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PERIODICITY OF EXPOSURE OF HYDROPONIC LETTUCE PLANTS TO NUTRIENT SOLUTION[1]

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ABSTRACT - A balanced periodicity of the nutrient solution flow is essential for better agronomic performances and low production costs in hydroponic systems. Thus, the objective of this work was to evaluate the effect of periodicity of exposure of lettuce plants to the nutrient solution in an NFT hydroponic system on the production, nutrition, and profitability of this crop. The experiment was conducted in a randomized block design with five replications. The treatments consisted of four periodicities of exposure of lettuce plants to the nutrient solution, consisting of intervals of 60, 30, and 15 minutes between pumping periods of 15 minutes; and uninterrupted flow of the nutrient solution. The plants were harvested at 30 days after transplanting, and 15 lettuce plants of each experimental plot were used to determine total fresh weight; root fresh weight; shoot freshweight; and contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn in shoots, roots, and in the diagnostic leaf; accumulation of these nutrients in shoots and roots; and nitrate and ammonium contents in plant shoot. The highest production and profitability of lettuce were found using uninterrupted nutrient solution flow, which provided higher shoot and root nutrient contents to plants, and resulted in a better nutrient use efficiency.

Keywords: *Lactuca sativa* L. Leaf nutrient concentration. Diagnostic leaf. Profitability. NFT hydroponic system. Intermittent flow of nutrient solution.

PERIODICIDADE DE EXPOSIÇÃO DA ALFACE AMERICANA À SOLUÇÃO HIDROPÔNICA

RESUMO - O equilíbrio entre o tempo de alternância do fluxo da solução nutritiva visando o melhor desempenho agronômico e menor custo de produção é de fundamental importância no cultivo hidropônico. Dessa forma, o objetivo deste trabalho foi avaliar efeito da periodicidade de exposição à solução nutritiva em sistema hidropônico NFT, na produção, nutrição e rentabilidade de alface americana. O delineamento experimental foi em blocos casualizados, com cinco repetições. Os tratamentos foram quatro combinações de intermitência de exposição da solução nutritiva em intervalos de bombeamento / intervalo de ausência de bombeamento, sendo estes em minutos: 15/60; 15/30; 15/15 e FI (Fluxo ininterrupto da solução nutritiva). A colheita foi realizada aos 30 DAT sendo massa fresca total, do sistema radicular e da parte aérea das 15 plantas de alface de cada uma das parcelas experimentais. Também foram avaliados os teores de N, P, K, Ca, Mg, S, B, Cu, Fe, Mn e Zn na parte aérea, raízes e na folha diagnose da alface e calculados os acúmulos dos mesmos de nutrientes na parte aérea e raízes das plantas. Ademais, determinou-se os teores de nitrato e amônio na parte aérea da alface. A maior produção e rentabilidade de alface americana foi obtida com fluxo ininterrupto (FI) da solução nutritiva, devido ao maior acúmulo de nutrientes na parte aérea e raiz e eficiência de utilização de nutrientes.

Palavras-chave: *Lactuca sativa* L. Concentração de nutrientes foliar. Diagnose foliar. Lucratividade. Sistema hidropônico NFT. Alternância do fluxo da solução nutritiva.

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INTRODUCTION

Lettuce (*Lactuca sativa* L.) is the most market and consumed leafy vegetable in Brazil because it can be produced throughout the year, has culinary characteristics, and good acceptance by consumers (ABCSEM, 2017). Its national production for the wholesale market in 2016 was 105.207 Mg, generating more than BRL (R$) 288 million (CONAB, 2017), and it is estimated that the retail sales reached BRL (R$) 8 billion, with a production higher than 1.5 million Mg (ABCSEM, 2017). These data were from lettuces produced using two growing systems: with soil or without soil (hydroponics).

Hydroponics is an intense production method for vegetables and an alternative for the supplying of an increasing demand for these foods due to the lack of soils with adequate physical, chemical, and sanitary characteristics for growing these crops (LEIVA ESPINOZA, 2019).

Hydroponics is an alternative for the growing of crops in soils, presenting advantages to consumers, producers, and environment, such as: reduced crop cycle, high yield, and better uses of water and agricultural inputs (PAULUS et al., 2012).

