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Dry matter production and macronutrient leaf composition in lettuce under fertigation with nitrogen, potassium and silicon

Renan S. de Souza[1], Roberto Rezende[1], Paulo S. L. de Freitas[1], Antonio C. A. Gonçalves[1] & Graziela S. Rezende[2]

[1] Departamento de Agronomia/Universidade Estadual de Maringá. Maringá, PR. E-mail: nansoares86@hotmail.com (Corresponding author); rrezende@uem.br; pslfreitas@uem.br; goncalves.aca@gmail.com
[2] Departamento de Biologia/Universidade Estadual de Maringá. Maringá, PR. E-mail: grazi_9@msn.com

Key words:
Lactuca sativa L.
chemigation
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ABSTRACT

The objective of this study was to evaluate, in greenhouse, the response of the lettuce cultivar 'Vera', with respect to the marketable shoot dry matter production and macronutrient accumulation, as a function of the application of different doses of nitrogen (N) and a potassium silicate-based leaf fertilizer. The lettuce was cultivated from August 10, 2012 (sowing) to October 16, 2012 (harvest). The experimental design was completely randomized with three replicates, referring to nine treatments, resulting from the combination between top-dressing doses of N (9, 54, 90, 126 and 171 kg ha^{-1}) and Si/K_2O (1.15, 6.90, 11.50, 16.10 and 21.85 kg ha^{-1}), using the Plan Puebla III experimental matrix, and a control treatment without fertigation. Drip fertigation was used for the application of the doses. The highest doses of N and Si/K_2O resulted in the highest marketable shoot dry matter production and highest leaf accumulation of magnesium, calcium, potassium and phosphorus.

Palavras-chave:
Lactuca sativa L.
quimigação
massa seca
composição nutricional

Produção e composição foliar de macronutrientes em alface sob fertirrigação com nitrogênio, potássio e silício

RESUMO

O objetivo deste trabalho foi avaliar, em ambiente protegido, a resposta de alface cultivar Vera, quanto à produção de massa seca comercial da parte aérea e ao acúmulo de macronutrientes em função da aplicação de diferentes doses de nitrogênio (N) e de fertilizante foliar à base de silicato de potássio. O cultivo de alface ocorreu entre os dias 10/08/2012 (semeadura) e 16/10/2012 (colheita). O delineamento foi inteiramente casualizado com três repetições referentes a nove tratamentos resultando de combinação entre doses em cobertura de N (9; 54; 90; 126 e 171 kg ha^{-1}) e de Si e K_2O (1,15; 6,90; 11,50; 16,10 e 21,85 kg ha^{-1}) empregando a matriz Plan Puebla III e um tratamento controle sem fertirrigação. Utilizou-se fertirrigação por gotejamento para aplicação das doses. As maiores doses de N, Si e K_2O resultaram na maior produção de massa seca comercial da parte aérea e na maior acumulação foliar de magnésio, cálcio, potássio e fósforo.

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Introduction

Lettuce (*Lactuca sativa* L.) belongs to the botanical family Asteraceae and is an option in the olericulture for the cultivation both in protected environment and at the field. Commonly, the produced leaves are commercialized and freshly consumed in the form of salad, which is an alternative of healthy food in the Brazilian menu.

The increment in yield and in the quality of the obtained production requires the adoption of technologies for the protection of plants and the supply of water and nutrients, in order to reduce production costs, the period from planting to harvesting and food risks (Maggi et al., 2006). The use of protected environment can lead to some advantages like, according to Martins (2008), the increase in yield, improvement in product quality, reduction in supply seasonability, better use of fertilizers, pesticides and water, and total or partial control of climatic factors.

In the cultivation in protected environments, localized drip irrigation is an alternative (Andrade Júnior & Klar, 1997). The economy of water, increase in irrigation efficiency, the favoring of the use of fertigation, the high nutrient use efficiency and the reduction of phytosanitary problems, are some of the advantages promoted by drip irrigation (Filgueira, 2008).

