

DEVELOPMENT OF LETTUCE (*Lactuca sativa*) IN HYDROPONICS TREATED WITH LOW FREQUENCY ELECTRIC PULSES ¹

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1 RESUMO

Novas tecnologias têm incrementado a produção agrícola no mundo e as hortaliças folhosas, como a alface, ganham destaque comercial no Brasil por ser as mais consumidas *in natura*. Métodos como a hidroponia, elevam a produtividade graças a seu nível de tecnificação, mas ainda podem ser aprimorados. Existem trabalhos e relatos que indicam que a aplicação de pulsos elétricos de baixa frequência potencializa a produtividade das culturas por isso é necessário realizar estudos detalhados. Nesse sentido, o presente trabalho tem como objetivo avaliar a influência no desenvolvimento da alface hidropônica em casa de vegetação utilizando um sistema eletrônico anti-incrustação. Utilizou-se o delineamento inteiramente casualizado, em esquema fatorial com parcelas sub-subdivididas 3x2x3, com quatro repetições. Os fatores avaliados foram frequência do uso do sistema eletrônico (constante, intermitente e sem uso), dois níveis de fertilização de 80% e 100% da solução recomendada por Furlani *et al.* (1999) e três ciclos de produção. O uso de pulsos elétricos de baixa frequência constante resultou em menores médias para as variáveis de crescimento. Dosagem nível de fertilização de 80% promoveu os melhores resultados em condições de estresse por temperatura, e o tratamento da água de irrigação com pulsos elétricos de forma intermitente propiciou resultados similares ao tratamento convencional na cultura de alface hidropônica.

Palavras-chave: nft; produção; tecnologia; irrigação

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2 ABSTRACT

New technologies have increased agricultural production worldwide, and leafy vegetables, such as lettuce, have gained commercial prominence in Brazil because they are the most consumed fresh. Methods such as hydroponics raise productivity thanks to their technification level but can still be improved. There are works and reports that indicate that the application of low-frequency electrical pulses enhances culture productivity, so it is necessary to perform detailed studies. In this sense, the present work aims to evaluate the influence on the development of hydroponic lettuce at a vegetation house using an anti-inconstation electronic system. The entirely randomized design was used in a factorial scheme with 3x2x3 subsubdididids with four repetitions. The factors evaluated were frequency of the use of the electronic system (constant, intermittent and unused), two fertilization levels of 80% and 100% of the recommended solution by Furlani *et al.* (1999) and three production cycles. The use of constant low-frequency electrical pulses resulted in lower averages for growth variables. A dosage fertilization level of 80% promoted the best results under stress conditions per temperature, and the treatment of intermittent electrical pulsed irrigation water provided results similar to conventional treatment in hydroponic lettuce culture.

Keywords: nft, production, technology, irrigation.

3 INTRODUCTION

Population growth requires greater technological implementation in agriculture, which can guarantee the quantity and quality of food demanded. New technologies have increased agricultural production in crops such as soybeans, corn, sugarcane and some vegetables, favoring supply in large cities and countries such as Brazil (IEA, 2020).

Among the most commercially prominent leafy vegetables in Brazil and the world, lettuce (*Lactuca sativa* L.) is one of the most consumed *fresh*, having great economic and social importance, as it is mostly cultivated by small producers (MITOVA *et al.*, 2017).

The ideal temperature for lettuce development varies from 15 to 25 °C, and higher temperatures can stimulate premature bolting due to stress (XAVIER *et al.*, 2021;

MAGALHÃES *et al.*, 2010) as well as a high flow rate above 3 l/me (AL-TAWAHA *et al.*, 2018), reducing its quality.

Alternative methods to conventional production, such as hydroponics, stand out due to their level of technology and productivity with sanitary quality and yield equal to or greater than those obtained conventionally (FURLANI *et al.*, 1999; AL-TAWAHA *et al.*, 2018). As the hydroponic method is improved, new techniques are being tested to allow for better results in crops.

There are some studies and reports that indicate improvements in productivity when treated water is used in crop development with an electronic anti-scaling system, which consists of treating water without the application of chemicals. The application of low-frequency electrical pulses alters the calcium crystallization

process in hard water, causing the particles to lose their ability to attach to surfaces and helping to reorganize water molecules (CHIBOWSKI; SZCZES, 2018; MERCIER *et al.*, 2016; PIYADASA *et al.*, 2017).

It has also been reported that the use of this technique has an impact on microbial control and the formation of algae on the surfaces of pipes, in addition to making available nutrients that are insoluble compounds, which can favor an increase in crop productivity. There is still no work in the literature on its impact on biotic or abiotic stress conditions in plants (XIAO *et al.*, 2020).

The hydroponic system allows detailed monitoring of plant development and reduces environmental interference when conducted in a greenhouse. Despite positive testimonials and reports on the impact of the electronic anti-fouling system on crop development, more detailed studies need to be carried out.

In this sense, the present work aimed to evaluate the influence on the development of hydroponic lettuce in a greenhouse using an electronic anti-fouling system in the conditions of Botucatu - SP.