This technique consists of growing plants without any contact with soil, which receive a nutrient solution made of nutrients dissolved in water; thus, this solution can supply all the essential elements that plants need to grow.

The nutrient film technique (NFT) is one of the most common technique in hydroponics, which consists of a circulating system that supplies water containing nutrients to plant roots (MOHAMMED, 2018). NFT hydroponic system is largely used in Brazil, mainly for lettuce crops (LUZ et al., 2017).

In this system, the water containing nutrient solution flows through growing channels where the plant roots are to irrigate and supply oxygen and nutrients to plants (MARTINS et al., 2009). The definition of intermittent exposure of plants to the nutrient solution is mainly dependent on environmental characteristics, such as solar radiation and air temperature and humidity, and plant physiology.

The intermittence of the nutrient solution flow in the growing channels should be based on the plant water demand. The absence of supply of nutrient solution to plants decreases water availability and will cause water deficit, increase in leaf temperature, and stomatal closure, decreasing photosynthesis and, consequently, the crop production, since the plants will adequate their photosynthesis to the water availability conditions.

However, a nutrient solution that circulates longer than necessary, without improving the crop performance, affects directly the electrical energy consumption, which can reach 19.7% of the total cost (LONDERO; AITA, 2000). Therefore, a balanced periodicity of the nutrient solution flow is essential for better agronomic performances and low production costs in hydroponic systems, which is a factor sometimes underestimated by producers and researches.

Thus, the objective of this work was to evaluate the effect of periodicity of exposure of lettuce plants to the nutrient solution in an NFT hydroponic system on the production, nutrition, and profitability of lettuce.

MATERIAL AND METHODS

The experiment was conducted between May and June 2017 in a commercial hydroponic crop under a 25% red shade screen, in Aparecida do Taboado, MS, Brazil (20°3'58"S; 51°10'54" W; and altitude of 379 m). The climate of the region presented air temperatures of 11 ºC to 25 ºC and relative air humidity of 50% to 90% during the experiment period (Figure 1).

A randomized experimental block design with five replications was used. The treatments consisted of four periodicities of exposure of lettuce plants to the nutrient solution, consisting of intervals of 60 (15/60), 30 (15/30), and 15 (15/15) minutes between pumping periods of 15 minutes, and uninterrupted flow of the nutrient solution. Each experimental plot was composed of 15 lettuce plants, and the evaluation area consisted of 9 plants.

The experimental units were installed on 7-meter long individual benches with 10% slope. Growing channels were made of PVC tubes (8 cm width and 4 cm height) with a rectangular session, containing holes at the top for placing the plants every 25 centimeters. Each bench consisted of 7 growing channels spaced 20 cm apart, an individual pumping system, and a 310-L tank that was kept at least 95% full.

