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AGRONOMIC EFFICIENCY AND GROWTH OF EGGPLANT CROP UNDER DIFFERENT POTASSIUM AND NITROGEN DOSES¹

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ABSTRACT - Fertilization is important for the optimization of plant growth and yield, which are necessary for agronomic activities. Soil fertilization should increase net earnings that depend on nutrient use efficiency. The aim of this study was to evaluate the agronomic efficiency of eggplant under different doses of potassium (K) and nitrogen (N). Four levels of K (0, 54, 108, and 216 kg ha⁻¹) and four levels of N (0, 67, 134, and 268 kg ha⁻¹) were applied weekly by fertigation. The highest plant and the largest stem diameter were found with 165–175 kg ha⁻¹ of N. Leaf area was more influenced by N than by K. Isolated application of different K doses did not statistically influence height plant, stem diameter, or leaf dry matter. The agronomic efficiency of nitrogen is reduced with increasing levels of N and K.

Keywords: Mineral nutrition. Fertigation. Protected environment. *Solanum melongena* L..

EFICIÊNCIA AGRONÔMICA E CRESCIMENTO DA CULTURA DA BERINJELA SOB DIFERENTES DOSES DE POTÁSSIO E NITROGÊNIO

RESUMO - A adubação é importante para otimizar o crescimento e produtividade, sendo necessário para atividade agrícola. A adubação de solo deve aumentar o lucro líquido, que depende da eficiência de uso de nutrientes pela planta. O objetivo deste estudo foi avaliar a eficiência agronômica em berinjela sob diferentes doses de potássio (K) e nitrogênio (N). Quatro níveis de K (0, 54, 108 e 216 kg de K ha⁻¹) e quatro níveis de N (0, 67, 134 e 268 kg de N ha⁻¹) foram aplicados semanalmente via fertirrigação. As plantas mais altas e com maior diâmetro de caule foram obtidas com 165-175 kg ha⁻¹ de N. A área foliar foi mais influenciada pelo nitrogênio em comparação com o potássio. Aplicações isoladas de diferentes doses de K não influenciaram a altura de planta, diâmetro de caule e matéria seca da folha. A eficiência agronômica do nitrogênio é reduzida com o aumento da dose de N e K.

Palavras-chave: Nutrição mineral. Fertirrigação. Ambiente protegido. *Solanum melongena* L..

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Paper extracted from the dissertation of the first author

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INTRODUCTION

Eggplant (*Solanum melongena* L.) is an important vegetable in Brazil and worldwide and belongs to the Solanaceae family (SILVA et al., 2015). It has been cultivated in protected environments as a strategy for horticulturists to increase competitiveness, resulting in larger products that can be harvested continuously (MARQUES et al., 2011).

Eggplant responds well to nitrogen (N), phosphorus, and potassium (K) fertilization (OLONIRUHA, 2011). N fertilization increases the growth and yield of eggplant due to the effects of the nutrient on carbohydrate influx and the synthesis of regulators in growing plants (AMINIFARD et al., 2010).

N deficiency decreases growth and results in chlorotic leaves caused by lean assimilate formation, which predates flowering and leads to shortening of the cycle (AZARPOUR et al., 2012). Azarpour et al. (2012) observed increased eggplant production with N application. Aminifard et al. (2010) reported that 100 kg ha⁻¹ of N resulted in the highest fruit yield of eggplant.

K is a macronutrient required by fruits and vegetables, which regulates cell turgor, activates enzymes involved in respiration, and controls stomatal opening and closure (FAQUIN; ANDRADE, 2004). K levels affect the total yield and fruit quality of eggplant (FAWZY; EL-NEMR; SALEH, 2007; HOCHMUTH; HOCHMUTH; DONLEY, 1993).

Nutritional stress is one of the main factors limiting crop productivity; this may occur due to an excess or a deficit of nutrients. Accurate fertilization techniques are needed to prevent nutritional stress. Drip fertigation systems are successful agricultural tools, mainly for the precise application of N, K, and micronutrients (FELEAFEL; MIRDAD, 2013).

Correct fertigation management in the cultivation of protected environments is important due to the lack of rain; that is, balanced application must consider the varying demands over time to reduce the possibility of salinity.

Plants only absorb part of the nutrients supplied by fertilization (OLIVEIRA et al., 2008). One way to evaluate nutrient use efficiency is to calculate the agronomic efficiency, which is the ratio of production to the unit of applied nutrient (FAGERIA, 1998).

With the aim of providing adequate nutrition for eggplant crops, studies on the effects of N and K fertilization must be conducted to better address the needs of the crop and to increase the utilization efficiency of these nutrients. Therefore, the aim of the present study was to investigate the growth and agronomic efficiency of eggplant under different doses K and N doses.

