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## Head lettuce production and nutrition in relation to nutrient solution flow

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### ABSTRACT

The optimum flow rate of nutrient solution in hydroponic system can better nourish the crops, allowing healthy and faster growth of lettuce. However, flow also interferes with electric power consumption, so further researches are necessary, mainly on the effect of flow rate, nutrient accumulation and lettuce production. In this context, the aim of this study was to evaluate nutrition and production of head lettuce in relation to the nutrient solution flow in NFT hydroponic system. The treatments consisted of nutrient solution application at the flow rates 0.5; 1; 2, and 4 liters per minute in each cultivation channel. Five replicates per treatment consisted of 15 plants each. The flow in hydroponic systems to produce head lettuce alters the technical performance of the crop. Due to the greater nutrient accumulation in shoot and use efficiency of these elements, the highest production (g/plant) of head lettuce was obtained with a flow rate of 1 L/min of the nutrient solution.

**Keywords:** *Lactuca sativa*, foliar nutrients contents, foliar diagnosis, nutrient accumulation, NFT hydroponic system.

### RESUMO

#### Produção e nutrição da alface americana em função da vazão da solução nutritiva

A vazão ótima da solução nutritiva no sistema hidropônico pode nutrir melhor as plantas, possibilitando maior e mais rápido crescimento da alface. Entretanto, a vazão também interfere no consumo de energia elétrica, por isso são necessárias mais pesquisas, principalmente sobre o efeito da taxa de fluxo (vazão), no acúmulo de nutrientes e produção de alface americana. Diante do exposto, objetivou-se com esta pesquisa, estudar a nutrição e a produção de alface americana em função da vazão da solução nutritiva em sistema hidropônico NFT. Os tratamentos utilizados constaram da aplicação de solução nutritiva nas vazões de 0,5; 1; 2 e 4 litros por minuto (L/min) em cada canal de cultivo. Cada tratamento possuiu cinco repetições, compostas por 15 plantas cada. A vazão em sistemas hidropônicos para produção de alface americana altera o desempenho técnico da cultura. Devido ao maior acúmulo de nutrientes na parte aérea e eficiência de utilização destes elementos, a maior produção (g/planta) de alface americana é obtida com a vazão da solução nutritiva de 1 L/min.

**Palavras-chave:** *Lactuca sativa*, teores de nutrientes foliar, diagnose foliar, acúmulo de nutrientes, sistema hidropônico NFT.

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Lettuce is the most widely-consumed leafy vegetable in Brazil, since it can be produced all year long, culinary characteristics and cultural acceptance (Abcsem, 2017). Its production totaled over 288 million reais in 2016, in wholesale market, reaching 105 thousand t (Conab, 2017). In retail market, the production had probably reached 8 billion reais, over 1.5 million t (Abcsem, 2017). Soil cultivation of this vegetable uses 48% of its production cost associated with labor (Abcsem, 2017), progressively making room for hydroponic cultivation, seems to be the best alternative due to substantial cost reduction and best added value.

Only in São Paulo State, hydroponic production corresponds to 5% of total commercialized, at a 280% market value superior to the conventional (Conab, 2017).

Lettuce is the most expressive species grown in soilless cultivation system, possibly because it is the most popular leafy vegetable, for its short life cycle, high productivity and quick return on invested capital (Londero & Aita, 2000; Santos, 2000; Gualberto *et al.*, 2009). Additionally, in hydroponic lettuce cultivation, plants generally show better quality and sharp reduction in diseases and pests and are also suitable for a uniform production, resulting in

high quality and productivity, as well as, efficient use of water and agricultural inputs (Helbel Junior *et al.*, 2008).

