Original Research Article

Gas Exchange and Nitrogen Compartmentalization of Eggplant Under Nitrogen and Silicon Doses

---

.

ABSTRACT

Aims: To evaluate the effect of fertilization with N and Si on gaseous exchanges, dry mass, concentrations, accumulations and compartmentalization of nitrogen fractions in eggplant.

Study design: The experimental design was a randomized entirely design, in a 5 x 4 factorial arrangement with four replications and one plant per plot, totaling 80 experimental units.

Place and Duration of Study: The experiment was conducted in a protected environment at Center of Sciences and Agri-Food Technology of the Federal University of Campina Grande, Campus of Pombal, Paraiba, Brazil, between July and September 2016.

Methodology: The nitrogen doses applied was 25, 125, 250, 350 and 500 mg dm^{-3} and four silicon doses was 0, 75, 150 and 200 mg dm^{-3} both supplied by root. In pre-flowering stage were evaluated growth components; gas exchange, which are: photosynthesis, stomatal conductance, transpiration rate and intercellular CO_2 concentration; levels and accumulation of fractions of nitrogen (NO_3^-, NH_4^+, and total), and the silicon concentration in the leaves.

Results: There was no significant interaction ($p > 0.05$) between the factors nitrogen and silicon doses for any of the evaluated variables. However, the nitrogen doses increased all the plant characteristics evaluated, while the silicon doses affected only some of these characteristics. The doses of N promoted increases in transpiration rate photosynthetic rate and stomatal conductance and a decrease in internal CO_2 concentration.

Conclusion: The nitrogen supply increased the photosynthetic rate, dry mass and nitrogen accumulation and decreased the leaf silicon concentrations. Silicon did not interfered with dry mass production, but increased leaf area index, decreased nitrate levels and accumulations in the roots at lower doses of this element.

Keywords: Solanum melongena L.; photosynthesis rate; beneficial element; nitrogen use efficiency

1. INTRODUCTION

Eggplant (*Solanum melongena* L.) is a fruit vegetable appreciated in many countries, including Brazil. This crop has importance in human food, due to its rich in mineral nutrients, antioxidants and vitamin [1]. For the adequate growth and development of eggplant, usually high nitrogen (N) doses are require [2,3]. However, the application of high doses of N is costly and can provide losses of this nutrient through the ammonia volatilization and nitrate leaching, causing negative environmental impacts [4]. In addition, nitrogen excess in plant can increase the susceptibility to the incidence of diseases [5]. Thus, it is necessary to establish strategies to increase the efficiency of nitrogen fertilization and to reduce the doses to be applied, especially in species with high nitrogen demand, such as eggplant.

Silicon (Si) is not an essential element, but it can provide several benefits to plants such as the induction of resistance to biotic [6,7] and abiotic stress by improving the plant architecture and light interception [8,9] and the better utilization of some nutrients, such as N [10,11].

Researches about the silicon and nitrogen interaction have been carried out mainly in grasses, especially rice [12,13,14]. In this sense, Ávila et al. [12] observed an increase in the chlorophyll and nitrogen contents under root silicon supply in rice cultivated in nutrient solution. According to Ávila et al. [12] the supposed increase of the photosynthetic rate provided by Si accumulation in the leaves of plants would increase the energy efficiency of N assimilation and therefore decrease the accumulation of soluble N forms such as ammonium and nitrate in plant tissues. Campos et al. [13], found that the supply of Si in the culture medium, under excess of ammonium, mitigates the toxicity of ammonium in cucumber, resulting in higher accumulations of total nitrogen and dry matter of plants.

On the other hand, in other studies with rice cultivation, silicon leaf contents decreased with increasing N rates, increasing the susceptibility of the crop to the incidence of diseases [14].

Fruits vegetables not accumulate Si as well as rice, but some studies have shown that this element may contribute to increase the photosynthetic rate and plant growth for some species such as eggplant and melon [15,16]. However, there is a lack of work about the interaction between Si and N in horticultural species such as eggplant, in terms of their influence on the accumulation of mineral and total nitrogen in the tissues of the plant.

The objective of this work was to evaluate the effect of fertilization with N and Si on gaseous exchanges, dry mass production, concentrations, accumulations and compartmentalization of nitrogen fractions in eggplant.