The procedure of dissolving certain fertilizers in the irrigation water represents fertigation (Filgueira, 2008), whose importance derives from the increase in the use of drip irrigation system and is related to the increase in yield and reduction of production costs. The most used nutrients are the ones with higher mobility in the soil, like nitrogen (N) and potassium (K) (Carrijo et al., 2004). In addition, the practice of fertigation can be advantageous, since fertilizations can be divided (Duenhas et al., 2002) and because of the possibility of more homogeneous distribution in the root zone and in the soil profile (Coelho & Silva, 2005).

In a study on lettuce performed by Garcia et al. (1982), the accumulation of nutrients followed the production of dry matter, in general. According to Beninni et al. (2005), there is a direct relationship between the accumulations of nutrients and dry matter, when lettuce is cultivated in a conventional system (soil) and, in this case, the order of accumulation of macronutrients by the shoots is K > N > Ca > P > S > Mg.

Using top-dressing N doses (0, 60, 120 and 180 kg ha^{-1}), additional to the dose of 60 kg N ha^{-1} applied by the farmer, and five doses of molybdenum (Mo) through foliar application (0.0, 35.1, 70.2, 105.3 and 140.4 g ha^{-1}), Resende et al. (2012) evaluated the nutritional composition of dried samples of the marketable part of lettuce (cultivar 'Raider') and observed the highest N content at the dose of 161.5 kg of N ha^{-1}, while, in the absence of Mo, P contents showed linear response as N doses increased. Resende et al. (2012) observed no significant difference of the treatments for K contents, in the absence of Mo fertilization; however, in the absence of Mo fertilization, the highest return of Ca content was observed at the N dose of 124.6 kg ha^{-1}. These authors also observed that the N dose of 125.8 kg ha^{-1} resulted in the highest Mg content and that the increment in N doses, for the absence of Mo fertilization, promoted increase in S content.

Kano et al. (2010), studying lettuce for seed production in protected environment and pots under K_2O doses (0.0, 1.0, 1.5, 2.0 and 2.5 g $plant^{-1}$), observed significant influence of K doses on the K and Mg contents in the shoots, but did not observe significant effects for the contents of N, P, Ca and S. However, these authors also observed that the increase in K doses resulted in linear increase of K contents and promoted linear reduction in Mg contents.

With the application of Ca-silicate doses in experiment with lettuce cultivars in pots and greenhouse, Ferreira et al. (2010) did not observe significant differences for the effect of Ca-silicate on the leaf contents of N, P, K, Ca, Mg and S; however, they observed that increasing Ca-silicate doses resulted in N deficiency.

N and K fertilizations can influence the nutritional composition of lettuce. It is necessary to verify whether the association between the applications of N and Si/K has any effect on dry matter production and macronutrient composition. It is important to perform this verification in specific production situations, such as in protected environment and using drip fertigation, in order to generate knowledge for a better management of these techniques.

In this context, this study aimed to evaluate marketable shoot dry matter and macronutrient mineral composition in leaves of crisphead lettuce, cultivar 'Vera', in protected environment and as a function of doses of N and K-silicate-based fertilizer as top-dressing and via drip fertigation.

Material and Methods

The experiment was conducted from August 10 to October 16, 2012, in a greenhouse, at the Technical Irrigation Center (CTI) of the Maringá State University (UEM), in Maringá-PR, Brazil (23° 23' 56.50" S; 51° 57' 7.53" W; 512 m). This location corresponds to the climatic class Cfa (subtropical), according to Köppen's classification.

Samples of a soil classified as distroferric Red Nitosol, according to EMBRAPA (2006), were collected in the depth of 0.10 m, for the evaluation of the following attributes: pH ($CaCl_2$) = 7.10; pH (H_2O) = 7.90; organic matter and C = 25.57 and 14.83 g dm^{-3}, respectively; P = 214.59 mg dm^{-3}; K^+, Ca^{+2}, Mg^{+2}, Al^{+3}, $H^+ + Al^{+3}$, sum of bases and cation exchange capacity = 0.46, 6.68, 1.53, 0.00, 1.75, 8.67 and 10.42 $cmol_c$ dm^{-3}, respectively; base saturation = 83.21% and S = 10.62 mg dm^{-3}.