Nutrient Film Technique (NFT, Laminar Nutrient Flow Technique) is characterized by the application and circulation of nutrient solution in cultivation channel among plant roots, with frequency and shifts already programmed (Cooper, 1996). NFT is a closed hydroponical system in which the nutrient solution is pumped from one reservoir and passes through the plant roots in bench channels and then returns to the reservoir by gravity (Faquin & Furlani, 1999; Santos, 2000; Helbel Júnior, 2004). In this system, plant roots

are partially immersed in the solution nutrient flow, which is not supposed to flood the whole plant: approximately 2/3 of the roots must be submerged to absorb water and nutrients and 1/3 should be remained non-submerged in order to absorb oxygen (Staff, 1998). However, only the accumulated solution in the reservoir may not have sufficient oxygen concentration (O<sub>2</sub>) and need dilution, to permit the roots, of non-aquatic species such as lettuce to breath properly. Thus, the circulation of the solution under turbulent regime plays an essential role in fluid oxygenation (Carmelo, 1996), considering that O<sub>2</sub> distribution is not uniform in the solution passing through the channels. Therefore, the greater the turbulent area and the amount of water involved in the movement, the better the gas exchange will be (O<sub>2</sub> entry into solution and CO<sub>2</sub> outlet to atmosphere).

Hydroponics technique requires appropriate as well as constant nutrient supply in order to obtain satisfactory productivities. The amount of nutrients absorbed by lettuce follows the decreasing order K > N > Ca > P > Mg > S > Fe > Zn > Mn > B > Cu (Faquin *et al.*, 1996). Conversely, little is known about the influence of nutrient solution flow of hydroponic system on the nutritional state of lettuce. Such information is extremely important, since the flow is responsible for nutrient, water and oxygen conduction to the crop, which normally has no aquatic adaptation (Rodrigues, 2002). Therefore, the ideal nutrient flow rate will be able to feed the plants better, allowing greater and faster growing of the lettuce. Nevertheless, flow also interferes in electrical energy consumption of the hydroponics system, that is the reason why further studies, mainly, on flow rate effect which in most systems ranges from 1.5 to 2.0 liters per minute are necessary to help out producers to cultivate head lettuce. Given the above, the aim of this study was to evaluate nutrition and production of head lettuce in relation to the nutrient solution flow in a hydroponics system NFT.

## MATERIAL AND METHODS

The experiment was carried out

at a commercial facility covered with red screen with 25% shading, in the municipality of Aparecida do Taboado-MS (20°3'58"S, 51°10'54"W) from April to May, 2017. Temperature during the experiment ranged from 17 to 24°C and relative humidity from 60 to 93%.

The experimental design was completely randomized, with five replicates. Treatments consisted of four nutrient solution flows: 0.5; 1.0; 2.0 and 4.0 liters per minute in each cultivation channel. We used 20 experimental plots with 15 lettuce plants per plot.

Experimental units were installed on 7-meter individual benches, bench slope of 10%. Cultivation channels were installed in rectangular section PVC profile, 8-cm width and 4-cm height, perforated at the top, every 25 cm, for the plants. Each bench consisted of seven cultivation channels spaced 20 cm, with individual pumping system, and a 310-liter reservoir, kept at a minimum of 95% of its capacity.

We used cultivar Betty, which is large, plenty of broad and thick leaves which provided adequate head protection, as well as being tolerant to early bolting, 70-day average cycle and an ideal population from 80 to 160 plants per hectare (Horticeres, 2018).

Lettuce seedlings were produced in phenolic foam trays and kept in a nursery for 12 days. After this period, seedlings were transplanted to definite benches, where they remained for 22 days until harvest. The nutrient solution was pumped in a closed circuit, flashing for 15 minutes on and 30 minutes off for 24 hours each day. The authors used Plenaferti PM1 and Plenaferti PM2 concentrates (with densities 1.23 g/mL) produced by Plenaferti, on all phases of the crop. The solution contained the following nutrient contents in g/L: 77.65 N, 15.95 P, 75.26 K, 23.39 S, 41.60 Ca, 17.82 Mg, 0.27 B, 0.08 Cu, 1.09 Fe, 0.29 Mn, 0.05 Mo, 0.06 Ni and 0.11 Zn. Conductivity and pH were maintained every morning, observing punctual conductivity and replacing the nutrient solution. The nutrient solutions of all treatments were kept at 0.9 dS/m-conductivity in the nursery, at 1.2 dS/m in the first 10 days after transplanting (DAT) and at 1.6 dS/m during the rest

of the cycle.