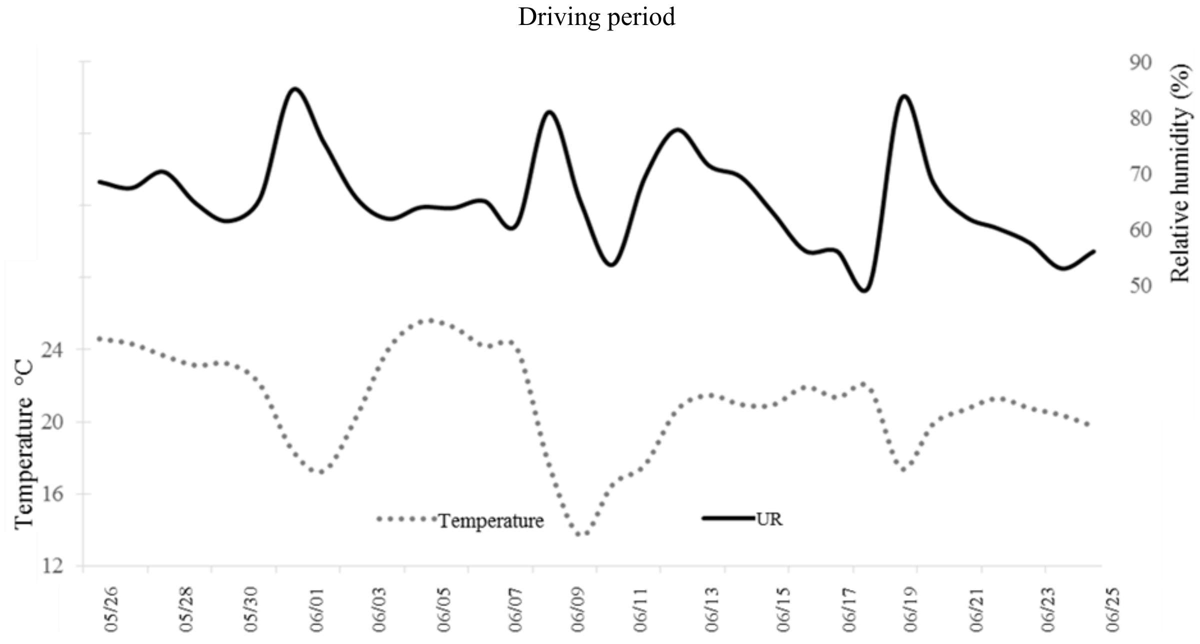

Figure 1. Air temperature and relative air humidity during the experiment period. Aparecida do Taboado, MS, Brazil, 2018.

The Betty lettuce cultivar (Horticeres®) was used, which is of the Americana group. It is a tall plant with high volume of large and thick leaves, having a good head protection, and presents good tolerance to early bolting. Its average cycle is 70 days when growing in soils, however, its presents early cycle when growing in hydroponic systems; its ideal plant population is between 80 and 160 thousand plants per hectare (Horticeres, 2019).

The lettuce seedlings were produced in phenolic foams and kept for 12 days in a nursery covered with 25% red shade screen; subsequently, they were transplanted to the growing channels on the benches where they were kept for 22 days until the harvest.

A nutrient solution was pumped using a closed-circuit system with flow rate of 1 L per minute through each growing channel, according to the intermittence of each treatment. The nutrient solution used consisted of diluted concentrate fertilizers (PlenanFerti PM1@ and PlenanFerti PM2@) at 1.23 g mL^{-1}, which were supplied at equal proportion; the nutrient concentrations in the nutrient solution were (g L^{-1}): 77.65 of N, 15.95 of P, 75.26 of K, 23.39 of S, 41.60 of Ca, 17.82 of Mg, 0.27 of B, 0.08 of Cu, 1.09 of Fe, 0.29 of Mn, 0.05 of Mo, 0.06 of Ni, and 0.11 of Zn. Initially, 0.3 L of each fertilizer were used for each 300 L of solution, however, the replenishment of salts in the nutrient solution varied according to the plant demand in each treatment, based on the electrical conductivity (EC) of the solution. EC and pH were measured on all plants every morning and corrected when necessary by adding nutrients to the nutrient solution. The EC of the solution was kept at 0.9 dSm^{-1} for the seedlings; in the first 10 days after transplanting (DAT) the EC was kept at 1.2 dSm^{-1}; and after 10 DAT up to the end of the crop cycle, the EC was kept at 1.6 dSm^{-1}.

The plants were harvested at 30 DAT with a 344-degree-day thermal accumulation, and total fresh weight, root fresh weight, and shoot fresh weight of the 15 lettuce plants of each experimental plot were evaluated. Subsequently, these plants were dried in a forced-air circulation oven at 60 °C for 72 hours for determination of their total dry weight, root dry weight, and shoot dry weight.

Then, these plant materials were ground in a Wiley mill for determination of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn contents in shoots, roots, and in the diagnostic leaf young developed leaves (TRANI; RAIJ, 1997) according to the methodology of Malavolta, Vitti and Oliveira (1997). The nutrient accumulation in shoots and roots of these plants were determined based on their respective dry matters and contents of the evaluated nutrients. Nitrate and ammonium contents in plant shoots were determined according to the methodology described by Tedesco, Volkweiss and Bohnen (1985).

The nutrient use efficiency (NUE) of each treatment was obtained according to Equation 1 (SIDDIQI; GLASS, 1981).

Equation 1

$$NUE = (\text{total dry weight of the plant})^2 / (\text{total nutrient accumulation in the plant})$$

The data were subjected to analysis of variance. The means of the treatments (periodicity of exposure of plants to the nutrient solution) were compared by the Tukey's test at 5% significance, considering the need to find the periodicity that aggregated the highest number of variables of productive interest, not individual results of optimal periodicity for each variable. The SISVAR program was used for the analyses.