MATERIAL AND METHODS

Eggplant *S. Melongena* L. 'Çiça' was grown in a protected environment located in the Irrigation Technical Center of the State University of Maringá, Paraná, Brazil (23°25'57''S latitude; 51°57'08''W longitude; altitude of 542 m above sea level), from February to August 2015. The classification of this location is a temperate climate with a hot summer (Cfa), according to the Koppen-Geiger climate classification (PEEL; FINLAYSON; MCMAHON, 2007).

Soil samples were collected from the 0.0–0.20 m soil layer and classified as Latossolo Vermelho Distrófico (Oxisol). Particle size was analyzed as described by Ferrari et al. (2014), and the results showed that the texture was sandy (190, 30, and 780 g kg⁻¹ clay, silt, and sand). Soil chemical analysis was conducted in accordance with the methods described by Embrapa (2011). Soil contained: 8.63 mg dm⁻³ of P, 2.10 mg dm⁻³ of Na⁺, 0.07 cmol_c dm⁻³ of K⁺, 1.56 cmol_c dm⁻³ of Ca²⁺, 0.38 cmol_c dm⁻³ of Mg²⁺, 0.7 cmol_c dm⁻³ of Al³⁺, 2.48 cmol_c dm⁻³ of H⁺, and 4.66 g dm⁻³ of organic matter. Liming and basal fertilization were performed 60 days prior to transplantation with the application of 333 kg of dolomitic limestone, 312 kg of P₂O₅, 105 kg of K, and 5200 kg of organic compost per hectare.

On February 21, eggplant seeds were seeded in polyethylene trays filled with a commercial substrate based on pine bark. On April 9, one seedling was transplanted into a plastic pot of approximately 25 dm³ (diameter 31 cm and depth 35 cm), containing 25 kg of air-dried soil. The drainage system consisted of a non-sealed bottom, with 4 kg of n°1 crushed stone, sufficient to fill the bottom of the pot. A non-woven fabric disk was placed over the crushed stone to avoid losing the finer fraction of the soil.

One drip irrigation (3.9 L h⁻¹) was used in each experimental unit, operating at a pressure of 10 m.w.c. Irrigation was controlled by weighing the pots daily using a digital scale with a capacity of 40.0 kg (± 2.0 g). When soil water tension approached the critical tension of -15 kPa (BILIBIO et al., 2010), corresponding to 0.08 g g⁻¹, the soil was irrigated until the moisture in the pot reached field capacity (0.2 g g⁻¹) (CASAROLI; JONG VAN LIER, 2008).

Four doses of K were applied using KCl (0, 54, 108, and 216 kg ha⁻¹ of K) to supplement the basal fertilization with K (105 kg ha⁻¹ of K). Four doses of N were applied using urea (0, 67, 134, and 268 kg ha⁻¹ of N). The experiment was arranged in a completely randomized design including four K doses, four N doses, and four replicates, for a total of 16 treatments and 64 pots. All the pots were re-randomized once per week to minimize any positional effects. The plants were spaced 0.8 m

apart, and lateral rows were spaced 1.2 m apart.

Total doses of N and K were previously fractionated for weekly fertigation, according to the nutrient absorption capacity of eggplant crop (TRANI; TIVELLI; CARRIJO, 2011). First and second, third and fourth; fifth to tenth, and eleventh to sixteenth weeks, 3.45, 5.17, 8.62, and 5.17% of the total dose per week. The fertilizers were diluted in 1 L (1 dm³) of water and applied during irrigation.

Fruits with a shiny dark purple color were harvested 100 to 137 days after transplanting (DAT). To evaluate the eggplant growth in response to different doses of K and N, the plant height (PH [cm]), and stem diameter (SD [mm]), were measured 21, 35, 49, 63, 77, 91, 105, and 137 DAT. At the end of the cycle, the leaf area (LA [cm² per plant]), and leaf dry matter, (LDM [g per plant]), were measured.

Agronomic efficiency of fertilizers was calculated by dividing the difference in production with fertilization minus the production without fertilization, per amount of applied nutrient. Agronomic efficiency of N (AEN), and agronomic efficiency of K (AEK), were given as described by Fageria (1998) and Oliveira et al. (2008). AEN and AEK are reported as kilogram fruit yield per kilogram fertilizer applied (kg kg⁻¹).

The minimum and maximum temperatures were obtained through an automatic weather station to calculate the degrees day (DD). The data were obtained from transplantation (2015-04-10) until the last evaluation of growth (2015-07-23). The DD was determined in accordance with the methodology proposed by Ometto (1981). The highest and lowest temperatures considered to calculate DD, were 16 and 35°C.

Data were analyzed using the program Sisvar 5.6. The F test at a 0.05 probability level was applied; were significance was found, regression

analysis was applied. The statistical model selection criterion considered: Student's t-test for the regression coefficients ($p < 0.05$) and adjustment of the coefficient of determination (R^2_{adj}). The complete model considered was: $Z = \beta_0 + \beta_1(X) + \beta_2(Y) + \beta_3(X)^2 + \beta_4(Y)^2 + \beta_5(X)(Y)$, where: Z is the estimated value for the characteristic studied; β_0 , β_1 , β_2 , β_3 , β_4 , and β_5 are the regression coefficients, and X and Y are predictive variables.