2. MATERIAL AND METHODS

2.1 Location, Experiment description and Conduction

The experiment was carried out in a greenhouse and in the Laboratory fo Soil Fertility and Plant Nutrition, in agreenhouse of the Center of Science and Technology Agrifood, at the Federal University of Campina Grande (UFCG/CCTA), Campus of Pombal-PB, Brazil.

In the experiment were used samples of a Fluvent soil collected in the 0-40 cm layer in an area belonging to the CCTA Campus, which was pounded to break up clods and sieved through a 2.0 mm mesh sieve, for chemical and physics characterization according to the procedures described in Embrapa [17]. The soil sample showed the following attributes: pH ($CaCl_2$) = 6,7; the exchangeable concentration of K^+, Na^+, Mg^{+2}, Ca^{+2} and Al^{+3} of 0.22; 0.11; 2.3, 4.7 and 0.0 $cmol_c$ dm^{-3}, respectively, P = 53 mg kg^{-1}, and sandy loam texture.

The treatments were arranged in a 5 x 4 factorial arrangement, comprising five doses of N (25, 125, 250, 350 and 500 mg dm^{-3}) and four doses of Si (0, 75, 150 and 200 mg dm^{-3}). The experiment was carried out in a completely randomized design and four replications, totaling 80 experimental units. Each experimental unit consisted of a pot containing 6 dm^3 of soil, with two plants per pot.

Eggplant seedlings from variety 'Embú', were produced on expanded polystyrene trays with 128 cells filled with Tropstrato® (commercial substrate), which received one seed per cell. Thirty days after sowing, two leaves were transplanted per pot. Irrigations were performed manually according to the needs of the crop.

The nitrogen doses were applied in the form of urea (45% N) and Si in the form of potassium silicate, using commercial product Quimifol Silicio® (100 g Si/L and 83 g K/L). In order to avoid possible N losses by volatilization and K losses by leaching, doses were was divided into three applications (at 15, 30 and 40 days after transplanting). Fertilization with macro (except N) and micronutrients were performed according to Malavolta [18], applying the following doses in mg dm^{-3}: P = 100; K = 160; Ca = 230; Mg = 20; S = 155; B = 0.5; Cu = 1.5; Fe = 10; Mn = 4; Mo = 0.15 and Zn = 5.0. The sources of the nutrients used were as follows: simple superphosphate, KCl, $MgSO_4.7H_2O$, H_3BO_3, $CuSO_4.5H_2O$, Fe- EDTA, $MnSO_4.4H_2O$, ammonium molybdate and $ZnSO_4.7H_2O$. For potassium fertilization, the amounts of K supplied by potassium silicate were discounted to balance the nutrient doses between the treatments.

2.2 Evaluations

At the beginning of the flowering (45 days after transplating-DAT), leaf transpiration rate (E), intercellular CO_2 concentration (Ci), stomatal conductance (gs), and net CO_2 assimilation rate (A) were estimated. The evaluations were performed using infrared gas analyzer (IRGA) with a constant light source of 1,200 µmol of photons m^{-2} s^{-1}, starting the analysis at 7:00 p.m. employing two freshly ripened leaves per plant. On the same day and time, the leaf area index was also evaluated by photosynthetically active radiation method, using an equipment denominated ceptometer (AcupPAR model LP-80).These analyzes were performing in three replicates per plant.

Still at 45 DAT, plants were separated into roots, stems and leaves and placed in Kraft paper bags, identified with the respective treatments and dried in a forced-air oven (60 °C) until constant weight to obtain root dry matter (RDM), stem (SDM), leaves (LDM) and by the sum al dry mass (TDM) was estimate. In these tissues, total nitrogen (total-N) concentration were analyzed according to Malavolta [19], nitric nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) were analyzed as described in Tedesco [20]. By multiplying the data of the concentration of the nitrogen fractions by the respective dry mass produced for each plant part, the total accumulated these nitrogen forms in these tissues were obtained. In the leaves, the silicon concentration were also determined according to Furlani & Gallo [21] using the colorimetric method of molybdenum blue.