According to the layout in Figure 1, three beds with length of 14 m, width of 1.2 m and height of 0.1 m were built in the experimental area after soil turning with rotary hoe, which were prepared with 0.5 kg m^{-2} of poultry manure and 40 kg ha^{-1} of N (urea; 45% N). Each bed was divided into 10 parts, for the installation of the 30 experimental plots with length of 2.4 m, width of 0.6 m and height of 0.1 m.

The drip micro-irrigation systems used in the experiment comprised a 0.5-hp centrifugal pump connected to a 500-L water tank, one main PVC line with diameter of 32 mm and one return PVC line with diameter of 32 mm, which returned to the initial tank (Figure 1). The previously mentioned beds were separated by five transversal divisions and two longitudinal

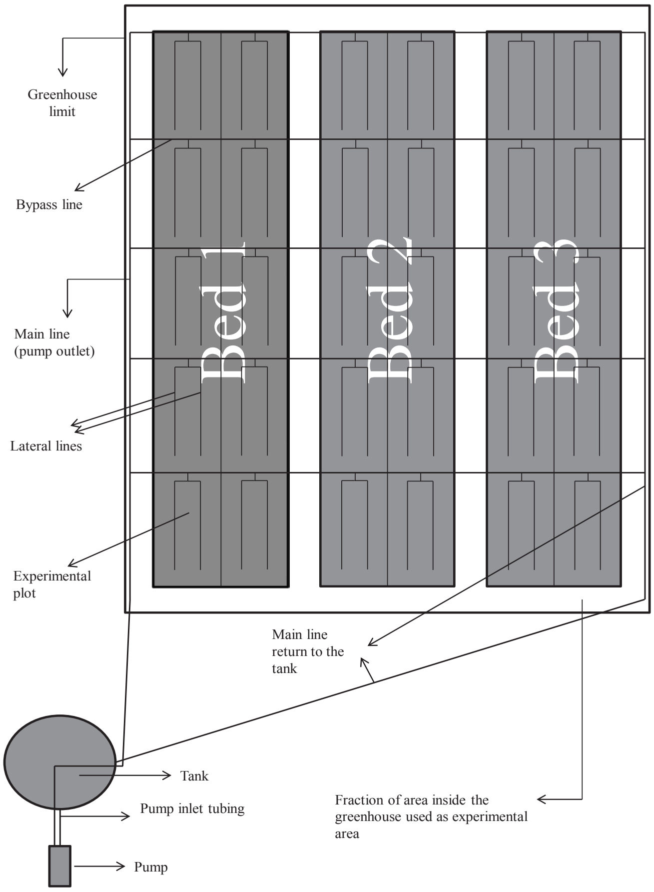


Figure 1. Layout with the spatial disposition of beds, experimental plots and irrigation system

divisions for each bed. Five bypass PVC lines with diameter of 32 mm, perpendicular to the main line, were installed in the transversal divisions of the beds. Therefore, because of the longitudinal divisions, each bypass line had six valves that were used for the individual control of irrigation and fertigation of one experimental plot, in a total 30 valves.

Two lateral lines of polyethylene drip tubes with diameter of 16 mm were connected to the valve of the plot through double outlets (Figure 1), each one with 12 pressure-compensating drippers, which showed mean flow rate per emitter of 0.85 L h^{-1}, for the operating pressure of 10 m.w.c., adopted for the procedures of irrigation and fertigation.

For the production of lettuce seedlings, one seed of the cultivar 'Vera' was placed in each one of the 128 cells of polystyrene trays, which were filled with the commercial substrate Mecplant®. When the seedlings had four leaves, they were transplanted to the soil in the experimental area, 26 days after seeding (September 5, 2012), using 36 seedlings for each plot, arranged as 12 plants in three rows with a spacing of 0.20 x 0.20 m, and placing each lateral line between lettuce rows.

For irrigation, the soil water tension of 15 kPa was used as a reference, based on Santos & Pereira (2004) and Vilas Boas et al. (2007), through the reading of tensiometers installed at a depth of 0.10 m.