An economic analysis was done using spreadsheets to calculate the production cost, according the methodology adapted by Matsunaga and Toledo (1976), in which the variable cost is only the direct disbursement, and the investment, depreciation, and opportunity cost of the invested capital are a single fixed cost, considering a cost structure based on fixed cost.

RESULTS AND DISCUSSION

The lettuce plants subjected to uninterrupted nutrient solution flow (UF) presented higher fresh and dry weights of shoots and roots (Figure 2), followed by those subjected to the treatments with nutrient solution flow periodicities of 15/60 and 15/15 minutes, which presented differences only for shoot dry weight.

The results of the lettuce plants in the treatments 15/30, 15/15, and UF is directly related to the evolution of the NFT hydroponic system regarding the growing channel slope, which was initially proposed as 3% to 4%; but the current recommendation is usually 10%. This change in the system allows the nutrient solution to flow at a higher speed and turbulence, generating better cooling and transport of dissolved oxygen to the submerse roots. Moreover, considering an adequate flow rate, this change indicates no need for intermittent flow of the nutrient solution under the conditions studied in the present experiment.

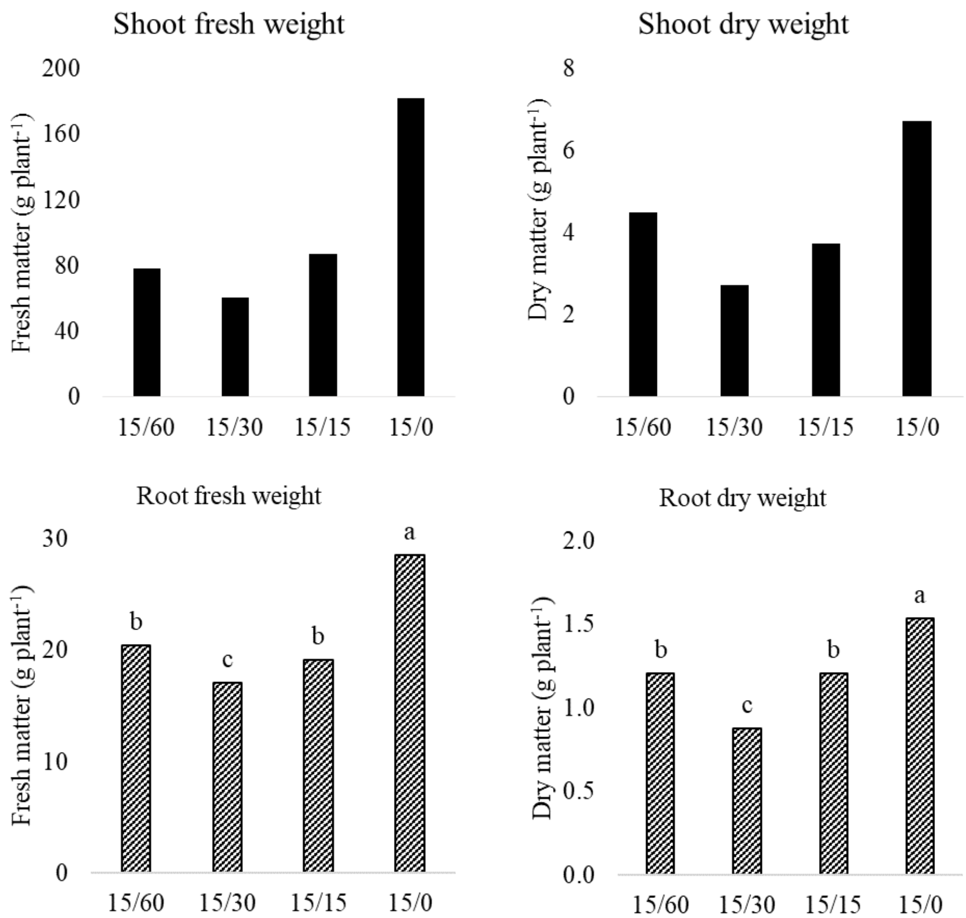

Figure 2. Shoot and root fresh and dry weights (g $plant^{-1}$) of lettuce plants grown under different periodicities of exposure to the nutrient solution in a hydroponic system. Aparecida do Taboado, MS, Brazil, 2018.