RESULTS AND DISCUSSION

The leaf area (LA) of eggplants was significantly influenced ($p < 0.05$) by the isolated application of K and N, and by their interaction (Table 1). According to the adjusted model, fertigation with K and N doses increased the LA of eggplant to the highest value (18,249.6 cm² per plant) with 116.5 kg ha⁻¹ of K and 268 kg ha⁻¹ of N (Figure 1). High K doses reduced the LA in the data best fitted to the quadratic equation. Following the trend of the equation, we can state that N doses exceeding 348 kg ha⁻¹ reduced the LA. According to the adjusted multivariate model, the increase in LA was greater for one kilogram of N than for one kilogram of K.

Feleafel and Mirdad (2013) fertigated eggplant on sandy soil (91.1% sand) weekly and obtained the maximum value of LA with 250 kg ha⁻¹ of K and 250 kg ha⁻¹ of N. Fawzy, El-Nemr and Saleh (2007) reported the highest vegetative growth with LA when using 300 kg ha⁻¹ of K. The K doses used by those researchers are similar to the results of the present study, considering the total K dose (221.5 kg ha⁻¹ of K), basal fertilization (105 kg ha⁻¹ of K), plus 116.5 kg ha⁻¹ of K.

Table 1. Summary of the analysis of variance for leaf area (LA [cm² per plant]), leaf dry matter (LDM [g per plant]), plant height (PH [cm]), stem diameter (SD [mm]), agronomic efficiency of nitrogen (AEN) and potassium (AEK) (kg kg⁻¹). CV: coefficient of variation; F values: ns: non-significant at the 0.05 level; *significant at the 0.05 level; **significant at the 0.01 level.

Variables	Variation sources			CV (%)	Average
	Potassium (K)	Nitrogen (N)	N × K		
 F values				
LA	5.202**	182.807**	3.570**	19.18	9843.86
LDM	1.049 ^{ns}	157.046**	2.058*	19.75	54.54
PH	0.475 ^{ns}	12.113*	0.609 ^{ns}	9.10	78.26
SD	1.415 ^{ns}	12.303**	3.229**	7.04	14.95
AEN	7.840**	154.070**	9.478**	19.70	137.72
AEK	7.278**	56.390**	17.031**	20.60	-12.85

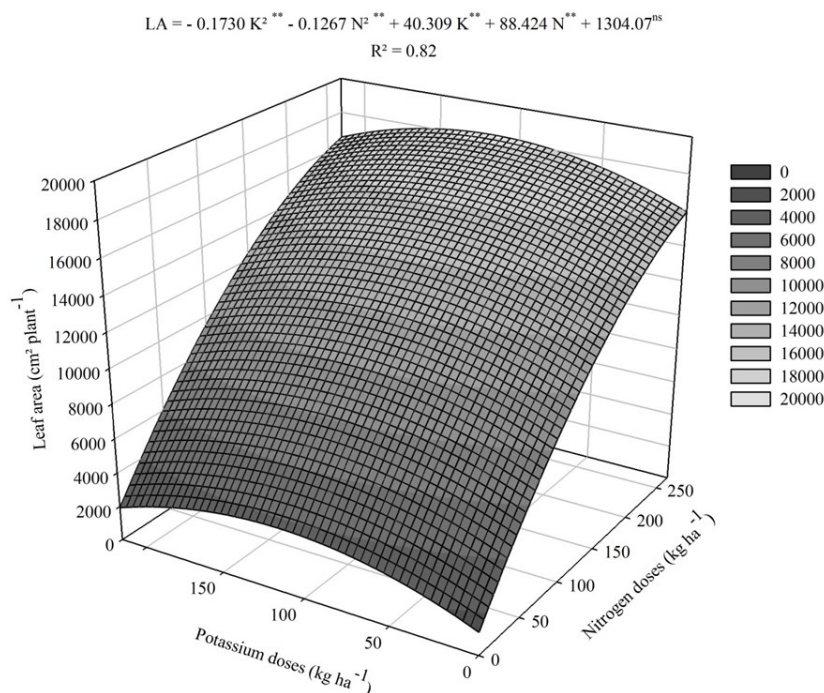


Figure 1. Leaf area of eggplant as a function of K and N doses cultivated in a protected environment.

According to the analysis of variance, leaf dry matter (LDM) was significantly affected by the interaction between K and N doses (Table 1). The individual effect of K application was not significant. The maximum LDM (106.9 g per plant) was obtained with 268 kg ha⁻¹ of N and 54 kg ha⁻¹ of K (Figure 2). N fertilization promoted increments of 501.5, 549.8, 360.6, and 512.1% of LDM in relation to the initial value, considering the levels K1 (0 kg ha⁻¹), K2 (54 kg ha⁻¹), K3 (108 kg ha⁻¹), and K4 (216 kg ha⁻¹), respectively.