Ten treatments were evaluated using a completely randomized design with three replicates. Nine treatments were obtained by the combination between top-dressing doses of N (9, 54, 90, 126 and 171 kg ha^{-1}) and Si/K (potassium oxide - K_2O) (1.15, 6.90, 11.50, 16.10 and 21.85 kg ha^{-1}), according to the Plan Puebla III experimental matrix (Turrent & Laird, 1975). One treatment was considered as a control and was not fertigated with N and Si/K doses. Urea was used as the N source and, for Si and K, the commercial product Fertisilício® was used, which is a liquid foliar fertilizer based on K-silicate, with the following composition: 12% of water-soluble Si (165.6 g L^{-1}) and 12% of water-soluble K_2O (165.6 g L^{-1}), guaranteed by the product.

For the top-dressing fertigation, N (urea) and Si/K (Fertisilício®) were separately supplied and the previously mentioned total doses were divided into for weekly applications. In addition, 15 L of fertilizer solution were used per treatment, and a previously prepared urea solution, at the concentration of 10% of N (m v^{-1}), was used for N fertigation. For Si/K fertigation, ¼ of the total doses of 1.15, 6.90, 11.50, 16.10 and 21.85 kg ha^{-1} of Si/K_2O are equivalent to 0.05, 0.30, 0.50, 0.70 and 0.95 mL of Fertisilício® per L of water, respectively.

Only the eight central plants of each experimental plot were collected and evaluated for marketable shoot dry matter (MSDM; g plant^{-1}) and the accumulation of magnesium (Mg), calcium (Ca), potassium (K), nitrogen (N), phosphorus (P) and sulfur (S) (macronutrients) (mg plant^{-1}) in the MSDM.

The fresh material from the evaluated plants of each experimental plot were dried in an oven at 65 °C until constant weight; then, a digital scale was used to obtain the MSDM and the means of the treatments and their respective replicates, in g plant^{-1}, were used in the statistical analyses.

MSDM samples of the evaluated plants in each experimental plot were sent to a laboratory for the determination of the contents of each macronutrient in the MSDM, according to Malavolta et al. (1997). The accumulation of macronutrients was obtained by the multiplication of MSDM and the content of macronutrient in the MSDM, and the values obtained for the treatments and their respective replicates, in mg plant^{-1}, were used in the statistical analyses.

Using the program SISVAR, the evaluated characteristics were studied using multiple linear regression analysis and Tukey test at 0.05 probability level for the absence of selection of a statistical model by the multiple linear regression analysis.

The selection of the statistical models by the multiple linear regression analysis was performed using the following criteria: F test significant for the regression ($p < 0.05$); F test not significant for the lack of adjustment ($p < 0.05$); Student's t-test significant for regression coefficients ($p < 0.05$) and adjusted coefficient of determination (R^2_{adj}). Considering the complete model $\hat{Y} = \beta_0 + \beta_1(N) + \beta_2(Si\ and\ K_2O) + \beta_3(N)^2 + \beta_4(Si\ and\ K_2O)^2 + \beta_5(N)(Si\ and\ K_2O)$, where: $\hat{Y}$ is the estimated value of the studied characteristic; β_0, β_1, β_2, β_3, β_4, β_5 are the regression coefficients; N is the dose of N (kg ha^{-1}) and Si and K_2O is the dose of Si and K_2O (kg ha^{-1}), other eleven possible linear models were studied. That is, twelve statistical models were evaluated in total, thus being possible to verify the presence of linear, quadratic and interactive effects, related to the doses of nutrients on the analyzed characteristics.