The intermittence of nutrient solution flow in NFT hydroponic systems contributes to the respiration and consequent oxygenation of the root system that was submerse in the nutrient solution. However, it causes collateral damages to plants, since the absence of nutrient solution flow can prevent the cooling of the tubes exposed to solar radiation, increasing the temperature inside these tubes, which causes the death of roots (CASAROLI et al., 2003).

The dry weights found in the treatment 15/60 minutes can be explained, since a severely compromised root system development hinders water and nutrient supply to plants and decreases significantly their development. Under such conditions, these plants emit adventitious roots for their recovery, thus avoiding their death and ensuring the supply of the nutrient demand of their aerial part (PRADO; CECÍLIO FILHO, 2016), but with an unnecessary energy expenditure.

The use of intervals of 15 to 45 minutes between pumping periods of 45 minutes altered the dry weight of the root system in an experiment conducted in Rio Grande do Sul, Brazil, with the highest values between 0.76 and 0.83 g per plant, and the treatment 45/45 minutes showed the best result (LUZ et al., 2008). Similar results were found for lettuce plants of the cultivar Regina that presented total dry weight of 9.7 g per plant during the spring (BACKES et al., 2003) and 7.1 g per plant during the autumn (CARON et al., 2003).

UF stood out as the only treatment that presented high or adequate nutrient contents in the diagnostic leaf, according to the sufficiency range proposed by Trani and Raij (1997) (Table 1).

Table 1. Nutrient contents in the diagnostic leaf of lettuce plants subjected to different periodicities of exposure to nutrient solution in a hydroponic system.

		15/60 minutes	15/30 minutes	15/15 minutes	UF
		Leaf content	Leaf content	Leaf content	Leaf content
N	$g\ kg^{-1}$	32.67 A	38.33 A	41.3 A	40.93 A
P		5.13 A	5.97 A	6.70 A	6.83 A
K		36.27 L	41.17 L	42.73 L	50.9 A
Ca		6.2 L	8.57 L	7.87 L	15.3 A
Mg		3.23 L	4.57 A	4.43 A	6.43 H
S		1.77 A	2.10 A	2.37 A	2.17 A
B	$mg\ kg^{-1}$	39.67 A	40.00 A	42.67 A	43.00 A
Cu		13.33 A	15.00 A	23.33 H	23.33 H
Fe		194.33 H	223.33 H	198.33 H	327.67 H
Mn		65.67 A	94.67 A	100.33 A	173.67 H
Zn		69.00 A	108.00 H	117.33 H	215.00 H

The nutrient contents in the diagnostic leaf of lettuce plants were interpreted based on Trani and Raij (1997): high (H), adequate (A), and low (L). 15/60, 15/30, and 15/15 minutes = times of exposure of the plants to the nutrient solution (flow/absence of flow) applied through a rectangular 7 meters long PVC tubes with 10% slope, at flow rate of 1 L per minute; UF = uninterrupted flow of nutrient solution.

The others treatments had similar deficiency of K and Ca; these low contents of these nutrients can be due to an inefficient absorption of the nutrient solution because of damaged root systems. However, K and Ca deficiency symptoms were not found in the plants, which characterize these low K and Ca contents as a moderate deficiency, or even as a low requirement of this lettuce cultivar for these exchangeable bases.

The nutrient solution in hydroponic systems is the only source of water and minerals to plants, thus, nutrition and water stability are reached by plants through absorptions of this substrate; and the plant physiology is the responsible for balancing nutrient and water uptakes to maintain the water potential of the plant shoot or balancing the water volume that is absorbed together with the nutrients (TAIZ; ZEIGER, 2004).

Thus, a higher absorption of the nutrient solution by better-performance plants contributes to a high micronutrient contents in plant tissues; this was denoted by the high micronutrient contents found in the plants subjected to uninterrupted flow of the nutrient solution, which decreased as the intervals between pumping periods were increased up to 60 minutes.

N, Mg, S, Cu, and B contents in the plant shoot were similar in all treatments evaluated. The highest P, Ca, Mn, and Zn contents were found in plants in the treatment UF, while the highest K and Fe contents were found in plants in the treatment 15/30, but with no significant differences between the treatments (Table 2).

Table 2. Content and accumulation of nutrients in shoot and root systems of lettuce plants subjected to different periodicities of exposure to nutrient solution in a hydroponic system.