In a study of eggplant culture, Marques et al. (2011) observed a reduction in the dry matter of leaves and stem with doses of K higher than 592.9 kg ha⁻¹ at 120 DAT using KCl. According to those authors, the reduction in dry matter indicates that the plants may have been stressed in response to soil salinity at high doses.

Aminifard et al. (2010) reported a reduction in the dry matter of eggplant leaves with N at a dose 150 kg ha⁻¹ of N. Meanwhile, Amiri, Gohari and Esmailian (2012) and Oloniruha (2011) showed that application of N in the range 120–180 kg ha⁻¹ resulted in the highest number of leaves per plant.

According to França et al. (2011) who studied corn crop, N availability can affect vegetative growth, influencing LA. LA is related to the interception of solar radiation and assimilation of carbon for the culture; high N availability results in higher accumulation of LDM, uptake of N, and income of the culture. For eggplant culture, it is

probable that those relationships are similar when the LA and the LDM are considered, i.e. an appropriate supply of the nutrient can result in higher availability and therefore, in higher values for those variables.

The results for plant height indicated significant effects of N fertilization (Table 1). For this variable, it was possible to adjust a quadratic model, such that the highest plant (82.8 cm) was obtained with fertilization of 175 kg ha⁻¹ of N and the shortest plant height (70.59 cm) was obtained without nitrogen fertilization (Figure 3). The results corroborate those of Lima et al. (2014), who found the highest eggplant plants with 200 kg ha⁻¹ of N, obtaining 68.14 cm. Additionally, Bozorgi (2012) reported the maximum plant height (111.5 cm) between 60 and 90 kg ha⁻¹ of N.

Aminifard et al. (2010) noted that plant height can be considered a vigor index, which depends on vigor and plant growth. They evaluated eggplants at 10, 30, and 50 DAT and found no significant differences between N doses of 50, 100, and 150 kg ha⁻¹. Significant differences were found compared with 0 kg ha⁻¹ of N, which promoted the development of the shortest plants. Other studies have shown that the shortest plants developed in the shortest N dose (AMIRI; GOHARI; ESMAILIAN, 2012; MIRDAD, 2011; OLONIRUHA, 2011; LIMA et al., 2014); this is because N is the second-most absorbed nutrient for eggplants after K (HAAG; HOMA, 1968).

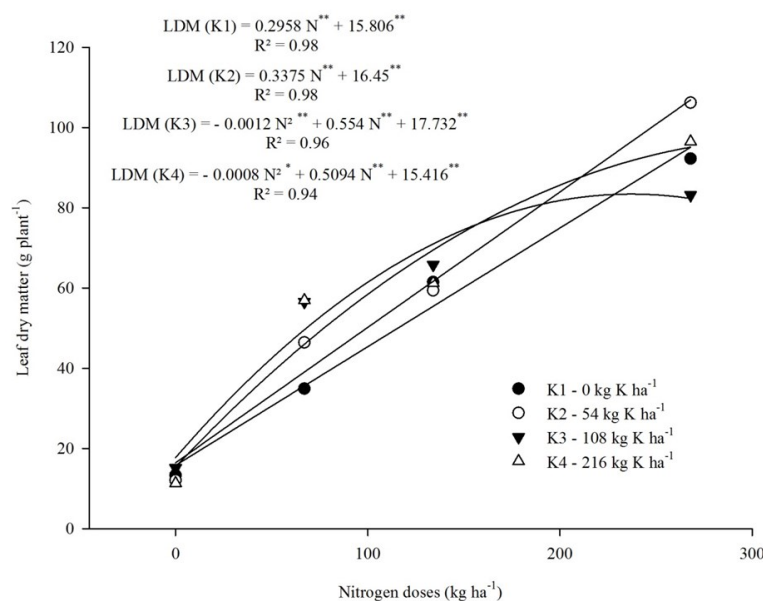


Figure 2. Leaf dry matter as a function of N dose in eggplants subjected to different K doses cultivated in a protected environment.