4 MATERIAL AND METHODS

4.1 Location of the experimental area

The experiment was conducted in the experimental area of the Department of Forestry, Soil and Environmental Science of the Faculty of Agricultural Sciences, Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), municipality of

Botucatu-SP, located at coordinates 22° 51' 03" South latitude and 48° 25' 37" West longitude. According to the Köppen classification, the region's climate is a type Cfa-humid warm temperate (mesothermal) climate, and the average temperature of the hottest month is above 25°C and an average altitude of 780 m. The average annual rainfall is 945.15 mm (CUNHA; MARTINS, 2009).

4.2 Experimental design

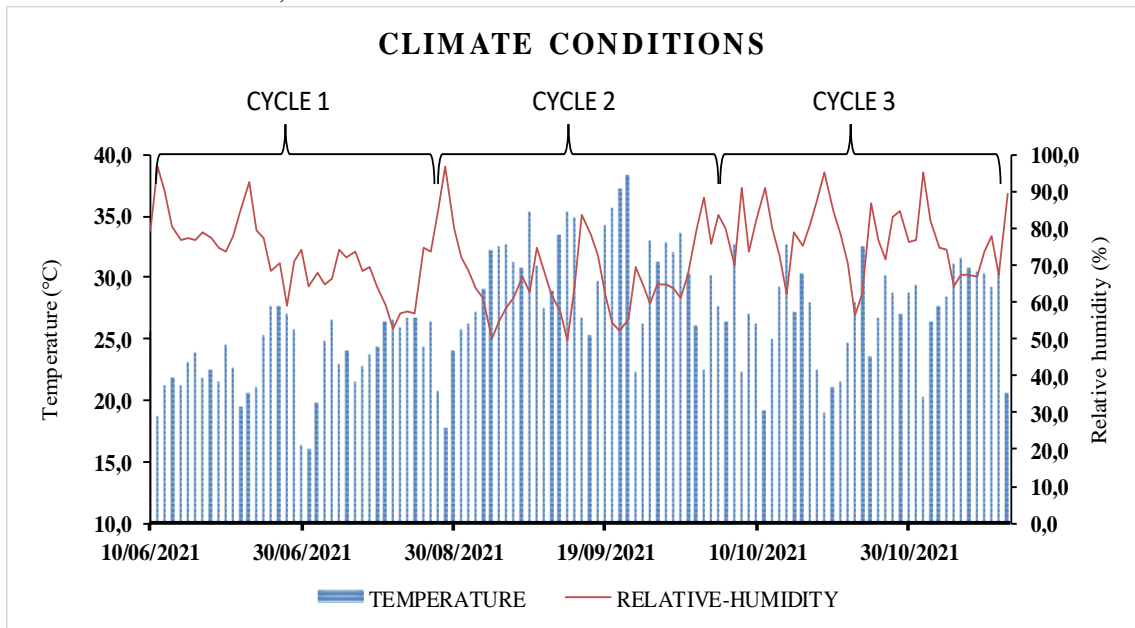
A completely randomized design was used in a factorial scheme with 3x2x3 subdivided plots, with four replications. The factors evaluated were the frequency of use of the electronic anti-fouling system: constant, intermittent and without use; two levels of fertilization: 100% and 80% of the solution recommended by Furlani *et al.* (1999); and three production cycles.

4.3 Hydroponic system

The greenhouse used is 24 meters long and 7 meters wide and has a ceiling height of 2.5 meters and a height of 3.8 meters at the highest part. Its cover is made of 150 micron plastic film with 2 upper windows. To control the temperature, the lanterns were opened daily when the temperature reached 25°C. The light was controlled with a 50% Aluminet® Screen installed 2 meters high over the hydroponic system.

The air temperature and relative humidity (RH%) inside the greenhouse are represented in Figure 1.

Figure 1. Behavior of relative humidity and temperature over three experimental cycles. Botucatu SP, 2021.