2.3. Statistical Analysis

The data were subjected using the analysis of variance by F test ($p < 0.05$). Mean values for the nitrogen and silicon doses were analyzed by polynomial regression at 5% probability. Statistical software Sisvar version 5.6 was used for data analysis [22].

3. RESULTS AND DISCUSSION

There was no significant interaction ($p > 0.05$) between the factors nitrogen and silicon doses for any of the evaluated variables (Tables 1, 2, 3 and 4). However, the nitrogen doses significantly ($p < 0.05$) affected all the plant characteristics evaluated, while the silicon doses affected only some of these characteristics.

The doses of N promoted increases in transpiration rate photosynthetic rate and stomatal conductance and a decrease in internal CO_2 concentration (Table 1). This effect was also observed by Souza et al. [2]. The increase of the photosynthetic rate is due to a greater stomatal opening, which increases the gas exchange and the stomatal conductance of the plant [23,24]. On the other hand, the decrease in the intercellular CO_2 concentration with increasing doses of N is perhaps, a response of the increase of the photosynthetic rate and stomatal conductance, decreasing the internal CO_2 [24]. Silicon doses not affected gas exchange in eggplant.

Table 1. Intercellular CO_2 concentration (Ci), transpiration rate (E), stomatal conductance (gs) photosynthesis rate (A), in eggplant leaves as function of nitrogen and silicon doses

Nitrogen ($mg\ dm^{-3}$)	**Ci ($mg\ L^{-1}$)**	**E ($mmol\ m^{-2}s^{-1}$)**	**gs ($mmol\ m^{-2}s^{-1}$)**	**A ($\mu mol\ m^{-2}s^{-1}$)**
25	293.84	4.33	0.32	8.91
125	276.63	4.11	0.33	11.68
250	261,03	4,76	0,40	14,29
350	237,81	4,62	0,37	16,02
500	247,00	5,00	0,44	16,81
L parameter	**	*	*	*
Q parameter	**	-	-	**
Silicon ($mg\ dm^{-3}$)				
0	266.03	4.63	0.37	13.35
75	266.03	4.41	0.38	13.72
150	254.48	4.62	0.36	13.93
200	266.53	4.60	0.37	13.18
L parameter	ns	ns	ns	ns
Q parameter	ns	ns	ns	ns

L *and Q –linear and quadratic parameter respectively, of the adjusted functions: linear* ($\hat{y} = a + Lx$) *and quadratic* ($\hat{y} = a + Lx + Qx^2$)*.* ** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$

The increase of the photosynthetic rate is probably due to the N action in the composition of the chlorophyll molecules, in which the active sites responsible for photosynthesis are found [26], as observed by Zhang et al. [27]. At lower doses of N, probably occurred a decrease in the turgescence potential of foliar tissues, causing stomata closure, increased CO_2 diffusion resistance, and a consequent decrease in the photosynthetic rate [24,26].

The leaf area index (LAI), leaves dry mass (LDM), stems dry mass (SDM), roots dry mass (RDM) and total dry mass (TDM) (Table 2) adjusted to the quadratic regression model with N doses, where maximum values were obtained at the doses of 262, 427, 445 and 373 and mg dm-3 of N, respectively. In other works, a positive effect of the N supply to the eggplant was observed on the growth [2,3]. The decrease in dry mass production at higher doses is probably due to the toxicity caused by excess N, which occurs mainly when it is supplied as urea [28]. The silicon doses also increases the LAI that adjusted to the quadratic regression model. This effect possibly is due improved of leaf architecture and thus increased interception of sunlight, as reported by Ávila et al. [12].

Table 2. Leaf area index (LAI), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), in eggplant plants under nitrogen and silicon doses

Nitrogen ($mg\ dm^{-3}$)	**LAI**	**LDM**	**SDM**	**RDM**	**TDM**
	---------------------------------------g per plant-------------------------------				
25	0.50	5.05	3.18	3.34	11.58
125	1.43	9.63	6.57	5.73	21.94
250	1.88	11.44	7.52	6.56	25.51
350	2.12	12.08	7.49	5.96	25.52
500	1.75	12.83	8.01	5.73	26.56
L parameter	**	**	*	**	
Q parameter	**	**	**	**	
Silicon ($mg\ dm^{-3}$)					
0	1.43	10.09	6.82	5.46	22.38
75	1.63	10.29	6.44	5.47	22.20
150	1.56	10.47	6.38	5.60	22.45
200	1.52	9.96	6.57	5.33	21.86
L parameter	*	ns	ns	ns	ns
Q parameter	*	ns	ns	ns	ns

