	S
Freq.		0.002	0.30	0.003	0.176	0.09	0.049
Solution		0.96	0.01	0.00 4	0.02	0.14	0.684
Freq. x Solution		0.004	0.01	0.002	0.211	0.75	0.023
Freq.	Const.	37.66a	5.71	54.18b	11.67	3.47	2.79ab
	Inter.	37.07a	5.97	72.19a	10.97	3.2	2.45b
	Without	35.73b	5.76	75.43a	10.71	3.15	2.88a
Solution	80	36.8±1.4	6.0±0.4a	75.0±19.4a	11.6±0.7a	3.2±0.3	2.7±0.4
	100	36.8±2.3	5.6±0.4b	59.5±5.3b	10.6±1.2b	3.4±0.3	2.7±0.3
		B	**Ass**	**Faith**	**Mn**	**Zn**	
Freq.		0.16	0.02	0.24	0.011	0.018	
Solution		0.003	0.56	0.62	0.009	0.001	
Freq. x Solution		0.36	0.002	0.33	0.12	0.0006	
Freq.	Const.	30.45	11.72a	106.93	51.67b	55.15	
	Inter.	29.19	9.53b	110.41	62.69a	64.18	
	Without	26.75	9.43b	122.2	65.48a	65.44	
Solution	80	26.1±3.6b	10.4±1.5	115.0±20.1	65.0±13.3a	68.8±12.6a	
	100	31.4±4.4a	10.0±3.2	111.3±22.4	54.9±5.1b	54.3±5.8b	

Freq. : frequency; Const. : Constant; Inter. : Intermittent: different letters indicate significant differences

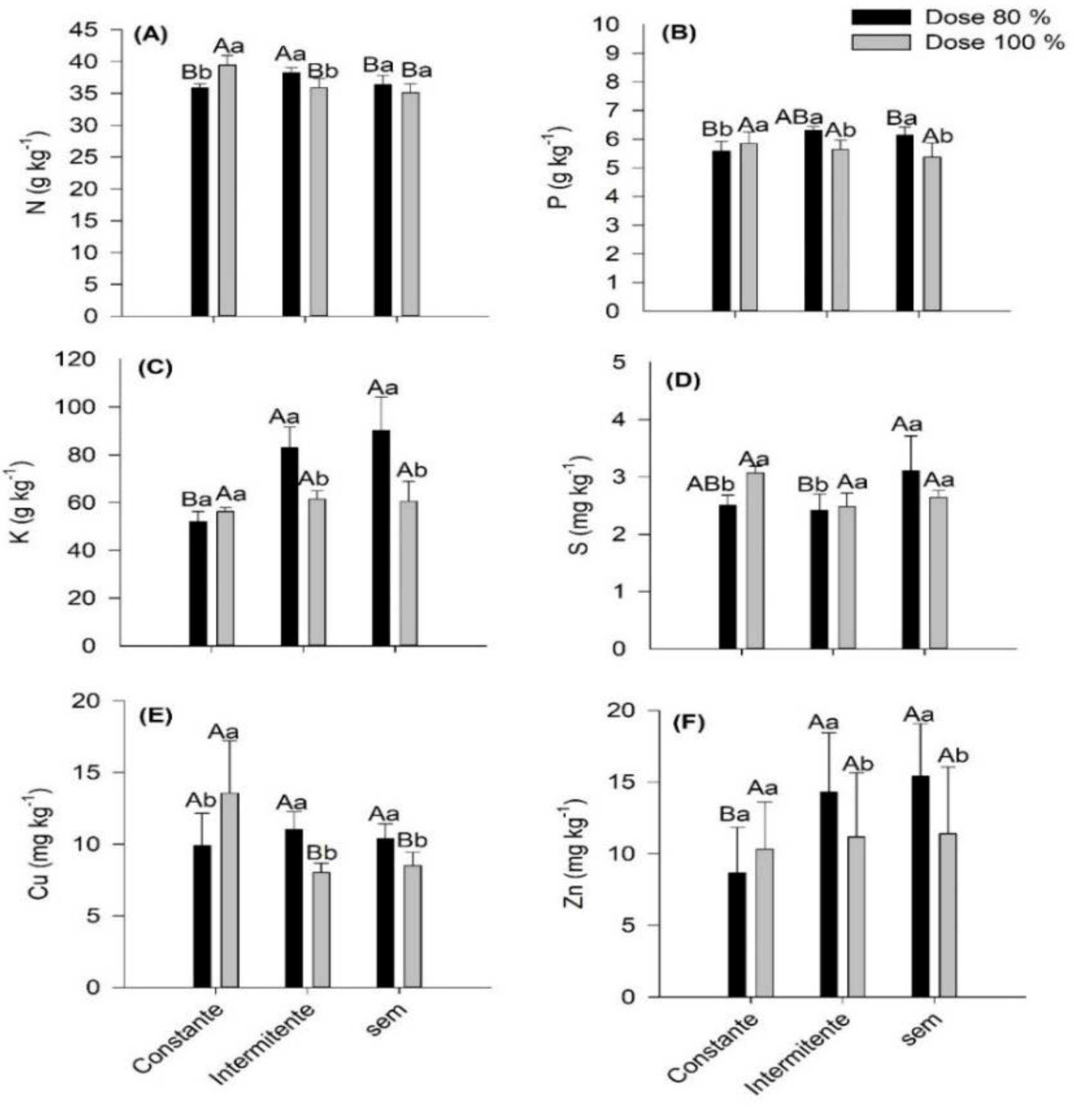
The constant frequency of use of low-frequency electrical pulses resulted in the lowest foliar concentrations of potassium and manganese. There was no significant difference between the constant and intermittent frequencies in terms of the nitrogen and sulfur concentrations, whereas the constant frequency had a greater effect on the copper concentration. The nutrients phosphorus, calcium, magnesium, boron, iron and zinc did not significantly differ in response to the frequency of hydroponic lettuce production (Table 1).