Harvest was performed at 22 DAT, when the authors evaluated total, root and shoot fresh masses of 15 lettuce plants. Then, plants were dried in a dryer with forced air circulation at 60°C for 72 hours; afterwards, plants were weighed to obtain total, root and shoot fresh masses. After weighing, the plant material was ground using a Willey type mill, passed through 40-mesh sieve; later, it was homogenized and finally, packed in polyethylene bags, properly labelled and stored in a dry chamber until analysis.

In order to determine N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn contents for shoot, root and leaf diagnosis (newly developed leaves), as recommended by Trani & Raji (1997), the plant samples were subjected to wet digestion, according to the methodology described by Malavolta *et al.* (1997).

Nutrient accumulation in shoot and root of plants was calculated based on dry masses and the nutrient contents. Nitrate and ammonia contents were also determined on the dry mass collected from the shoots and roots of lettuce, according to adapted methodology of Silva (2009).

Nutrient use efficiency (EUN) for each treatment was calculated using the following formula:  $EUN = (\text{total dry mass of plant})^2 / (\text{total nutrient accumulation in plant})$ ; in (g of MS)<sup>2</sup> / g of the accumulated nutrient (Siddiqi & Glass, 1981).

Results were submitted to analysis of variance and, initially, to analysis of polynomial regression, in order to obtain adjustments and equation with low determination coefficient (R<sup>2</sup>), though; considering the practical need to recommend the best flow which considers greater number of evaluations performed considered productive interest of the crop, we compared the averages of treatments (nutrient solution flows) using Tukey test at 5% probability, using SISVAR program version 5.6 (Ferreira, 2015).

## RESULTS AND DISCUSSION

Lettuce cultivated in a nutrient solution at 1.0 L/min flow rate had the highest shoot production on both a fresh

and dry weight basis (Figure 1), followed by 2.0 and 4.0 L/min which did not differ among each other. The least satisfactory result for production of fresh and dry mass of shoot was verified with 0.5 L/min which was lower in 28 and 32%, respectively, when compared to 1.0 L/min. The lowest production of fresh and dry mass of shoots was at 2.0 and 4.0 L/min flow rates comparing to 1.0 L/min, showing excessive application of nutrient solution (Figure 1).

NFT method recommends obtaining a nutrient solution depth at the bottom of the cultivation channel measuring no larger than 4 mm thickness, so that just one third of the root system remains uncovered by the nutrient solution, allowing roots to be oxygenized.

Increasing the flow rate from 2.0 L/min to 4.0 L/min, the depth raised above the second third root, which provoked darkening and necrosis of the structure and also the emergence of pronounced adventitious roots, aiming to compensate the loss of part of root system, nutritional damages were already irreversible, though (Prado & Cecilio Filho, 2016).

Nevertheless, the increment of the flow proportionally increased the speed of the nutrient solution, which promoted greater friction to the roots acting as physical barriers to

the solution trajectory. The effect of increasing friction caused damage to the root system, which contributed to the reduction of the nutrient absorption capacity of the roots, observed by the lowest nutrient accumulation in shoot area (except for Zn) in relation to 1.0 L/min flow (Figure 2), thus impairing the development of lettuce. This fact could be observed both for the lowest production of fresh and dry mass (Figure 1), and for the lowest root system of lettuce showing signs of low oxygenation (Figure 3).