L *and Q –linear and quadratic parameter respectively, of adjusted functions: linear* ($\hat{y} = a + Lx$) *and quadratic* ($\hat{y} = a+Lx+Qx^2$). ** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$

The LAI measures the relation of the area covered by the leaves in relation to the area of the soil occupied by the plant and is related to the leaf expansion and consequently to the vegetative growth of the leaves. Thus the photosynthetic rate is generally positively related to this variable [29]. The lowest LAI values as well as LDM, SDM and RDM in the lowest doses of N are due to the N requirement for the plant, a fact related to the role of this nutrient on the cellular division and expansion [6].

All nitrogen fractions concentrations were positively affected by N doses (Table 3). N-ammonium concentrations in the plant tissues were higher in the leaves while nitrate was concentrated mainly in the stem and root. Alves et al. [30] observed higher levels of N-nitrate in the sunflower in stem in relation to the leaves. In addition, the ammonium is absorbed by the roots and is almost all assimilated in these tissues [30]. In turn, N-total concentration in all plant tissues were linearly elevated as a function of the N rates applied in accordance with the N-mineral fractions. The highest levels of these N fractions were observed in leaf tissues, a fact that is justified by the composition of these tissues, which are rich in chlorophylls and several nitrogen compounds, such as amino acids and proteins, since they are the main tissues of assimilation of N [31]. In relation to silicon doses, there was effect solely for the nitrate-N concentration in the roots, which decreased in the doses of 75 and 150 mgdm^{-3} and increased in the highest dose. Similar results were obtained in rice by Ávila et. al. [12] and indicates that possibly the silicon decrease the translocation of N-nitrate to the aerial part or increased its assimilation in the roots

Table 3. Ammonium (NH_4^+-N), nitrate (NO_3^-N) total nitrogen concentration in leaves of eggplant plants under nitrogen and silicon doses

Nitrogen (mg dm^{-3})	**NH_4^+-N**			**NO_3^--N**			**Total-N**		
	Leaf	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**
	-------------------------------------mg kg^{-1}---								
25	0.93	0.21	0.17	0.13	0.08	0.25	14.56	7.00	9.69
125	1.00	0.24	0.23	0.12	0.11	0.18	23.31	9.06	12.81
250	1.49	0.31	0.41	0.08	0.19	0.13	32.31	13.50	19.31
350	1.88	0.63	0.73	0.13	0.62	0.32	39.44	18.69	21.06
500	2.19	1.19	0.86	0.26	0.98	0.83	46.94	24.25	22.50
L parameter	**	**	**	**	**	**	**	**	**
Q parameter	**	**	**	**	**	**	**	**	**
Silicon (mg dm^{-3})									
0	1.60	0.50	0.50	0.14	0.44	0.36	32.40	14.80	17.10
75	1.55	0.51	0.45	0.12	0.36	0.31	30.15	14.00	17.20
150	1.38	0.54	0.50	0.17	0.41	0.24	30.95	14.95	16.85
200	1.46	0.50	0.47	0.14	0.37	0.45	31.75	14.25	17.15
L parameter	ns	ns	ns	ns	ns	*	ns	ns	ns
Q parameter	ns	ns	ns	ns	ns	*	ns	ns	ns

L *and Q –linear and quadratic parameter respectively, of the adjusted functions: linear* ($\hat{y} = a + Lx$) *and quadratic* ($\hat{y}= a+Lx+Qx^2$). ** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$