The use of nutrient solutions in lettuce production in the NFT system significantly differed, with 80% solution being preferable to that recommended by Furlani *et al*. (1999) with respect to the nutrients phosphorus, potassium, calcium, manganese and zinc. For the 100% solution, only an increase in the concentration of the nutrient boron was observed.

The constant use of low-frequency electrical pulses in the hydroponic lettuce nutrient solution resulted in a reduction in the concentration of the nutrients potassium and manganese compared with intermittent exposure and the absence of the use of technology. According to Fontana *et al*. (2018), the techniques used in lettuce production can influence its development as significantly as fertilization, considering that external factors such as the environment, cultivar and agronomic management affect productivity.

The concentrations of macronutrients and some micronutrients in lettuce crops in a hydroponic system, which were fed water treated continuously and intermittently with low-frequency electrical pulses, are shown in Figure 3.

Figure 3. Average values of nutritional variables in the interaction between solution and frequency of water treatment with low-frequency pulses in hydroponic lettuce crops.



Capital letters indicate significant differences between treatments (constant, intermittent and without) within the same graph, whereas lowercase letters represent differences within the same treatment. Source: Authors (2024)

The nitrogen concentration (Figure 3A) at the intermittent frequency showed an average increase of 8.4% in relation to the constant frequency and the absence of electrical pulses in solution 80. For solution 100, the constant frequency increased by 10.3% compared with those of the other treatments. Significant differences between the nutrient solution levels were observed, favoring an intermittent frequency of 6.3% in solution 80.

With respect to phosphorus (Figure 3B), no differences were found between the frequencies in solution 100. However, in solution 80, the intermittent frequency showed an average increase of 6.8% compared with the treatments without use and with constant frequency. Differences between the levels of nutrient solution were also observed in solution 80, which favored the intermittent frequency and the frequency without the use of low-frequency electrical pulses by 9.6% and 13%, respectively.

These results indicate that intermittent exposure to nutrient solutions results in differences in nitrogen (N) and phosphorus (P) uptake in hydroponic lettuce treated with low-frequency electrical pulses in solution 80. According to Taiz *et al.* (2017), N and P are two of the nutrients required for plant development. Abobatta (2019) and Putti *et al*. (2023) reported improvements in nutrient uptake efficiency via magnetism and electromagnetism, which are technologies similar to those employed in this study.

Martinez, Martins and Feiden (2016) reported relatively high N and P concentrations in hydroponic culture. The use of technologies similar to low-frequency pulses, such as magnetism and electromagnetism, can modify properties such as the surface tension of water and its solubility, benefiting the absorption of nutrients by the roots and thus increasing their concentration in the aerial part (Wang; Wei; Li, 2018; Pradela *et al.*, 2018; Al-Tawaha *et al.*, 2018; Lemos *et al.*, 2021; Putti *et al.*, 2022; 2023).

Compared with the no-use and intermittent treatments, the constant-frequency treatments resulted in mean reductions of 39.7% for potassium and 46% for zinc in solution 80 (Figures 3C and F, respectively). In solution 100, there were no significant differences between the treatments. The mean reductions in foliar K and Zn concentrations in solution 80 were 23% and 31.5% for the intermittent and no-use treatments, respectively, compared with those in solution 100.

For sulfur (Figure 3D), solution 80 without use resulted in an average increase of 23% compared with the other treatments. In solution 100, the intermittent frequency decreased by 19.2% compared with that in the constant and unused treatments. Nutrient solution levels were greater in solution 80 without the application of low-frequency electrical pulses.

Copper (Figure 3E) did not significantly differ between the treatments evaluated. The constant frequency provided an average increase in the solutions of 46% in relation to the intermittent frequency and no use. Differences between the levels of nutrient solution were found in favor of intermittent frequency and no use, with values on the order of 36% and 30% in solution 80, respectively.

The exposure of hydroponic lettuce crops to low-frequency electrical pulses altered the absorption of K, Zn, S, and Cu. Intermittent use resulted in increases in the concentrations of K, Cu, and Zn, even at the lowest concentration of the solution, which may reduce the need for fertilization, benefiting the end consumer, as suggested by Putti *et al*. (2023). Lemos *et al*. (2021) reported a reduction in nutrient absorption with the constant use of a magnetic system.

The positive effects on plant development associated with the use of magnetism and electromagnetism can be attributed to changes in nutrient uptake in the hydroponic system (Martinez; Martins; Feiden, 2016; Al-Ogaidi *et al.,* 2017; Liu *et al.,* 2019; Abobatta, 2019). The use of low-frequency electrical pulses improves the solubility of compounds such as $CaCO_3$ and Fe, increasing their availability to plants (Piyadasa *et al*., 2017, 2018; Xiao *et al*., 2020; Mendonça, 2022). Elements such as Zn and Cu influence RNA synthesis and control plant transpiration (Taiz *et al*., 2017).

6 CONCLUSION

The constant use of low-frequency electrical pulses did not result in significant advantages in terms of nutrient absorption over conventional hydroponic lettuce production. In contrast, intermittent application in solution 80 resulted in differences in the absorption of N, P, K and Zn by hydroponic lettuce crops in the NFT system. However, the response of other crops to this technology under different soil and climate conditions requires further investigation to assess its technical and economic feasibility.

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