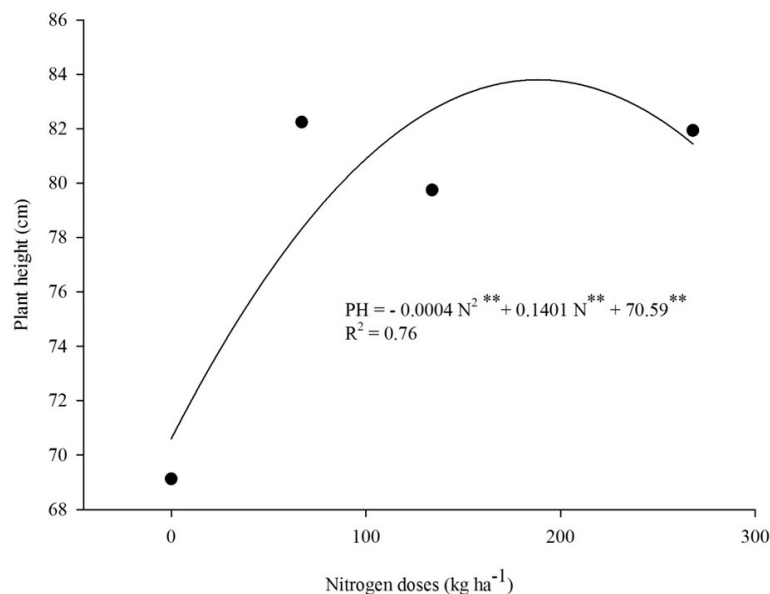


Figure 3. Eggplant height as a function of N dose, cultivated in a protected environment.

There was a significant interaction between N and K on stem diameter (SD); however, the adjustment of complete regression models was not possible, with the quadratic model only adjusted for the general effects of N (Figure 4).

The maximum SD (15.8 mm) was obtained with 165 kg ha⁻¹ of N, with higher doses causing a decrease in SD. Lima et al. (2014) applied up to 200 kg ha⁻¹ of N and found no significant differences in eggplant SD. Oloniruha (2011) obtained the largest diameter with 130 kg ha⁻¹ of N; this is close to the dose required to reach the maximum SD. Mirdad (2011) applied different N doses in two eggplant cycles. The first cycle resulted in larger SD

(2.46 cm) with 300 kg ha⁻¹ of N, and the second obtained 2.61 and 2.62 cm with 200 and 300 kg ha⁻¹ of N, respectively.

It is possible that N has important effects on growth variables at several stages. According to Lopes and Lima (2015), high levels of N are required by all cultivated plants. N influences protein synthesis and the production of new plant tissue, since carbon metabolism supplies energy for the incorporation of N. Therefore, it is possible that the correct supply of N results in a high height and SD due to the maintenance of appropriate metabolic activity in the eggplant.

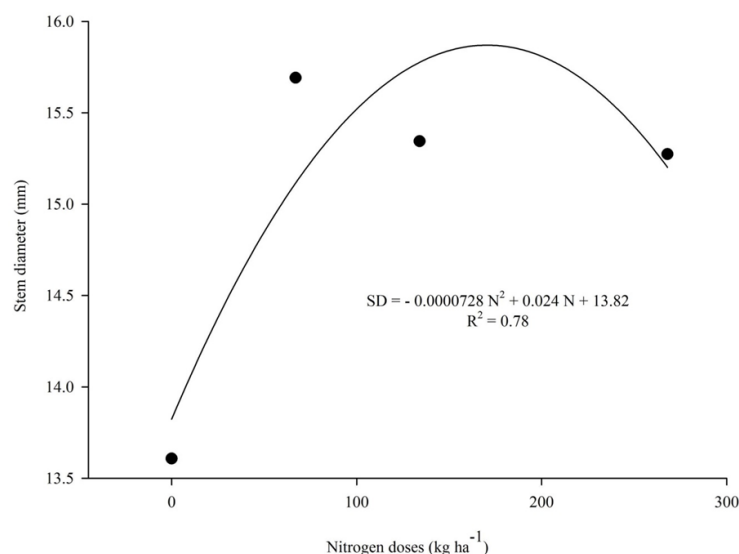


Figure 4. Stem diameter of eggplant as a function of N dose, cultivated in a protected environment.

The daily average temperature over the growing season ranged from 13.3 to 31.2°C and the average relative humidity was 62.5%. Climatological data registered during the experiment were used to calculate the sum of degrees day (DD). The values for DD as a function of days after transplanting (DAT) were: 0 (0), 193 (21), 310 (35), 399 (49), 485 (63), 567 (77), 622 (91), and 691 (105).

Variance analyses for PH and SD as a function of the sum of DD subjected to different NA doses were significant at a 1% level of probability.

The data were fitted to a Sigmoid function, as utilized by Melo et al. (2010), which plotted PH and SD as a function of DAT. As shown in Figure 5A, PH increases slowly up to approximately 200 DD. After 200 DD, the PH increases quickly, with the maximum growth rate reported at 380 DD (0.165 cm DD⁻¹). Minami, Simão and Mantovani (1980) showed that eggplants grow quickly after 42 DAT; this value was between 310 and 399 DD. The maximum growth rate reported for SD (0.0218 mm DD⁻¹) occurred at 360 DD (Figure 5B). According to Trani, Tivelli and Carrijo (2011), eggplant has the highest nutritional demand between 35 and 70 DAT.

Analysis of variance revealed no significant differences in eggplant growth for different doses of N at the first vegetative stages; however, growth differences were observed from 77 DAT.