All the N fractions accumulated in to dry mass of eggplant increased linearly with the N doses and were higher aerial part (leaves + stem) (Table 4). These results reflect the combination of the dry mass production and the higher concentration of the N fractions in the leaves and the stem. The shoot accumulated more ammonium-N than nitrate-N, whereas in the roots, the values for both nitrogen forms were similar. In general, plants tend to accumulate more nitrate than ammonium in tissues, depending on the form of nitrogen supplied [28]. The higher accumulation of N-ammonium in the aerial part in relation to the N-nitrate may have been a consequence of the use of urea as source of N. The fact that N doses gave a linear response for total N, and quadratic for dry mass, indicates that the plants did not respond in growth in the same proportion as the amount of N accumulated by the plant, that is, above the maximum point there was accumulation of unmetabolized or mineral nitrogen [7] with increasing doses of N. The NUE values decreased with N rates as a result of decreasing dry mass production at the higher N doses. Leaf content of Si decreased with N doses, possibly due to "dilution" caused by increasing leaf dry matter production due to increasing doses of N [14] or due to the lower absorption of Si. Wu et al.[32] studying the interaction between N and Si in rice, observed that in the highest doses of N tested, there was a decrease in leaf concentration of Si and that this decrease was associated with the decrease of the expression of the OsLsi1 and OsLsi2 genes, which encode for the synthesis of Si transporters.

The Si doses influenced only the nitrate-N accumulation in the roots and the silicon concentration in the leaves. The leaf content of Si obtained in the highest dose of silicon was equivalent to 11.9 g/kg of SiO2 in the mass and is within the range of contents generally observed for dicotyledonous species that is 10 to 30g/kg of SiO_2 [19].

Table 4. Ammonium (NH_4^+-N), nitrate (NO_3^-N), and total nitrogen accumulation in shoot and root, nitrogen use efficiency (NUE) and silicon content in leaves in eggplant under nitrogen and silicon doses

Nitrogen (mg dm^{-3})	**NH_4^+-N**		**NO_3^--N**		**Total-N**			
	Shoot	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**NUE**	**Leaf Si**
	--------------------------mg per plant--------------------------						g^2/mg N	gkg^{-1}
25	5.34	0.57	0.78	0.83	96.59	32.45	1.06	5.78
125	11.15	1.33	1.75	0.99	285.18	73.00	1.36	5.93
250	19.19	2.63	2.25	0.83	474.13	126.59	1.10	3.73
350	27.25	4.34	5.88	1.90	621.65	126.82	0.88	4.32
500	37.53	4.95	10.50	4.80	808.12	129.26	0.76	4.85
L parameter	**	**	**	**	**	*	**	*
Q parameter	-	-	-	-	-	-	*	*
Silicon (mg dm^{-3})								
0	19.56	2.75	4.43	1.97	427.95	93.41	1.01	4.50
75	19.29	2.46	3.59	1.68	400.58	94.01	1.06	4.16
150	17.98	2.80	4.39	1.37	419.54	94.35	1.06	5.42
200	17.79	2.49	3.79	2.41	409.86	91.37	1.00	5.61
L parameter	ns	ns	ns	*	ns	ns	ns	*
Q parameter	ns	ns	ns	*	ns	ns	ns	-

L *and Q –linear and quadratic parameter respectively, of the adjusted functions: linear* ($\hat{y} = a + Lx$) *and quadratic* ($\hat{y} = a+Lx+Qx^2$). ** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$

4. CONCLUSION

The nitrogen supply increased the photosynthetic rate and all growth components of the eggplant, especially the dry mass of leaves and stem and decreased the silicon leaf concentrations.

The eggplant accumulated more ammonium in the leaves and the stem, while the nitrate was accumulated more in the roots.

Silicon did not interfered with eggplant dry mass production, but increased leaf area index, decreased nitrate levels and accumulations in the roots at lower doses of this element.