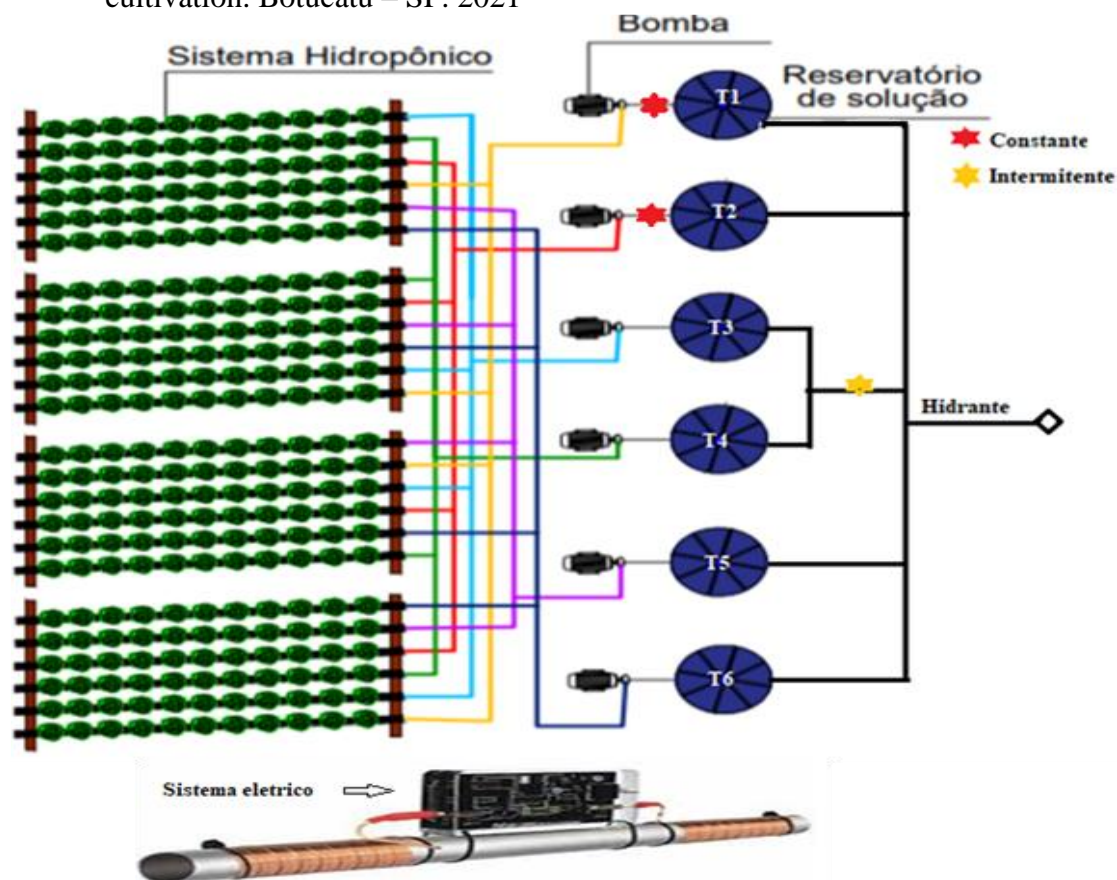


Source: Authors (2023)

The hydroponic system has four benches (repetition) with a 5% slope and is supported by 5 easels spaced 1.40 m apart: the first easel is 1.10 m and the last 0.80 m high. Each bench is 1.2 m wide and spaced 70 centimeters apart. Six hydroponic profiles (treatments) were installed on each

bench, each 6 meters long and spaced 20 cm apart. Each profile is made up of a 60 mm PVC tube with 24 holes 5 centimeters in diameter. The 20 central plants were considered useful portions. The hydroponic system scheme is shown in Figure 2.

Figure 2. Schematic of the design of the hydroponic system used in the development of lettuce cultivation. Botucatu – SP. 2021



Source: Author (2023)

The nutrient solution used per treatment was stored in 500 liter reservoirs and duly measured. Irrigation of the crop from the reservoir was carried out using 25 mm polypropylene piping at the entrance to the hydroponic profile. The return of the nutrient solution from the cultivation channels to the reservoirs was carried out by gravity with the help of 40 mm polypropylene tubing fixed at the end of the hydroponic profile for treatment to its corresponding reservoir.

The nutrient solution pumping system was carried out by a 0.5 hp FERRARI® peripheral motor pump in each reservoir or treatment, controlled by an electromechanical *timer* programmed to remain on for 15 minutes and off for 15 minutes, from 6:00 am to 6:00 pm: 00 hours and 5 minutes every hour from 18:00 to 6:00

with a flow rate between 1.5 and 2.0 L per minute.

The nutrient solution used was based on the recommendation of Furlani *et al.* (1999) with dosages of 80% and 100%, now called 80 and 100. In cultivation cycles with high temperatures, the solution was diluted by 20%, maintaining the proportions.

The exposure of the nutrient solution to the electronic anti-scaling system or low-frequency electrical pulses (3 – 32 kHz) was constant and intermittent, with constant exposure being maintained throughout the crop cycle and intermittent exposure to water only during the period of filling the reservoirs, repeating the process with each change in nutrient solution. The other treatments had no exposure to the system and maintained nutritious doses.

The lettuce seedlings were produced in phenolic foam in a protected environment

for a period of 30 days until they had 5 to 7 true leaves and were uniform; then, they were transferred to the hydroponic system.

4.4 Reviews

At 24 days after transplantation (DAT), 4 plants were collected per plot, duly identified and transported in plastic trays. The collection consisted of leaving one plant at the beginning and one at the end of each bench as a border effect and collecting the next four plants in planting order, alternating the end of the bench with each new collection. The border effect was maintained throughout the cycle.

The variables analyzed were number of leaves, fresh mass of the root and aerial part with the aid of a precision scale (0.01 g), dry mass of the root and aerial part, obtained using a forced air circulation oven at a temperature of 65°C until reaching a constant weight for approximately 72 hours and subsequently determined using a precision scale (0.01 g).