There was an interaction between K and N dose for AEN, which allowed to fit a values surface in that AEN is a function of the K and N doses (Figure 6). K and N doses reduced the AEN; however, N had a greater influence than K. The

effect of K on decreasing the AEN was considerable at high doses.

The best AEN value (280.5 kg fruit per kg N) was obtained in the absence of K and N (0 kg ha⁻¹ for both). This was consistent with the findings of Oliveira et al. (2014), who examined the effect of water salinity and N fertilization on eggplant crop, and obtained the highest AEN (373 kg fruit per kg N) when lower doses were applied. Those authors showed that AEN decreased with increasing N doses, independent of the salinity of the irrigation water.

These results are not consistent with those obtained by Aujla, Thind and Buttar (2007), who studied irrigation methods and levels of N, and confirmed an increase in AEN up to 120–150 kg ha⁻¹ of N. However, of note, when calculating the agronomic efficiency of nutrients, those authors (AUJLA; THIND; BUTTAR, 2007; OLIVEIRA et al., 2014) did not consider the difference between productivity of the dose studied minus the productivity of the control treatment (0 kg ha⁻¹ of N). Thus, their values were higher than if they had considered in numerator of division the productivity with fertilizer minus the productivity of the control treatment.

To guarantee that AEN and AEK would represent variation in production due to the amount nutrient of applied, and not due to the total amount of nutrient in the soil, the evaluation of agronomic efficiency considered the discount of control treatment productivities as described by Fageria (1998) and Oliveira et al. (2008).

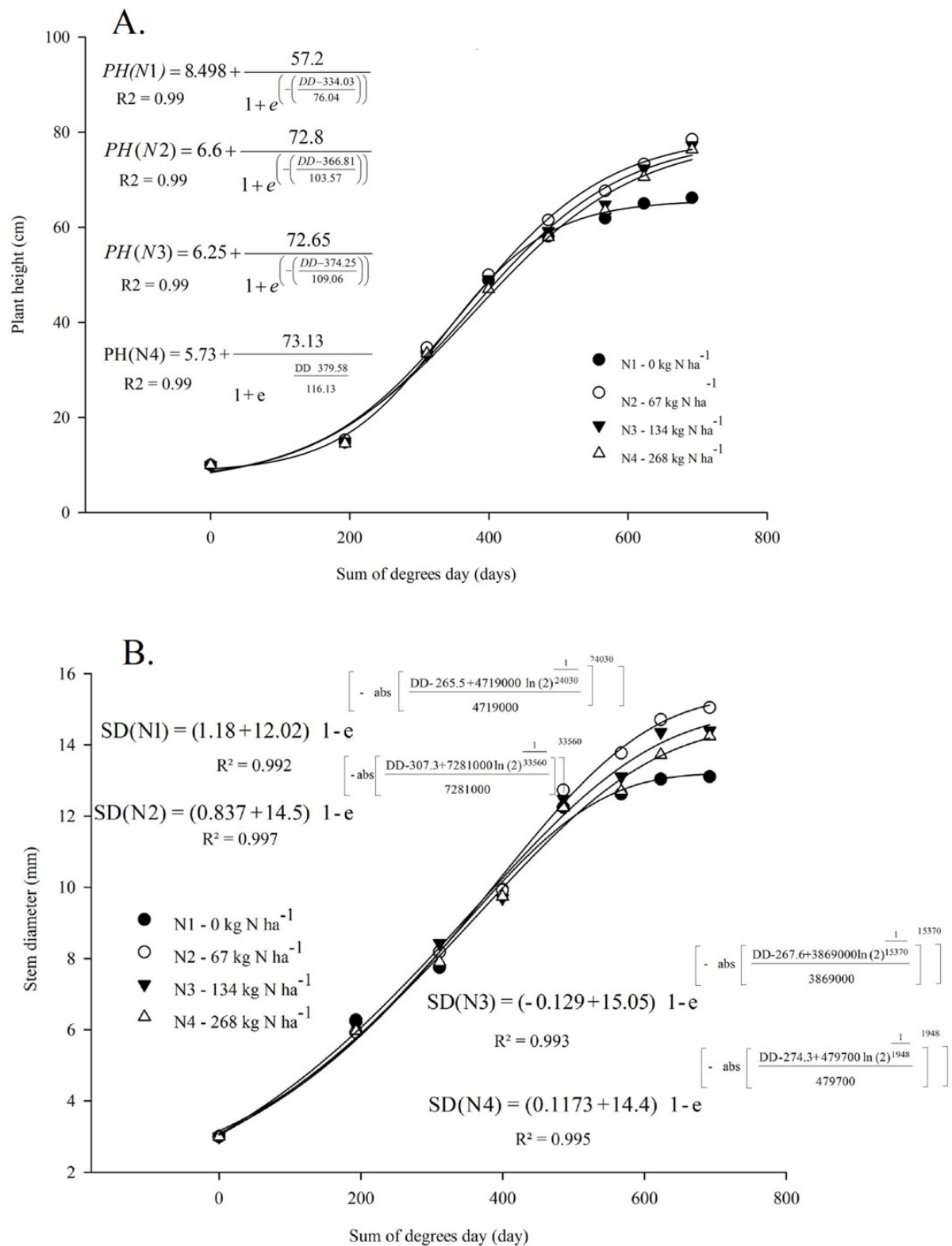


Figure 5. Plant height (A) and stem diameter (B) as a function of the sum of degrees day (DD) in eggplant subjected to different N doses cultivated in a protected environment.