	15/60	15/30	15/15	UF	15/60	16/30	15/15	UF
	Content in plant shoot system (g kg^{-1})				Accumulation in plant shoot system (g $plant^{-1}$)			
N	37.87a	39.07a	37.67a	37.33a	0.15b	0.11c	0.14B	0.25a
NO_3^-	0.49a	0.68a	0.24b	0.007c	0.002a	0.002a	0.001B	0.0004c
NH_4^+	0.76a	0.41b	0.68a	0.64a	0.003b	0.002c	0.002C	0.004a
P	6.13b	6.53b	7.60b	10.47a	0.03b	0.02b	0.03B	0.07a
K	66.60ab	74.60a	42.57b	41.47b	0.30a	0.21b	0.16C	0.28a
Ca	12.10b	16.57ab	14.97b	20.97a	0.05b	0.05b	0.06B	0.14a
Mg	6.90a	7.23a	7.10a	7.43a	0.03b	0.02b	0.03B	0.05a
S	2.37a	2.47a	2.37a	2.80a	0.01b	0.01b	0.01B	0.02a
	Content in plant shoot system (mg kg^{-1})				Accumulation in plant shoot system (mg $plant^{-1}$)			
B	38.33a	41.67a	49.00a	37.33a	0.17b	0.12c	0.18B	0.25a
Cu	21.67a	21.00a	26.00a	25.00a	0.10b	0.06c	0.10b	0.17a
Fe	520.67b	659.00a	562.00ab	566.67ab	2.35b	1.80c	2.12d	3.79a
Mn	116.00c	151.00b	152.00b	229.00a	0.52b	0.41b	0.58b	1.54a
Zn	108.33b	161.33ab	213.33ab	274.67a	0.49c	0.44c	0.83b	1.84a
	Content in plant root system (g kg^{-1})				Accumulation in plant root system (g $plant^{-1}$)			
N	45.00a	44.60a	47.23a	46.90a	0.054b	0.039b	0.057a	0.072a
P	14.90b	17.33ab	16.96ab	19.40a	0.018b	0.015c	0.020b	0.030a
K	23.86a	21.56a	25.03a	24.76a	0.029b	0.019c	0.030b	0.038a
Ca	6.30a	5.16b	5.30b	5.33a	0.008a	0.005b	0.006b	0.008a
Mg	2.36a	2.06a	2.10a	2.03a	0.003b	0.002b	0.003b	0.003a
S	9.70a	11.16a	10.10a	10.23a	0.012b	0.010b	0.012b	0.016a
	Content in plant root system (mg kg^{-1})				Accumulation in plant root system (mg $plant^{-1}$)			
B	19.33a	25.66a	28.33a	26.66a	0.023b	0.022b	0.036a	0.041a
Cu	186.66b	220.66b	224.33b	286.00a	0.226c	0.193c	0.270b	0.438a
Fe	6768.00c	1047.00b	7864.00bc	14507a	8.166b	9.171b	9.471b	22.19a
Mn	97.00a	105.33a	105.33a	109.33a	0.117b	0.092c	0.128b	0.168a
Zn	221.33a	223.00a	199.66a	222.00a	0.268b	0.195c	0.241b	0.341a

Means followed by the same letters in the rows, within each quadrant, are not different by the Tukey's test ($p < 0.05$). 15/60, 15/30, and 15/15 minutes = times of exposure of the plants to the nutrient solution (flow/absence of flow) applied through a rectangular 7 meters long PVC tubes with 10% slope, at flow rate of 1 L per minute; UF = uninterrupted flow of nutrient solution.

N and S are nutrients involved with formation of organic compounds in plants, whereas Mg is a component of the chlorophyll molecule, among other functions. Cu is involved with electron transport, and B is responsible for cell stretching (TAIZ; ZEIGER, 2004). The similar contents found for these nutrients in plants in both treatments indicate that the plants kept an adequate photosynthetic process and, consequently, continued to development, but though at different rates.

Therefore, the higher periodicity of exposure of plants to the nutrient solution in the treatment UF resulted in a higher N assimilation from nitrate, which partially explains the higher fresh and dry weights found in plants in this treatment. N is a constituent of amino acids, proteins, enzymes, coenzymes, and nucleotides (MALAVOLTA; VITTI; OLIVEIRA, 1997); in hydroponic systems, it is supplied to plants as ammonium and nitrate ions. However, nitrate must be reduced to nitrite in the plant cell cytoplasm and subsequently converted to ammonium in the chloroplasts during the photosynthesis process; but, under water stress conditions, even when moderate, the plant photosynthesis rate decreases (LAWLOR; TEZARA, 2009), favoring accumulation of nitrate in its tissues.