The unsatisfactory result obtained with 0.5 L/min flow, both in fresh and dry mass, in the developing of shoot area or root system, shows that there was lower water absorption by the plants. Bandeira *et al.* (2011)

reported that this can be explained by the decrease in leaf water potential, stomatal conductance and CO<sub>2</sub> flow, resulting in an adverse impact on accumulations of photoassimilate compounds and as a consequence, reduction in crop production. Water deficit effect causes changes in stomatal responses, osmotic adjustment and important movement of photoassimilates to the roots, metabolic energy consumption and affects crop production anywhere in the plant as well as its commercial quality (Geisenhoff *et al.*, 2016). According to Soares (2007), plants submitted to increasing salinity were less tender, showing more coriaceous leaves: these characteristics were also observed in this study.

In similar study, a flow rate of 0.5 L/min also provided lower dry

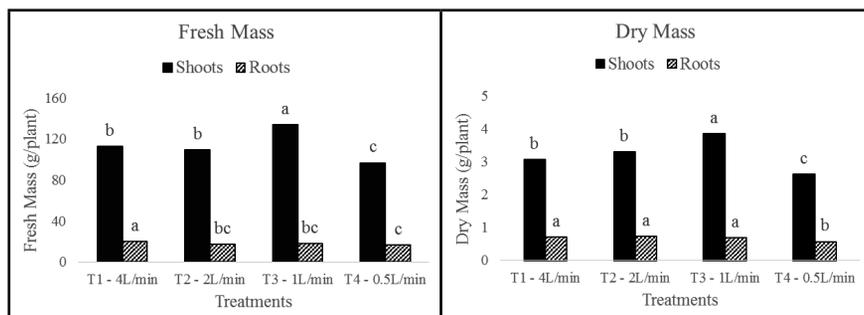
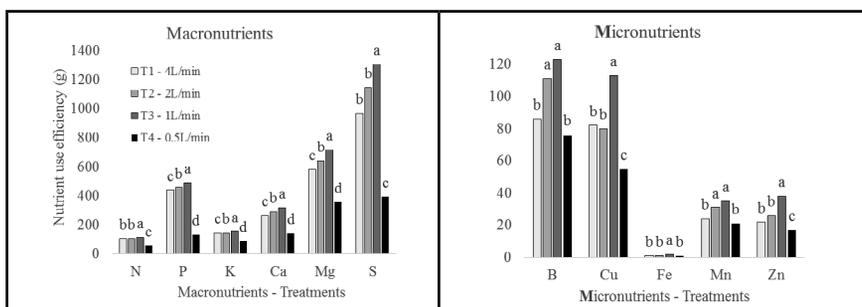


Figure 1. Fresh and dry mass of head lettuce grown in hydroponic system under flow rates of the nutrient solution. Averages followed by same letters did not significantly differ by Tukey test, p<0.05. Aparecida do Taboado, UNESP, 2017.

Table 1. Nutrient contents in the diagnosis leaf of head lettuce grown in hydroponic system under flow rates (4, 2, 1 and 0.5 L/min) of the nutrient solution. Aparecida do Taboado, UNESP, 2017.

Nutrients	4 L/min		2 L/min		1 L/min		0.5 L/min	
	Content	%	Content	%	Content	%	Content	%
N	39.43 A	43%	43.80 A	45%	42.0 A	46%	43.43 A	42%
P	7.43 H	8%	6.73 A	7%	7.53 H	8%	10.20 H	10%
K	20.37 L	-22%	24.57 L	-25%	21.70 L	-24%	20.97 L	-20%
Ca	15.17 A	17%	12.80 L	-13%	11.70 L	-13%	18.43 A	18%
Mg	4.77 A	5%	4.93 A	5%	5.20 A	6%	5.90 A	6%
S	3.53 H	4%	3.13 H	3%	2.97 H	3%	3.83 H	4%
B	77.33 H	0.08%	62.67 H	0.06%	55.00 A	0.06%	102.33 H	0.10%
Cu	39.00 H	0.04%	24.67 H	0.03%	15.33 A	0.02%	40.67 H	0.04%
Fe	242.67 H	0.27%	164.67 H	0.17%	149.67 A	0.16%	237.33 H	0.23%
Mn	176.33 H	0.19%	124.67 A	0.13%	134.67 A	0.15%	182.67 H	0.18%
Zn	244.67 H	0.27%	134.67 H	0.14%	117.67 H	0.13%	184.33 H	0.18%