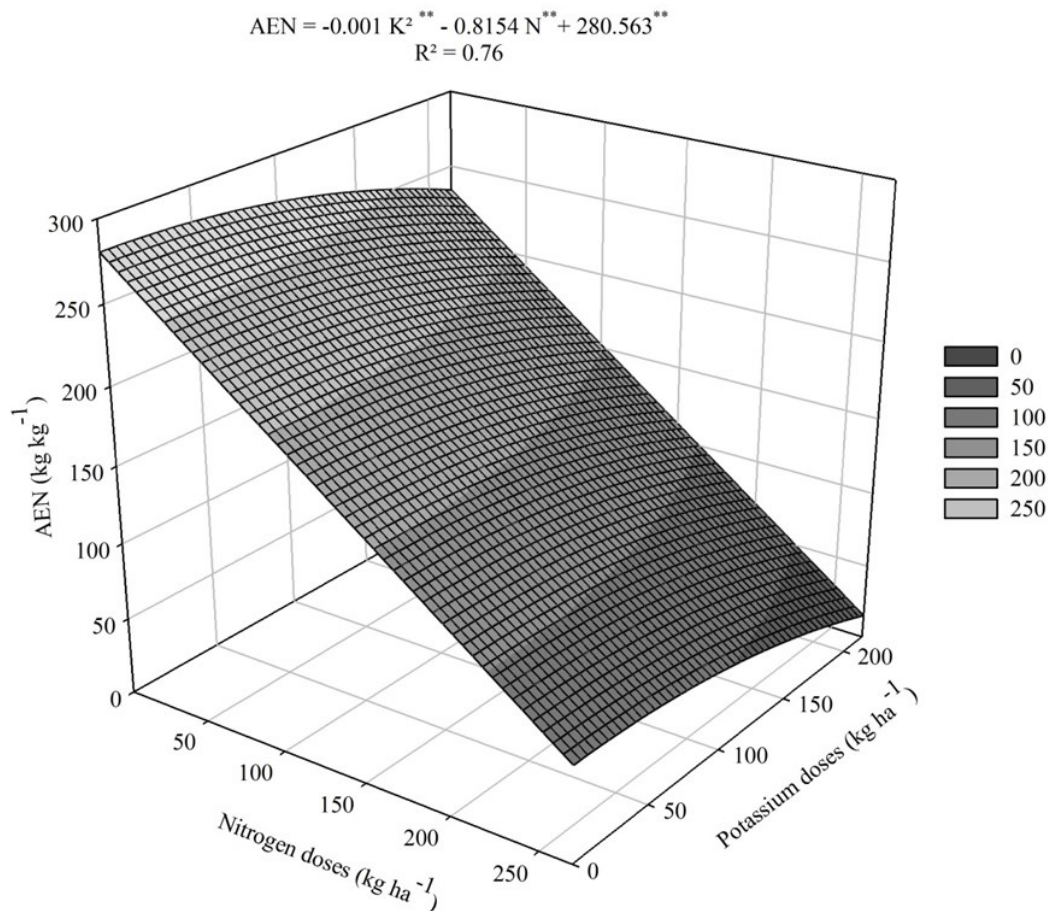


Figure 6. Agronomic efficiency of N as a function of K and N doses in eggplant cultivated in a protected environment.

Analysis of variance indicated significant differences in the interaction between K and N doses for AEK (Table 1). As shown in Figure 7, the highest AEK (99.5 kg fruit per kg N) was obtained with 54 kg ha⁻¹ of K in the level N3 (134 kg ha⁻¹). Oliveira et al. (2016) fertigated sweet pepper and obtained the maximum AEK value (135 kg kg⁻¹) when the lowest dose was applied. Those authors concluded that nutritional efficiency was reduced when high doses of K and N were applied.

Oliveira et al. (2008) fertigated melon with K and N and reported the highest AEK (132.63 kg fruit per kg N) with the lowest doses, and showed that increasing the K and N decreased the AEK values.

Negative agronomic efficiency values are due to decreased production compared with the production of plants without K fertigation, probably due to salinity, as shown by Oliveira et al. (2014).