Chlorophyll was measured between 7 and 10 am in the leaf with the highest photosynthetic activity using two different technologies. The first with a portable electronic plant green color intensity meter (SPAD), model Digital SPAD 502 (Minolta Camera Co. Ltda), with four measurements being taken on each leaf, two on the left side and two on the right side of the leaf blade and taking the average. The second used the portable chlorophyll meter CM1000 Chlorophyll meter (Spectrum Technologies, Inc.) Four measurements were taken on the crown of each plant, locating the lasers on the leaves with a distance of 1 m between the plant and the equipment. Regions with

secondary veins were avoided.

Spectrophotometry was carried out by collecting samples from each treatment at the beginning of the preparation of the solution in glass bottles properly closed and exposed to the sun between each change of the solution. The samples were analyzed at wavelength 430 on a 600 plus spectrophotometer in transmittance mode with the aim of verifying the formation of algae.

4.5 Statistical analysis

In each experiment, the normality of the data was initially checked using the Anderson–Darling test, and subsequent homoscedasticity (homogeneity of variances) was checked using the Hartley test. The data were subjected to analysis of variance, with significance levels of 5% probability of error. When significant, the means were submitted to the Tukey test at 5% significance using the statistical program R (version 4.1.2). The graphs were produced using the SigmaPlot program (version 14.0).

5 RESULTS AND DISCUSSION

5.1 Biometric analyses

The variables number of leaves, fresh and dry mass of the root and aerial parts responded to the interaction between frequency and dose factors, frequency and cycle, and dose and culture cycle. However, the variables shoot dry mass, SPAD and chlorophyll index had no interaction between the dose, cycle and frequency factors, as shown in Table 1.

Table 1. Summary of the analysis of variance for the variables number of leaves, fresh and dry mass of roots and shoots and the SPAD index, chlorophyll and spectrophotometry of lettuce treated with low-frequency electrical pulses in a hydroponic system, Botucatu, São Paulo. 2021

Source of variation	Freq.	Doses	Cycles	Freq. X Dose	Freq. X Cycles	Doses X Cycles	Doses X Cycles X Freq.
Biometrics	Mean square (p < 0.05)						
N. Leaves	0.401	0.007	<0.0001	0.007	0.113	0.0015	0.03
MF.	0.381	0.003	<0.0001	0.0003	0.002	0.041	0.040
Source							
MS.	0.230	0.027	<0.0001	0.02	0.30	0.01	0.04
Source							
MF. Pa	0.234	0.0002	<0.0001	0.0001	<0.0001	0.0005	0.017
MS Pa	0.357	0.004	<0.0001	0.004	<0.0001	0.003	0.103
SPAD	0.126	0.20	<0.0001	0.801	0.007	0.03	0.109
IC	0.142	0.809	<0.001	0.004	0.180	0.10	0.275

MF: Fresh pasta. MS: Dry pasta. Pa: Aerial part. CI: Chlorophyll index.

Source: Authors (2023)

The average values of the biometric variables in the lettuce crop are shown in Table 2.

The interaction in the constant frequency of application of low-frequency electrical pulses showed a reduction in the number of leaves and fresh and dry mass of the aerial part.

Dosage 80 showed better performance in the variables of fresh and dry mass of roots and shoots in general.

Cycle 3 obtained the best results, followed by cycle 1 for the variables dry and fresh mass of roots and shoots. The best SPAD performance was presented in cycle 3, followed by cycle 2. Cycles 2 and 3 showed better results for the number of leaves. The chlorophyll index and spectrophotometry showed no differences for any interaction of frequency, dose and cycle.

Table 2. Mean values and standard deviation of lettuce vegetative growth variables treated with low-frequency electrical pulses in a hydroponic system, Botucatu, São Paulo. 2021

Source of variation		N. Leaves	MF. Source	MS. Source	MF. Shovel
Freq.	Constant	24.93±4.32b	37.24±12.9	1.98±0.66	174.4±76.3b
	Intermittent	27.98±5.49 a	41.83±13.56	2.42±0.81	268.4±109 a
	Sem	27.58±6.04 a	45.57±14.36	2.41±0.64	270.2±110.9 a
Doses	80	27.57±6.22 a	44.26±14.37 a	2.38±0.72 a	258.9±111.9 a
	100	26.09±4.47 a	38.83±12.96b	2.16±0.74b	216.5±101.9b
Ciclos	1	20.35±1.87b	42.74±8.67b	2.44±0.65b	273.97±34.85b
	2	30.54±3.40 a	29.22±6.85c	1.65±0.38c	131.2±62.9c
	3	29.59±3.13 a	52.67±13.4 a	2.72±0.66 a	308±112.8 a
Tratamento		MS. Pa	SPAD	IC	Espectro
Freq.	Constante	9.2±2.98b	18.75±6.28	168.33±23.2	92.08±3.21
	Intermitente	13.01±4.51 a	17.31±5	168.68±23.34	88.39±5.46
	Sem	13.41±4.59 a	17.43±5.17	163.9±28.59	88.52±4.7
Doses	80	12.79±4.68 a	17.48±5.12	166.74±23.07	88.41±5.64
	100	10.96±4.1b	18.18±5.86	167.2±26.95	90.91±3.38
Ciclos	1	12.26±2.42b	11.28±2.47c	151.64±11.87	-
	2	8.52±3.27c	19.01±1.89b	152.66±14.71	92.06±4.05
	3	14.85±4.88 a	23.19±2.59 a	196.61±13.48	87.26±4.23

Doses: % of formulation. N: number. MS: dry mass. MF: fresh pasta. CI: Chlorophyll index. - Analysis not performed. Different letters have significant differences.