Nutrients contents in the diagnosis lettuce leaf, based on data obtained by Trani & Raji (1997), indicated as high (H), adequate (A) and low (L). Values in % show an increase or reduction in relation to the average content of each nutrient. <sup>1</sup>Flow rates submitted to a rectangular PVC duct, with intermittence of 15 minutes and intervals of 30 minutes, seven-meter length and slope of 10%.



**Figure 2.** Nutrient use efficiency of head lettuce grown in hydroponic system under flow rates of the nutrient solution. Aparecida do Taboado, UNESP, 2017.



**Figure 3.** Lettuce root system showing signs of stress caused by low oxygenation (left), related to a nutrient solution at 4.0 L/min flow rate and well-developed root system with adequate oxygen supply (right), nutrient solution at 1.0 L/min flow rate {source: Dalastra (2017)}. Aparecida do Taboado, UNESP, 2017.

mass production than the other rates in experiments carried out in Parana (Santos *et al.*, 2011) and Rio de Janeiro (Genuncio *et al.*, 2012). We highlight that temperature, relative humidity and more intense solar radiation where the experiment was conducted also contribute for water stress, causing even more damage to the plants grown at this flow rate.

In relation to lettuce root system, for fresh mass, the highest development was obtained at 4.0 L/min, followed by 2.0 and 1.0 L/min which did not differ from 0.5 L/min, which obtained the lowest value for root fresh mass (Figure 1). The treatment with 4.0 L/min was the only one to provide different behavior between dry and fresh mass, showing an increase in fresh mass as opposed to dry mass (Figure 1). The expression of this behavior may be associated with

the beneficial effect of heat dissipation inside the cultivation channel, given the high volume of current solution in this treatment (Casaroli *et al.*, 2003). Thus, the plants absorbed more water, but as they absorbed less CO<sub>2</sub>, there was less accumulation of lettuce dry mass in this treatment.

Evaluating nutrient contents in diagnose leaf based on sufficiency ranges proposed by Trani & Raj (1997), the authors verified that, for all treatments, leaf nutrient contents were adequate or high, except for K which was deficient (Table 1). We also highlight that the flow rates 1.0 and 2.0 L/min provided Ca contents in leaves lower than the one recommended by the mentioned authors. However, no K and Ca deficiency symptoms were observed, which characterizes a moderate deficiency (hidden hunger)

or even a smaller demand of this lettuce cultivar in relation to these exchangeable bases. Petrazzini *et al.* (2014), evaluating simple omissions (K, Ca, B, Zn) and combined omissions (Ca and B; K and Zn; B and Zn) of nutrients and a control (with all nutrients) in head lettuce Rider Plus, concluded that under Ca omission, the plants showed chlorosis on younger leaf margins, and K was the nutrient which the most restricted the production of fresh mass, shoot dry mass and root dry mass. Paulus *et al.* (2012), in hydroponic cultivation system with saline water, did not verify nutritional deficiency symptoms in lettuce plants cv. Verônica and Pira Roxa.

For shoot nutrient contents (Table 2), the authors noticed higher contents of P, Ca, Mg, Mn and Zn at the lowest flow rate (0.5 L/min), due to concentration effect, since, in this treatment, we could notice lower dry matter accumulation. We highlight that this flow rate (0.5 L/min) provided higher nitrate content and lower ammonium content when compared to the others.