The nitrate and ammonium contents presented inversely proportional results (Table 2). The highest nitrate and lowest ammonium contents were found in plants in the treatment 15/30, and the lowest nitrate and highest ammonium contents in those in the treatment UF. These results indicate occurrence of a higher protein synthesis when using uninterrupted flow of the nutrient solution, which explains the highest growth and fresh and dry weights of lettuce plants in this treatment.

P is an essential nutrient for reactions involving ATP; Ca is involved with ATP hydrolysis reactions; Mn is involved mainly with O_2 evolution; and Zn is a component of the group of elements that participate of electron transport process (TAIZ; ZEIGER, 2004). The highest contents found for these nutrients in plants in the treatment UF are correlated to the highest dry weight gains found in this treatment, indicating a higher plant development, which was increasingly lower in the other treatments as the intervals between pumping periods were increased.

K is the main cation involved with turgor and electroneutrality of plant cells, and Fe is present in the cellular respiration process (TAIZ; ZEIGER, 2004); thus, plants subjected to large intervals between pumping periods were expected to need higher contents of these nutrients in their cells.

Regarding the nutrient accumulation in the shoot and root systems of the lettuce plants evaluated (Table 2), UF was again the best treatment, presenting the highest accumulations for all evaluated nutrients in these plant parts. The plants in the treatments 15/15 and 15/60 presented, in general, intermediate results for nutrient accumulation, and those in the treatment 15/30 minutes presented the lowest nutrient accumulation.

The highest P, Ca, Cu, and Fe contents in the plant root system were found in the treatment UF due to the uninterrupted availability of these nutrients in the nutrient solution. However, no significant differences were found for the contents of most nutrients (N, K, Mg, S, B, Mn, and Zn) in the different periodicities of nutrient solution flow tested.

The nutrient accumulation in the plant root system, in general, was similar to that found for the plant shoot system. The plants in the treatments UF and 15/30 presented the highest and lowest nutrient accumulations, respectively.

The macro and micronutrients absorption by plants in all treatments evaluated in the present study showed similar order to that established for high lettuce yields: K>N>Ca>P>Mg>S>Fe>Zn>Mn>B>Cu (FAQUIN; FURLANI NETO; VILELA, 1996).

The plants in the treatment UF presented the highest nutrient use efficiency (NUE), except for Zn, which presented higher NUE only by plants in the treatment 15/60 (Figure 3).

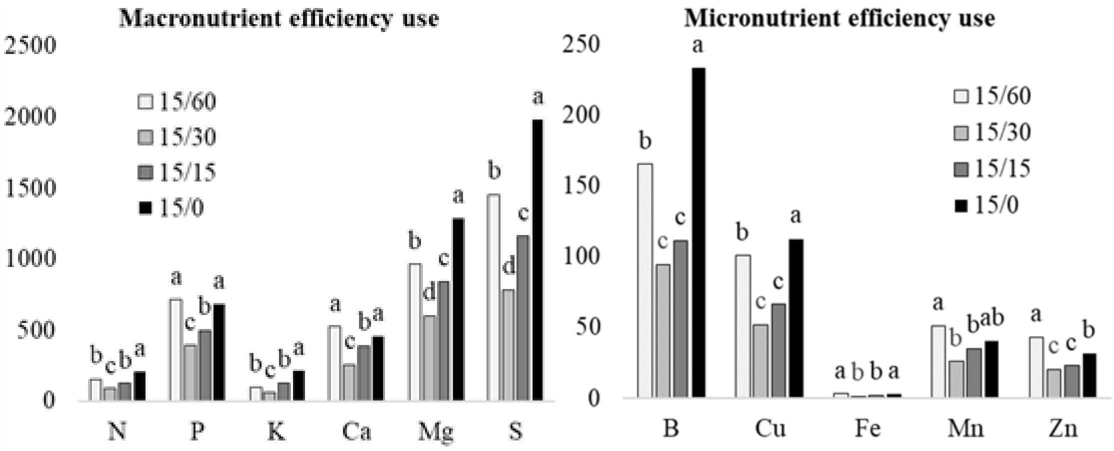

Figure 3. Nutrient use efficiency (NUE) of lettuce plants subjected to different periodicities of exposure to nutrient solution in a hydroponic system.