REFERENCES

1. Raigon MD, Prohens J, Mũnoz-Falcón JE, Nuez F. Comparison of eggplant landraces and commercial varieties for fruit content of phenolics, minerals, dry matter and protein. Journal of Food Composition and Analysis. 2008; 21 (5): 370-376. https://doi.org/10.1016/j.jfca.2008.03.006.
2. Souza RC, Resende R, Lorenzoni MZ, Seron CC, Hachmann TL, Lozano CS Response of eggplant crop fertigated with doses of nitrogen and potassium. Revista Brasileira de Engenharia Agrícola e Ambiental. 2017; 21 (1): 21-26. http://dx.doi.org/10.1590/1807-1929/agriambi.v21n1p21-26.
3. Sousa, RC, Resende R, Lorenzoni MZ, Seron CC, Santos, FAS. Agronomic efficiency and growth of eggplant crop under different potassium and nitrogen doses. Revista Caatinga. 2018; 31 (3): 737-747. http://dx.doi.org/10.1590/1983-21252018v31n324rc.
4. Chagas, WFT, Guelfi DR, Caputo ALC, Souza TL, Andrade AB, Faquin V. Ammonia volatilization from blends with stabilized and controlled-released urea in the coffee system. Ciência e Agrotecnologia. 201;40:497-509. http://dx.doi.org/10.1590/1413-70542016405008916.
5. Bazzano M, Elmer W. Interactions and consequences of silicon, nitrogen, and *Fusarium palustre* on herbivory and DMSP levels of *Spartina alterniflora.* Estuarine Coastal and Shelf Science. 2017;198-106-113. http://dx.doi.org/10.1016/j.ecss.2017.08.046.
6. Marschner H. Mineral nutrition of higher plants (3.ed), Elsevier, London. 2012; 643.
7. Masclaux-Daubresse C, Daniel-Vedele F, Dechorgnat J, Chardon F, Gaufichon L, Suzuki A. Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture. Annals of Botany. 2010; 105 (7): 1141–1157. https://doi.org/10.1093/aob/mcq028.
8. Aminifard MH, Aroiee H, Fateim H, Ameri A, Karimpour S. Responses of eggplant (*Solanum melongena* L.*)* to different rates of nitrogen under field conditions. Journal of Central European Agriculture. 2010; 11 (4): 453-458. https://doi.org/10.5513/JCEA01/11.4.863.
9. Han Y, Lei W, Wen L, Hou M. Silicon-mediated resistance in a susceptible rice variety to the rice leaf folder, *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera:

Pyralidae). Plos One. 2015; 10 (4): e0120557. https://doi.org/10.1371/journal.pone.0120557.

10. Zhan, L-P.; Peng, D-L.; Wang, X-L.; Kong, L-A.; Peng, H.;Liu, S-M.; Liu, Y.; Huang, W-K. Priming effect of root-applied silicon on the enhancement of induced resistance to the root-knot nematode *Meloidogyne graminicola* in rice. Plant Biology**.** 2018;18 (1): 1-12. http://dx.doi.org/10.1186/s12870-018-1266-9.
11. Ma J F, Yamaji N. Silicon uptake and accumulation in higher plants. Plant Science.2006; 11 (8): 392-397. https://doi.org/10.1016/j.tplants.2006.06.007.
12. Ávila FW, Baliza DP, Faquin V, Araujo JL, Ramos SJ. Interação entre silício e nitrogênio em arroz cultivado sob solução nutritiva. Revista Ciência Agronômica. 2010; 140 (2): 184-190.
13. Campos CNS, Prado RM, Caione G, Lima Neto, AJ, Mingotte FLC. Silicon and excess ammonium and nitrate in cucumber plants. African Journal of Agricultural Research. 2016; 11 (4): 276-283. http://dx.doi.org/10.5897/AJAR2015.10221.
14. Mauad M, Crusciol CAC, Grassi Filho H, Machado SR. Deposição de sílica e teor de nitrogênio e silício em arroz. Semina: Ciências Agrárias. 2013; 34 (4):1653-1662. http://dx.doi.org/10.5433/1679-0359.2013v34n4p1653.
15. De Fátima RT, Nóbrega JS, Carreiro DA, Guerrero AC, Lima AS, Figueiredo FRA, Ferreira JTA, Brito MEB. Fluorescence and Growth of Eggplant under Irrigation Levels and Silicon Doses Journal of Experimental Agriculture International.2019; 36(4): 1-10. http://dx.doi.org/10.9734/JEAI/2019/v36i430240.
16. Gomes FAL, Araujo RHCR, Nóbrega JS, De Fátima RT, Silva MS, Lima AS, Teodósio AEMM, Oliveira CJA. Application of silicon to alleviate irrigation water salinity in melon growth. Journal of Experimental Agriculture International. 2018; 25(6):1-9. http://dx.doi.org/10.9734/JEAI/2018/43767.
17. EMBRAPA. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. 2.ed. rev. atual. Rio de Janeiro. 2011; 225.Portuguese
18. Malavolta E. Elementos de nutrição mineral de plantas. São Paulo, Agronômica Ceres. 1980; 251.Portuguese
19. Malavolta E, Vitti GC, Oliveira SA. Avaliação do estado nutricional das plantas: Princípios e aplicações. 2.ed. Piracicaba, POTAFOS.1997; 319. Portuguese
20. Tedesco MJ, Gianello, C, Bissani CA, Bohnen H, Volkweiss SJ. Análise de solo, plantas e outros materiais. 2.ed. Porto Alegre, Universidade Federal do Rio Grande do Sul. 1995;174. Portuguese
21. Furlani PR, Gallo JR. Determinação de silício em material vegetal, pelo método colorimétrico do “azul-de-molibdênio”. Bragantia. 1978; 37 (1): 5-11. http://dx.doi.org/10.1590/S0006-87051978000100018. Portuguese
22. Ferreira DF. Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia. 2011; 35 (6):1039–1042. http://dx.doi.org/10.1590/S1413-70542011000600001.
23. Cechin I, Fumis TF. Effect of nitrogen supply on growth and photosynthesis of sunflower plants grown in the greenhouse. Plant Science. 2004; 66 (5): 379–1385. https://doi.org/10.1016/j.plantsci.2004.01.020.
24. Boussadia O, Seppe K, Zgallai H, Bem El Hadj S, Braham M, Lemeur R, Van Labeke MC. Effects of nitrogen deficiency on leaf photosynthesis, carbohydrate