Source: Authors (2023)

The average values for the biometric variables that showed significant results for the interaction between doses and production cycles are shown in Figure 3.

The number of leaves (Figure 3A) increased by 15% and 3.5% in cycles 2 and 3, respectively, at dosage 80, compared to dosage 100 and higher than cycle 1 by 30.5% on average.

Fresh and dry root mass (Figure 3B, C) showed a reduction of 37% in cycle 2 in relation to 1 and 3 in general, with an average increase of 9.3% and 12.5% in the dosage of 80 in relation to 100.

The fresh and dry mass of the aerial part (Figure 3D, E) in cycles 1 and 3 had an average increase of 51.5% and 35.5%, respectively, in relation to cycle 2, and dosage 80 generated gains of the order of 7.6%, 40% and 10% in relation to 100, with a lower need for nutrients in temperature conditions above those recommended for lettuce.

The intensity of the plants' green color (SPAD) showed a difference between productivity cycles without variation in dosages of 100 and 80. Average values were found in cycle 2.

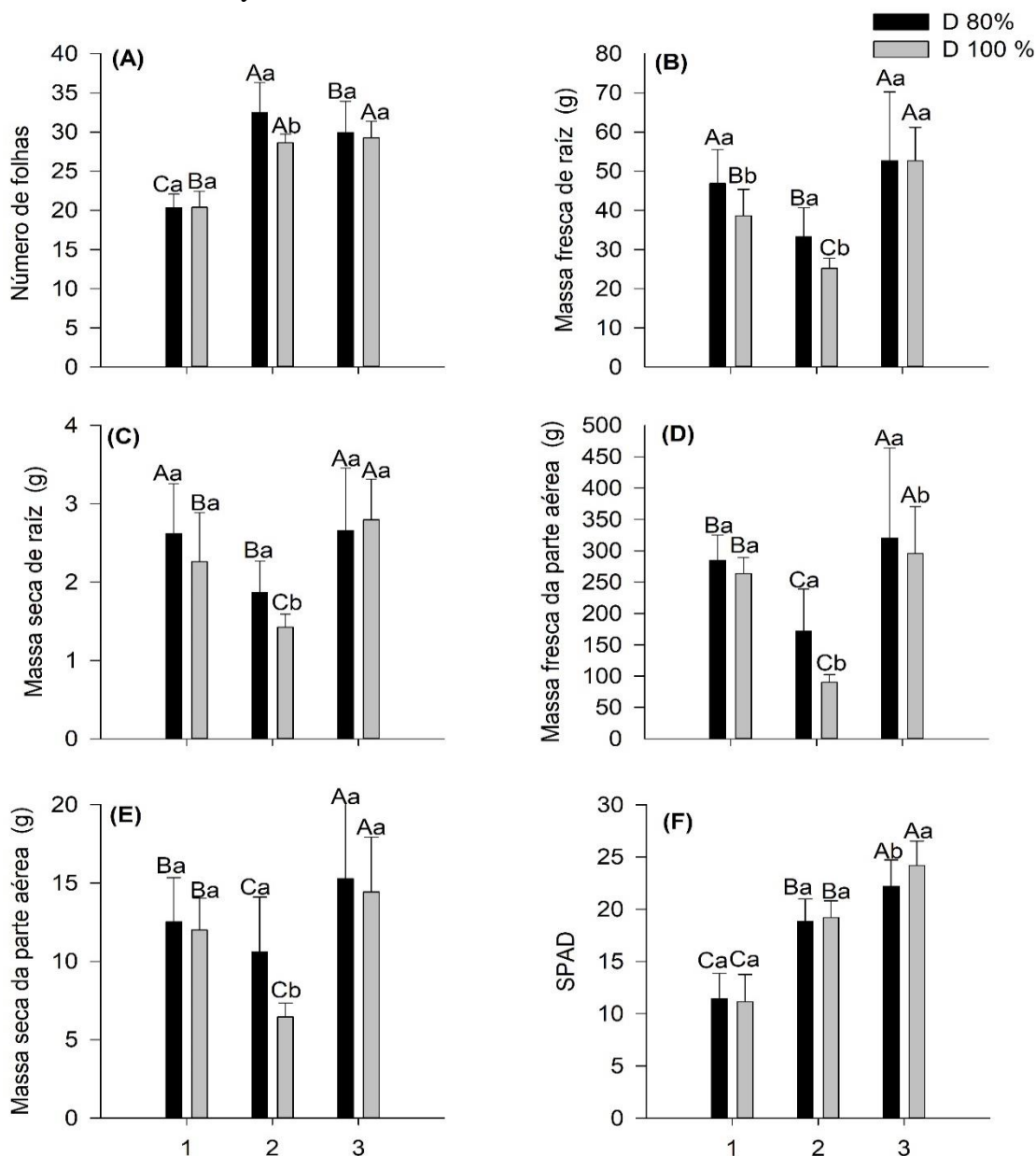
The results presented show better performance in lettuce cultivation at a dosage of 80% of that recommended by Furlani *et al.* (1999), obtaining greater tolerance to stress conditions produced by the increase in temperature mainly in cycle 2, which generated a greater number of leaves and less accumulation of mass in the roots and shoots. The SPAD index exhibited indifferent behavior to the fertilizer dosages used.