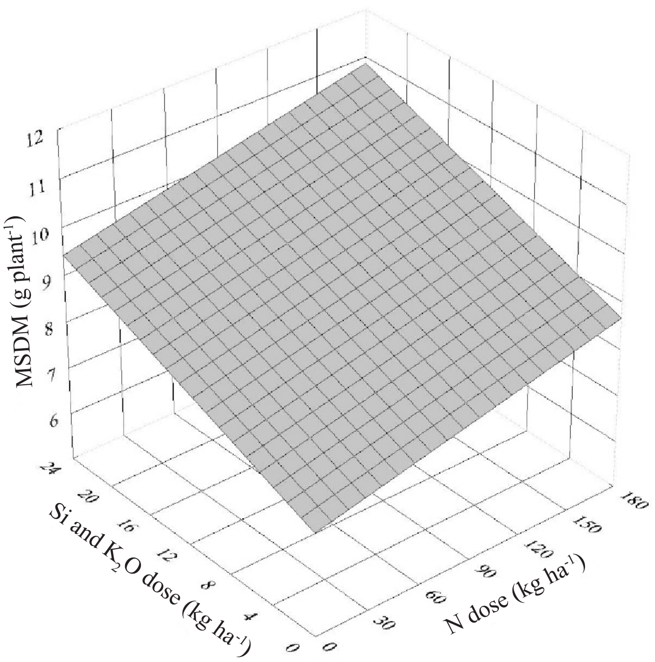
Results and Discussion

The statistical model selected for the marketable shoot dry matter pointed to significant influence of N and Si/K fertigation on this characteristic. According to the model, the increase in N and Si/K doses stimulated the production of marketable shoot dry matter of lettuce. The best response (10.60 g $plant^{-1}$) occurred at the highest doses of N (171 kg ha^{-1}) and Si/K_2O (21.85 kg ha^{-1}). The greatest variation in marketable shoot dry matter, between the dose zero and the highest dose, occurred with the use of Si/K fertigation (Figure 2).

Through the evaluation of treatments associated with N doses (0, 60, 120, 180 and 240 kg ha^{-1}) applied in the form of urea and via fertigation, in lettuce, Araújo et al. (2011) observed that shoot dry matter responded to N fertilization through a decreasing linear equation. This differs from the result in the present study, in which the marketable shoot dry matter was favored by the increase in N doses. This difference was possibly due to the organic fertilization performed in the study of Araújo et al. (2011). These authors concluded that there was an increase in soil fertility due to the organic fertilization so that N mineral fertilization was not necessary to increase lettuce production.

Biscaro et al. (2012), for a superficial irrigation system (drip hoses) and the dry matter of chicory, observed a quadratic response and the N dose of approximately 125 kg ha^{-1} was considered to have the highest technical efficiency. In the present study, although evaluating lettuce, the marketable shoot dry matter was favored by the increase in N doses, which agrees with the result reported by Biscaro et al. (2012).

Porto et al. (2013) evaluated six K_2O doses (0, 50, 100, 150, 200 and 250 mg dm^{-3}) on rocket plants and observed that shoot dry matter production showed a linear response, as a function of K doses, and was favored by K fertilization. In this study, the marketable shoot dry matter benefited from the K supply, which agrees with the result reported by Porto et al. (2013) for rocket.



$$MSDM = 7.2065 + 8.0567x10^{-3*}.(N) + 9.2162x10^{-2*}.(Si\ and\ K_2O)$$
$$R^2_{adj}{}^{(a)} = 0.5966$$

*Significant by Student's t-test ($p < 0.05$); (a)Adjusted coefficient of determination

Figure 2. Marketable shoot dry matter (MSDM) as a function of doses of N and Si/ K_2O

In the evaluation of the effects of K doses and sources, as top-dressing, on cabbage, Correa et al. (2013) used treatments resulting from K_2O doses (45, 90, 135 and 180 kg ha^{-1}), two sources (potassium chloride and sulfate) and a control (without K as top-dressing). These authors observed no significant differences for doses and sources of K on head dry matter. Unlike Correa et al. (2013), the supply of K favored the marketable shoot dry matter of lettuce in the present study.

Luz et al. (2006), using nutrient solution with Si, observed that hydroponically grown lettuce plants showed lower shoot dry matter, which disagrees with the present study, in which the supply of Si and K via fertigation favored the marketable shoot dry matter of lettuce.