status and biomass production in two olive cultivars ‘Meski’ and ‘Koroneiki’. Scientia Horticulturae. 2010; 123 (3): 336–342. https://doi.org/10.1016/j.scienta.2009.09.023.

25. Zou W, Jia R, Yang J, Li R, Yin G. Optimum nitrogen fertilization of Calophyllum inophyllum seedlings under greenhouse conditions. Frontiers of Agricultural Science and Engineering. 2016; 3 (1): 368-374. https://doi.org 10.15302/J-FASE-2016120.

26. Gai Z, Zhang J, Li C. (2017). Effects of starter nitrogen fertilizer on soybean root activity, leaf photosynthesis and grain yield. Plos One. 2017; 12 (4): e0174841. ttps://doi.org/10.1371/journal.pone.0174841.

27. Zhang Q, Wu S, Chen C., Shu L, Zhou X, Zhu S. 2014. Regulation of nitrogen forms on growth of eggplant under partial root-zone irrigation. Agricultural Water Management. 2014; 142 (1): 56-65. https://doi.org/10.1016/j.agwat.2014.04.015.

28. Araujo JL, Faquin V, Vieira NMB, Oliveira MVC., Soares AA, Rodrigues, CR, Mesquita AC. Crescimento e produção do arroz sob diferentes proporções de nitrato e de amônio. Revista Brasileira de Ciência do Solo. 2012. 36 (3): 921-930. https://dx.doi.org/10.1590/S0100-06832012000300022. Portuguese

29. Jarecki W J, Buczek J, Bobrecka-Jamro D. Response of spring wheat to different soil and foliar fertilization. Journal of Central European Agriculture. 2017; 18 (2):460-476. https://doi.org/10.5513/JCEA01/18.2.1919.

30. Alves LS, Torres Junior CV, Fernandes MS, Santos AM, Souza, SR. (2016). Soluble fractions and kinetics parameters of nitrate and ammonium uptake in sunflower (“Neon” Hybrid). Revista Ciência Agronômica. 2016; 47 (1):13-21. https://dx.doi.org/10.5935/1806-6690.20160002.

31. Bezerra IL, Nobre RG, Gheyi HR, Lima GS, Barbosa, JL. Physiological indices and growth of ‘paluma’ guava under saline water irrigation and nitrogen fertigation. Revista Caatinga. 2018;31 (4): 808-816. https://dx.doi.org/10.1590/1983-21252018v31n402rc.

32. Wu X, Yu Y, Baerson S.R, Song Y, Liang G, Ding C, Niu J, Pan Z, Zeng R. Interactions between Nitrogen and Silicon in Rice and Their Effects on Resistance toward the Brown Plant hopper *Nilaparvata lugens*. Frontiers in Plant Sciences. 2017; 28. http://dx.doi.org/10.3389/fpls.2017.00028.