The increase in temperature generates a greater concentration of salts in the nutrient solution, which can cause nutritional disorders (XAVIER *et al.*, 2021). According to Cova *et al.* (2017), the absorption of nutrients such as Ca and K is most affected by the presence of Na and Cl

in the solution. The deficiency of these nutrients reduces plant development,

impacting the accumulation of dry and fresh mass (TAIZ *et al.*, 2017).

Figure 3. Average values of biometric variables in the interaction between fertilizer doses and cultivation cycles.



Capital letters refer to significant differences between variables in the same graph, and lower case letters refer to differences within the same variable. 1, 2, 3: Production cycle.

Source: Authors (2023)

The SPAD index is directly related to the nutritional status of the plant, and nutrients such as nitrogen have a direct role in the synthesis of chlorophyll, which was not limited in the present study, resulting in the absence of differences between dosages

(TAIZ *et al.*, 2017). Electrical conductivity above 2.5 dSm^{-1} generally causes an imbalance in the plant's osmotic adjustment and delays its development (XAVIER *et al.*, 2021), which was observed in the present study in cycle 2.

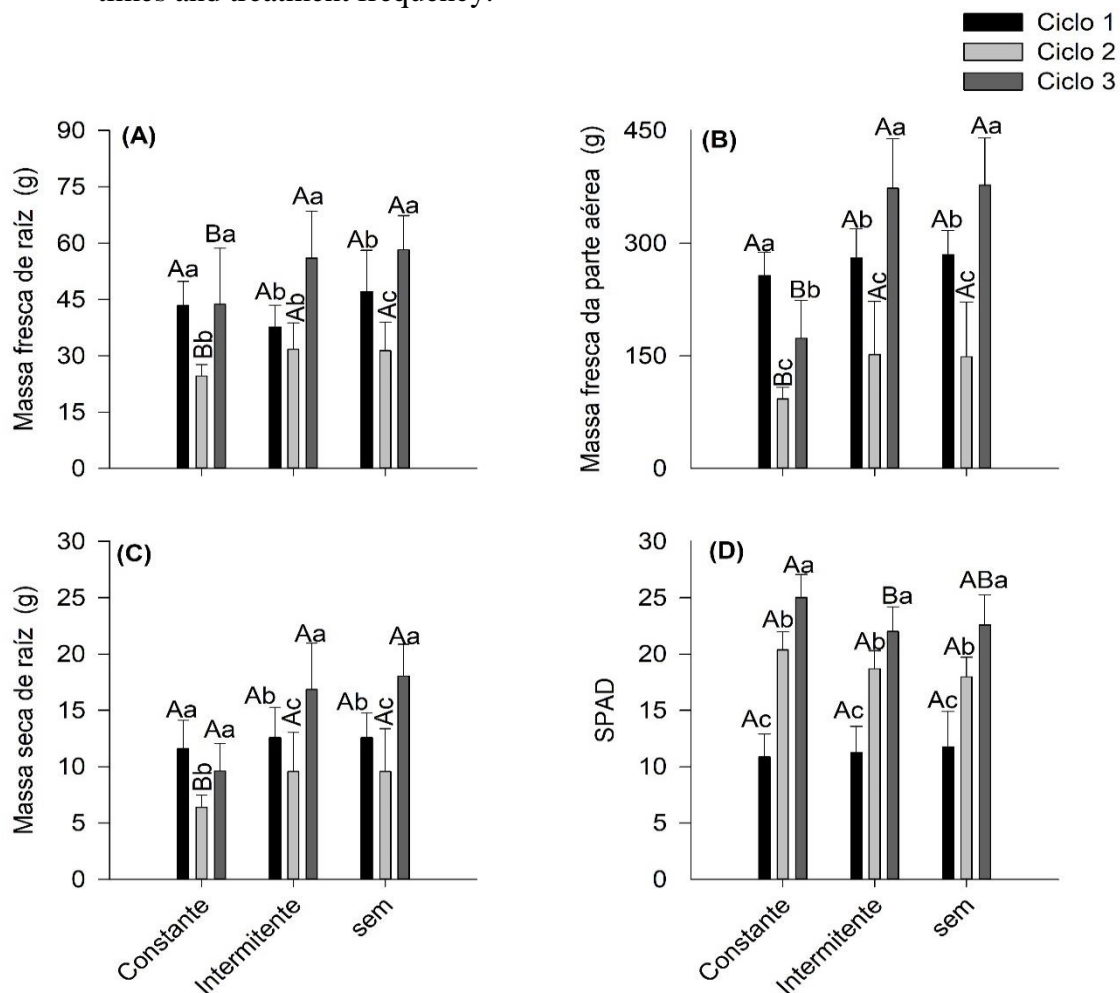
In general, the increase in the number of leaves at the expense of the accumulation of root and shoot mass observed in the present study in cycle 2 contradicts what was reported by Andrade (2019), who found adequate lettuce development at temperatures above 25 °C. However, the results obtained in this research agree with Soares *et al.* (2020), who stated that high temperatures associated with high EC levels reduce the accumulation of fresh and dry mass.