The NUE decreased for most nutrients in plants according to the following order of treatments: 15/60, 15/15, and 15/30; the latter presented plants with the lowest NUE for all nutrients evaluated.

Regarding the economic analysis, considering an average lettuce bunch price of BRL (R$) 2.50, the treatment UF resulted in the highest profits (128%), followed by the treatments 15/60 (36%) and 15/15 (18%). The value found in this analysis for plants in the treatment 15/30 was below their production cost, which indicates that this treatment will likely generate direct economic losses if used in a productive system (Table 3). Contrastingly, Luz et al. (2017) found best economic performance for plants in the treatment 15/60. This difference may be due to the location (environmental conditions) of that experiment, which was conducted under mild climate conditions, in Santa Maria, RS, Brazil, whereas the present study was conducted under higher temperature and solar radiation conditions; these factors cause different physiological responses in plants because of their transpiration rates.

Table 3. Production cost, and gross and net revenues per lettuce plants subjected to different periodicities of exposure to nutrient solution in a hydroponic system.

	15/60[1]		15/30		15/15		UF	
	BRL (R$)	%	BRL (R$)	%	BRL (R$)	%	BRL (R$)	%
Production cost (A)								
Workforce[2]	0.26	42%	0.26	40%	0.26	37%	0.26	30%
Electrical energy[3]	0.03	5%	0.07	11%	0.13	18%	0.26	30%
Fertilizer[4]	0.08	14%	0.07	11%	0.08	11%	0.11	13%
Water[5]	0.03	5%	0.03	5%	0.03	4%	0.03	3%
Seedlings[6]	0.07	11%	0.07	11%	0.07	10%	0.07	8%
Pesticides[7]	0.04	7%	0.04	6%	0.04	6%	0.04	5%
Fixed costs of implementation	0.10	16%	0.10	16%	0.10	14%	0.10	11%
Subtotal	0.61		0.64		0.71		0.87	
Gross revenue (B)								
Number of plants per bunch[9]	3	33%	4	25%	3	33%	1	100%
Subtotal	0.83		0.63		0.83		2.50	
Net revenue (A – B)								
	0.22		- 0.01		0.12		1.63	
Cost-benefit analysis	136%		97%		118%		287%	

[1]15/60, 15/30, and 15/15 minutes = times of exposure of the plants to the nutrient solution (flow/absence of flow) applied through a rectangular 7 meters long PVC tubes with 10% slope, at flow rate of 1 L per minute; UF = uninterrupted flow of nutrient solution. [2]Total workforce cost during the production cycle per plant; [3]Total electrical energy consumption cost considering an increasing pumping capacity of the nutrition solution in the hydroponic system as the flows are decreased); [4]Cost of the nutrient solution consumed during the production cycle; [5]Cost of the water consumed during the production cycle; [6]Total cost of the lettuce seedlings grown in phenolic foam, including their maintenance in the nursery; [7]Cost of application of Difenoconazole and Kasugamycin; [8]Rent cost of the greenhouse equipped for hydroponics; [9]Quantity of plants needed to compose a commercial bunch to be sold to wholesalers at a price of BRL (R$) 2.50.

A study conducted in Tijucas, Santa Catarina, Brazil, presented a production cost of BRL (R$) 0.79 per unit, which is a similar value to that found in the present study, and was considered economically profitable and viable for that region (ROVER; BARCELOS-OLIVEIRA; TEIXEIRA, 2014). Leite et al. (2016) estimated a net revenue of BRL (R$) 0.40 per hydroponic lettuce plant in Matão, São Paulo, Brazil, which is still reasonable for its production in family farms. Therefore, the net revenue of found in the present study for plants in the treatment with uninterrupted nutrient solution flow was higher: BRL (R$) 1.63.

CONCLUSIONS

The highest production and profitability of the lettuce plants evaluated were found for those in the treatment with uninterrupted nutrient solution flow, which resulted in plants with higher nutrient accumulations in their shoot and root systems and better nutrient use efficiency.

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