Fertigations with N ($Mg = 20.1858 + 4.1943.10^{-2}.N$; R^2_{adj} = 0.2867) and Si/K ($Mg = 19.9856 + 3.4797.10^{-1}.Si\ and\ K_2O$); R^2_{adj} = 0.3376) promoted linear Mg accumulation. The N increment of 25 kg ha^{-1} resulted in an increase of 1.05 mg $plant^{-1}$ in Mg accumulation, while the addition of 2.5 kg ha^{-1} in the dose of Si/K_2O promoted an increase of 0.87 mg $plant^{-1}$. The highest Mg accumulations occurred for the highest doses of N (171 kg ha^{-1}; 27.36 mg $plant^{-1}$) and Si/ K_2O (21.85 kg ha^{-1}; 27.59 mg $plant^{-1}$).

Ca accumulation increased linearly as a function of the increments in N ($Ca = 156.3394 + 3.6392.10^{-1}.N$; $R^2_{adj} = 0.3243$) and Si/K_2O ($Ca = 152.9444 + 3.1761.Si\ and\ K_2O$); R^2_{adj} = 0.4338). The addition of 25 kg of N ha^{-1} resulted in an increment of 9.10 mg $plant^{-1}$ in Ca accumulation, with its highest value (218.57 mg of Ca $plant^{-1}$) observed at the maximum N dose (171 kg ha^{-1}). On the other hand, the increment of 2.5 kg ha^{-1} in the dose of Si/K_2O promoted an increase of 7.94 mg of Ca $plant^{-1}$, and the best response (222.34 mg of Ca $plant^{-1}$) was observed at the maximum Si/K_2O dose (21.85 kg ha^{-1}).

K accumulation increased linearly with the increments in the doses of N ($K = 152.9528 + 1.8641.10^{-1}.N$; $R^2_{adj} = 0.1002$) and Si/K_2O ($K = 143.7624 + 2.3468.Si\ and\ K_2O$; $R^2_{adj} = 0.4577$). The addition of 25 kg ha^{-1} to the N dose resulted in an increase of 4.66 mg $plant^{-1}$ in K accumulation and its best response (184.83 mg of K $plant^{-1}$) was observed at the highest N dose (171 kg ha^{-1}). On the other hand, the increment of 2.5 kg ha^{-1} in the Si/K_2O dose promoted an increase of 5.87 mg $plant^{-1}$ in K accumulation, with its best response (195.04 mg of K $plant^{-1}$) at the maximum Si/K_2O dose (21.85 kg ha^{-1}).

No statistical model was selected for N accumulation. However, based on Tukey's mean test, there was significant difference between treatment means for this response variable, with superiority of treatments N4 and Si/K5 (354.33 mg of N $plant^{-1}$) and N5 and Si/K4 (354.86 mg of N $plant^{-1}$), in comparison to the control (175.31 mg of N $plant^{-1}$), which did not receive fertigation. The treatments N4 Si/K5 and N5 Si/K4 showed the highest means and result from the combination of the highest doses of N and Si/K_2O. The means of the treatments N4 Si/K5 and N5 Si/K4 were 102.12 and 102.42% higher compared with the means in the control, respectively (Table 1).

The statistical models selected for P accumulation indicated that fertigation with N ($P = 22.7004 + 5.9335.10^{-2}$ N; R^2_{adj} = 0.3094) and Si/K ($P = 21.6512 + 5.6573.10^{-1}$ Si and K_2O; R^2_{adj} = 0.5198) influenced this variable significantly. In the respective statistical models, P accumulation increased linearly as a function of the increase in the doses of N and Si/

Table 1. Tukey's means test for N accumulation in the marketable shoot dry matter of 'Vera' lettuce

Treatments	Doses (kg ha^{-1}) N	Doses (kg ha^{-1}) Si and K_2O	N (mg plant^{-1})
N2 Si/K2	54.00	6.90	248.55 ab
N2 Si/K4	54.00	16.10	251.18 ab
N4 Si/K2	126.00	6.90	352.96 a
N4 Si/K4	126.00	16.10	307.14 a
N3 Si/K3	90.00	11.50	253.09 ab
N1 Si/K2	9.00	6.90	321.30 a
N2 Si/K1	54.00	1.15	248.54 ab
N5 Si/K4	171.00	16.10	354.86 a
N4 Si/K5	126.00	21.85	354.33 a
Control	-	-	175.31 b

Means followed by the same lowercase letters in the column do not differ by Tukey test at 0.05 probability level

K_2O. According to the models, the addition of 25 kg ha^{-1} of N resulted in an increment of 1.48 mg of P plant^{-1}, with the best response (32.85 mg of P plant^{-1}) at the highest N dose (171 kg ha^{-1}). The increment of 2.5 kg ha^{-1} in the Si/K_2O dose promoted increase of 1.41 mg of P plant^{-1} and its highest value (34.01 mg of P plant^{-1}) was observed at the maximum Si/K_2O dose (21.85 kg ha^{-1}).