The use of lower nutrient concentrations reduces the impact of high

temperatures and improves lettuce quality compared to higher nutrient concentrations in the solution, in agreement with Luz *et al.* (2018), who obtained the best results at concentrations of 50% of the solution Furlani *et al.* (1999).

The average values of the biometric variables that presented a significant result for the interaction between production cycles and the frequency of use of low-frequency electrical pulses are shown in Figure 4.

Figure 4. Average values of biometric variables in the interaction between cultivation cycle times and treatment frequency.



Capital letters refer to significant differences between variables in the same graph, and lower case letters refer to differences within the same variable.

Source: Authors (2023)

The fresh mass of roots and shoots (Figure 4A, B) showed an increase of 8.5%, 17.3% and 38% in cycles 1 and 3 with intermittent frequency and without, respectively, in relation to constant frequency, and in general, it was higher than that in cycle 2 by 33% and 54% on average for each variable.

Root dry mass (Figure 4C) had a reduction in accumulation of 37% in cycle 2 in general. Constant frequency showed a reduction of 28.2% and 30% compared to intermittent and no use, respectively. The SPAD index (Figure 4D) had constant differences between cycles at all frequencies, constant, intermittent and without.

These results show that the constant application of electrical pulses reduces the accumulation of mass in the lettuce crop, which can generate stress in the plants and consequently reduce their mass accumulation, a pattern that was repeated in each cycle. Lima (2021) did not have conclusive results when evaluating the influence of electromagnetism on the development of common beans.

Liu *et al.* (2019) obtained positive results in the development of plants when using electromagnetism, a technology similar to that used in the present work. Treating water for irrigation with this technology improves the efficiency of water and nutrient use (ABOBATTA, 2019) and increases chlorophyll levels measured using the SPAD index (MENDONÇA, 2022). The results not proven in the present work.

The use of low-frequency electrical pulses or an electronic anti-scaling system has good results in the solubility of compounds such as CaCO_3 and Fe that can be absorbed by plants (XIAO *et al.*, 2020), in addition to helping to control the growth rate, viability, adhesion, and metabolic activity of microorganisms such as bacteria that consume nutrients from the solution (PIYADASA *et al.*, 2017; PIYADASA *et al.*, 2018; CHIBOWSKI *et al.*, 2018). The

results vary depending on the materials and time of exposure to the system (GOSSELIN *et al.*, 2018).

The average values of the biometric variables that were influenced by the interaction between the fertilization dosage and the frequency of using low-frequency electrical pulses are presented in Figure 5.

The number of leaves and fresh root mass (Figure 5A, B) had significant differences in dosage 80 in treatments with no frequency at 19% and 10% in the treatment with intermittent frequency in relation to dosage 100 and lower in constant frequency for the same dosage.