For root nutrient contents (Table 2), the lowest flow rate provided highest contents of P, S, Fe and Cu, whereas at the highest flow rate (4.0 L/min), we verified higher B content in the root. In relation to other nutrient contents, nitrate and ammonium, no difference between treatments was noticed.

However, when nutrient contents in lettuce shoot area were considered, we noticed that the flow rate of 1.0 L/min provided higher nutrient contents (except for Zn), ratifying the best performance for fresh and dry mass production in this treatment (Table 2). Zn content may have been lower due to ion antagonism since non-competitive inhibition presented between Zn and P (Moreira *et al.*, 2001). The flows of 4.0 and 2.0 L/min provided moderate nutrient accumulation, and the flow rate of 0.5 L/min provided lower accumulated amounts of most nutrients, and similar accumulation could be verified at the flow rate of 4.0 and 2.0 L/min for some nutrients. These results corroborate the conclusion that nutrient accumulation shows a close correlation with crop production in relation to

nutrient contents.

In root system, the situation is opposite; at the flow rate of 0.5 L/min, we noticed higher nutrient accumulation, except B and Mn (Table 2), whereas in the treatment with a flow rate of 1.0 L/min, we noticed lower accumulated nutrients in the roots. This is due to higher transport efficiencies (Dalastra, 2017) and due to use of all nutrients verified at a flow rate of 1.0 L/min (Figure 2).

Nitrate content in shoot was high when a lower flow rate (0.5 L/min) was used, reaching up to 3.5 g/kg. In the other treatments nitrate content

was lower than 0.85 g/kg (Table 2). Lower nitrate contents were obtained by Cavarianni *et al.* (2000), evaluating lettuce cultivars showing contents from 1.545 to 1.963 g/kg for loose leaf type lettuce, from 1.242 to 1.536 g/kg for crispy head lettuce and from 1.030 to 1.965 g/kg for head lettuce. We highlight that nitrate contents, except the ones obtained at the lowest flow rate, are quite lower than the standard set by European legislation, from 3.50 to 4.55 g/kg for fresh mass (Faquin & Andrade, 2004). Pôrto *et al.* (2012) verified that the maximum content of nitrate on leaves is below the risk limit for human health,

and that the increase of N availability in the nutrient solutions results in a linear increase of nitrate contents in different parts of lettuce cv. Elba.

Nitrogen, constituent of amino acids, proteins, enzymes, coenzymes and nucleotides (Malavolta *et al.*, 1997) is provided for the plant in hydroponic system in the form of ammonium ion and nitrate. However, nitrate is reduced to nitrite in the plant cell cytoplasm and then, nitrite is converted to ammonium in chloroplasts during photosynthetic process (Faquin & Andrade, 2004). Nevertheless, under water stress, even when it is moderate, the plant shows a

**Table 2.** Content and accumulation of nutrients in shoots and roots of head lettuce grown in hydroponic system under flow rates (4, 2, 1 and 0.5 L/min) of the nutrient solution. Aparecida do Taboado, UNESP, 2017.