According to the previously described selection criteria, no statistical model was selected for S accumulation (overall mean = 10.91 mg plant^{-1}), i.e., there was no significant effect of the treatments on this response variable.

In the evaluation of nutrient accumulation in lettuce, Garcia et al. (1982) concluded that, in general, this characteristic followed the production of dry matter. On the other hand, in a study on lettuce cultivation in hydroponic and conventional (soil) systems, Beninni et al. (2005) observed that, in both cases, the accumulation of nutrients is directly related to dry matter accumulation.

The increase in the marketable shoot dry matter, due to the fertigation with N and Si/K (Figure 2), was probably related to the increase in the accumulation of macronutrients. This agrees with Garcia et al. (1982) and Beninni et al. (2005) regarding the possibility of this relationship, which is reinforced because most macronutrients (Mg, Ca, K and P) were also stimulated by the doses of N and Si/K_2O, according to the statistical models selected by the multiple linear regression analysis. Likewise and as observed through the Tukey's means test, N accumulation was favored by the fertigation with N and Si/K, compared with the control (Table 1).

If the marketable shoot dry matter was favored, the accumulation of macronutrients probably was also favored, because in this case the nutritional requirements might have been higher. The marketable shoot dry matter was favored by the application of increasing doses of N and K (Figure 2). These elements probably favored plant physiological activity, which resulted in higher demand for the performance of these nutrients in the plants, in their respective functions, and, in contrast, in their higher accumulation in the shoots.

Since the accumulation of some macronutrients was favored by the fertigation with Si and K, the increase in Si dose possibly contributed to the mineral composition of lettuce and benefited it. According to Epstein & Bloom (2006), an example in which this element can be involved occurs with respect to the influence on mineral composition, such as the content of N, P and other elements.

The possible favoring of plant physiological activity, through the supply of N and K, which increased the demand of these nutrients, can also have increased the demand of the other macronutrients (Mg, Ca and P). This occurred due to respective functions of these nutrients in plants and consequently, there was an increase in its accumulation in the shoots.

As to the contents of N and P, the results agree with Resende et al. (2012). This occurs because the mineral composition of lettuce, with respect to the accumulation of N and P, was favored by N fertigation. However, unlike these authors for K contents, the present study observed favoring of mineral composition by the N application, with respect to K accumulation.

As observed by Resende et al. (2012), the mineral composition associated with Ca accumulation was favored by the supply of N in the present study. Likewise, N application in the present study also favored the mineral composition with respect to Mg accumulation. However, there was no response for S accumulation in the present study, which disagrees with the previously mentioned authors.

The results reported by Kano et al. (2010) disagree with those obtained in the present study, in which K fertigation favored the mineral composition of lettuce with respect to the accumulation of Mg, Ca and P. As observed by these authors, the supply of K in the present study favored the mineral composition of lettuce with respect to K accumulation.

Unlike Ferreira et al. (2010), the nutritional composition (accumulation of macronutrients in the marketable shoot dry matter), with respect to Mg, Ca, K and P, was positively influenced by the supply of Si and K in the present study.

Conclusions

1. The marketable shoot dry matter and its accumulation of Mg, Ca, K and P benefited from the fertigation with N and the potassium silicate-based foliar fertilizer, with the greatest values observed at the highest doses of N (171 kg ha^{-1}) and foliar fertilizer (21.85 kg ha^{-1} of Si and K_2O).

2. The inferiority of N accumulation in the control plants under all the treatments makes viable the technique of fertigation with N and Si/K in the cultivation of lettuce, cultivar 'Vera'.

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