Supplying high levels of fertilizer can increase soil salinity, which initiates a series of

negative effects on the cultures, such as reducing the absorption of water, inhibiting meristem activity, and cellular prolongation Oliveira et al. (2011) and, consequently, reduced agronomic efficiency of the nutrients.

In order to obtain appropriate values for the agronomic efficiency of nutrients, results from complex interactions must be considered; it does not depend solely on the availability of nutrients, but also on several metabolic activities of the vegetable, such as hormone production and the rates of photosynthesis, which can increase the absorption and use of the applied nutrients Gourley, Allan and Russelle (1994). In the present study, it is reasonable to state that high doses of the applied nutrients can reduce some of the aforementioned processes, and, therefore, the agronomic efficiency of N and K.

The results obtained in this study confirm the importance of appropriate management of fertigation with K and N doses in eggplant culture conducted in a protected environment.

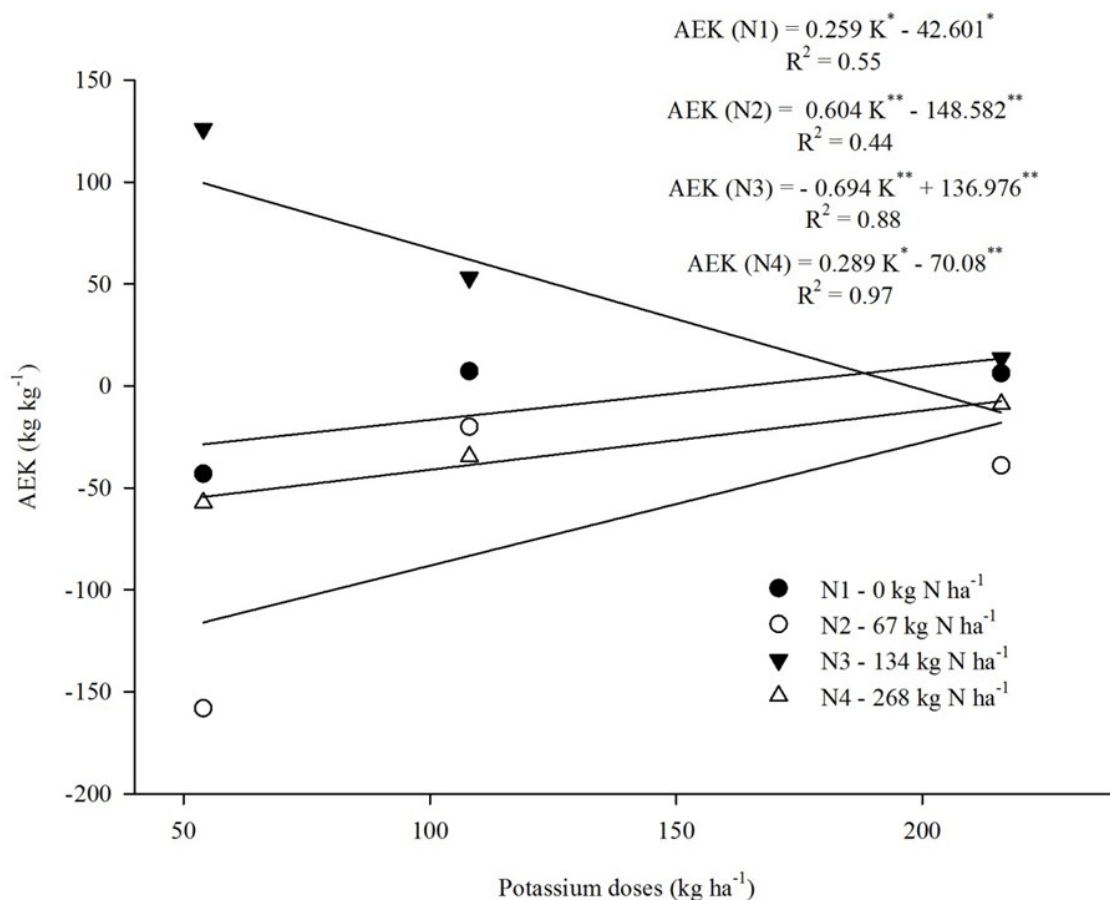


Figure 7. Agronomic efficiency of K as a function of K dose in eggplant subjected to different doses of N cultivated in a protected environment.

CONCLUSIONS

Maximum SD and plant height were obtained between 165 and 175 kg ha⁻¹ of N (16 and 17 g of N per plant). Leaf area is more influenced by the dose of N than of K. The agronomic efficiency of N reduced with increasing K and N doses and was much more influenced by N application. The isolated application of different K doses (0 to 216 kg ha⁻¹ of K) did not cause significant differences in SD, plant height, or LDM. It was possible to adjust a significant model of plant height and SD as a function of the accumulated DD of eggplant, for the cultivation conditions in the pot and in the protected environment. The nitrogen dose influenced plant height and SD, starting from 77 DAT.

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