Nutrients	4 L/min	2 L/min	1 L/min	0.5 L/min	4 L/min	2 L/min	1 L/min	0.5 L/min
	Content in shoots (g/kg)				Accumulation in shoots (g/plant)			
N	38.40 a	40.57 a	39.67 a	42.07 a	0.110 c	0.130 b	0.160 a	0.100 c
NO <sub>3</sub> <sup>-</sup>	0.642 b	0.858 b	0.805 b	3.500 a	0.002 b	0.003 b	0.009 a	0.009 a
NH <sub>4</sub> <sup>+</sup>	2.193 a	2.362 a	2.333 a	1.925 b	0.007 a	0.008 a	0.009 a	0.005 b
P	8.03 b	7.43 b	8.10 b	10.83 a	0.020 b	0.020 b	0.030 a	0.020 b
K	30.37 a	31.57 a	31.40 a	28.20 a	0.090 c	0.100 b	0.120 a	0.060 d
Ca	16.60 b	15.80 b	15.23 b	21.80 a	0.050 b	0.050 b	0.060 a	0.050 b
Mg	7.80 b	7.57 b	6.93 b	9.63 a	0.020 b	0.020 b	0.030 a	0.020 b
S	3.30 a	2.93 a	2.80 a	3.03 a	0.010 b	0.010 b	0.010 a	0.010 c
	Content in shoots (mg/kg)				Accumulation in shoots (mg/plant)			
	B	37.33 a	34.33 a	34.00 a	42.00 a	0.11 b	0.11 b	0.13 a
Cu	18.00 a	15.67 a	13.67 a	22.00 a	0.05 a	0.05 a	0.05 a	0.05 a
Fe	296.33 a	233.33 a	240.67 a	287.00 a	0.86 a	0.75 b	0.93 a	0.66 b
Mn	187.00 b	148.00 bc	137.67 c	191.67 a	0.54 a	0.47 b	0.54 a	0.44 b
Zn	188.00 a	162.00 ab	118.33 b	217.67 a	0.55 a	0.52 ab	0.47 b	0.50 ab
	Content in roots (g/kg)				Accumulation in roots (g/plant)			
	N	36.67 a	37.93 a	37.60 a	33.70 a	0.026 b	0.028 b	0.026 b
P	13.20 c	16.27 b	15.07 b	22.30 a	0.009 b	0.012 b	0.010 b	0.052 a
K	15.40 a	14.37 a	15.17 a	19.43 a	0.011 b	0.011 b	0.011 b	0.050 a
Ca	8.63 a	7.90 a	8.03 a	8.97 a	0.006 b	0.006 b	0.006 b	0.022 a
Mg	2.83 a	2.10 a	2.50 a	2.70 a	0.002 b	0.002 b	0.002 b	0.007 a
S	7.47 b	6.57 b	7.07 b	9.23 a	0.005 b	0.005 b	0.005 b	0.019 a
	Content in roots (mg/kg)				Accumulation in roots (mg/plant)			
	B	84.00 a	50.33 b	54.00 b	63.00 b	0.059 a	0.037 b	0.038 b
Cu	176.33 c	207.00 ab	186.67 bc	222.00 a	0.124 b	0.154 a	0.130 b	0.137 ab
Fe	127.94 c	152.11 b	115.31 c	245.23 a	8.961 c	11.29 b	7.957 c	15.070 a
Mn	91.33 a	75.33 a	73.00 a	76.67 a	0.064 a	0.056 b	0.051 bc	0.047 c
Zn	157.67 a	140.00 a	120.33 a	174.67 a	0.110 a	0.104 a	0.084 b	0.107 a

Averages followed by same letters on lines did not significantly differ from each other by Tukey's test,  $p < 0.05$ .

decrease in photosynthetic rate (Lawlor & Tezara, 2009), favoring nitrate accumulation in tissues. In other studies, nitrate behavior in lettuce tissues tended to increase as it becomes different from 1 L/min flow rate, higher or lower levels (Ohse *et al.*, 2009; Aprígio *et al.*, 2012), corroborating somehow the obtained results.

The treatments evaluated in this study showed the following order of macronutrients extraction: N>K>Ca>P>Mg>S (Table 2), similar to the reported: adequate for high lettuce productivity (Faquin *et al.*, 1996). For micronutrients, at flow rates of 2.0 and 0.5 L/min, the authors verified that extraction order was Fe>Zn>Mn>B>Cu, similar to the one described by Faquin *et al.* (1996); however, the flow rate of 4.0 L/min showed alternation between the order of Fe and Zn and the flow rate of 1.0 L/min reversed the order of Mn and Zn.

Given the above, we could conclude that the flow rate in hydroponics systems in order to produce head lettuce, alters the crop growth and development. The highest head lettuce production is obtained in a nutrient solution at 1.0 L/min flow rate.

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