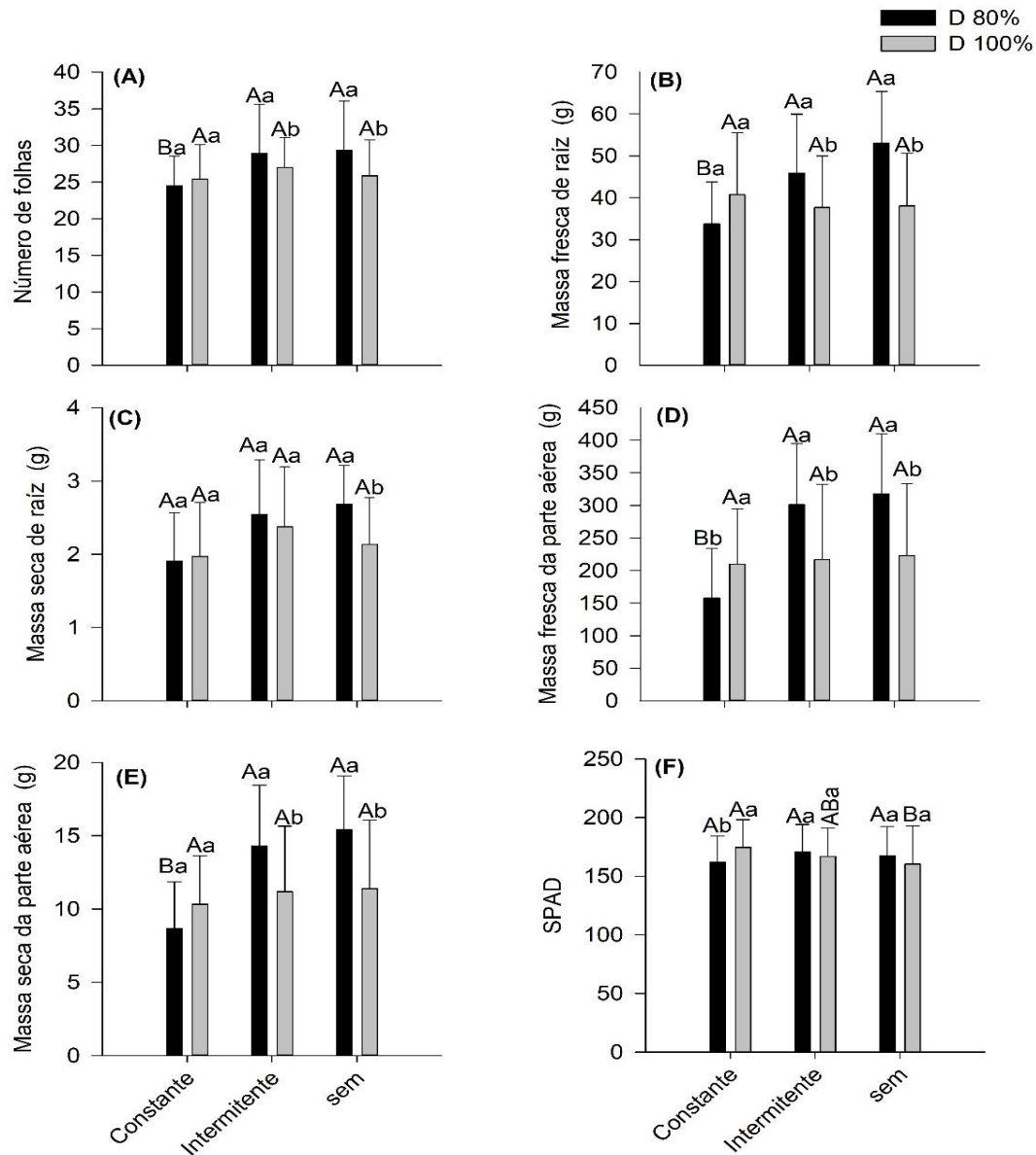
Root dry mass (Figure 5C) had gains of approximately 19% in the treatment without frequency in favor of dosage 80, showing no differences in the variable in constant and intermittent frequencies in relation to the dosages used.

The fresh and dry mass of the aerial part (Figure 5D, E) shows differences in favor of dosages of 80 of 29% and 25% in the nonfrequency and intermittent treatments, being higher than dosage 100. At constant frequency, the fresh and dry mass of the aerial part showed a 26% reduction at dose 80 compared to dose 100. The constant use of low-frequency electrical pulses generated a reduction in the accumulation of fresh mass.

The IC index (Figure 5F) shows significant differences between all frequency treatments at dosages 100 and higher by 10% at constant frequency in favor of dosage 100, but between dosages, the differences are reduced.

The use of low-frequency electrical flow negatively interfered with the development of the analyzed variables when used permanently. These results are contrary to those found by Lima (2021), who reports benefits in development using an electromagnetic system in bean cultivation, and Sales, Santos and Padilha (2010), who reports improvement in lettuce germination.

Figure 5. Average values of biometric variables in the interaction of fertilizer dose times and treatment frequency.



Capital letters refer to significant differences between variables in the same graph, and lower case letters refer to differences within the same variable.

Source: Authors (2023)

Intermittent treatment of irrigation water is more efficient than its constant use in the number of leaves, accumulation of fresh mass of roots and shoots and dry mass of the shoot using a dosage of 80 in hydroponic lettuce cultivation. Mendonça (2022) found variations in chlorophyll and improvements in growth variables, reducing stress effects (TORRES *et al.*, 2020).

There is greater dosage efficiency 80 being lower than the standard solution proposed by Furlani *et al.* (1999), similar results were reported by several authors such as Vasconcelos *et al.* (2014) in *Coriandrum sativum*, Luz *et al.* (2012) in *Petroselinum crispum* and Luz *et al.* (2018) in *Artemisia absinthium*. Lower dosages reduce the stress caused by the imbalance of osmotic potential

in stressful conditions (TAIZ *et al.*, 2017, ANDRADE, 2019).

6 CONCLUSION

The use of low-frequency electrical pulses in a constant manner obtained lower results in the growth variables in hydroponic lettuce cultivation.

The use of a dosage of 80% of that recommended by Furlani *et al.* (1999) promoted better results under temperature stress conditions.

Treatment of irrigation water with intermittent electrical pulses had similar results to conventional treatment in hydroponic lettuce cultivation.

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