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Growth and yield of strawberry plants fertilized with nitrogen and phosphorus

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ABSTRACT

Strawberry (*Fragaria* x *ananassa*) is a crop that has rapid growth and is highly influenced by fertilization. Due to its development speed, the plant needs to absorb sufficient macronutrients in order to meet its demand. The objective of this research was to evaluate growth and yield of strawberry under different doses of nitrogen (N), phosphorus (P) and potassium (K) fertilization. The treatments, using Box's central composite design, were distributed in randomized blocks with four replicates and consisted of five N doses (0.16, 0.37, 0.88, 1.4 and 1.6 g plant^{-1}) and five P doses (0.3, 0.58, 1.2, 1.8 and 2.1 g plant^{-1}), in the presence (1.67 g plant^{-1}) and absence of K. Seedlings of the cultivar 'Oso Grande' were cultivated in 10-L pots. The analysed variables were: plant height, fresh fruit mass, number of leaves, number of fruits, total soluble solids and titratable acidity. The fertilization with N and P increased the values for most of the studied variables. At the highest doses of N and P, K stimulated plant yield.

Palavras-chave:
Fragaria x *ananassa* Duch.
nitrogênio
fósforo
potássio

Crescimento e produção de morangueiro adubado com nitrogênio e fósforo

RESUMO

O morangueiro (*Fragaria* x *ananassa*) é uma cultura que apresenta rápido crescimento, além de ser bastante influenciada pela adubação motivo pelo qual é notória a necessidade de absorção suficiente de macronutrientes a fim de atender às demandas da planta. Propôs, neste experimento, avaliar o crescimento e a produção do morangueiro em função da adubação com nitrogênio e fósforo na ausência e na presença de potássio. Os tratamentos em que foi utilizada a Matriz Composto Central de Box foram arranjados em blocos ao acaso com quatro repetições. Foram avaliadas cinco doses de nitrogênio (0,16; 0,37; 0,88; 1,4 e 1,6 g planta^{-1}) e cinco de fósforo (0,3; 0,58; 1,2; 1,8 e 2,1 g planta^{-1}), na presença (1,67 g planta^{-1}) e na ausência de potássio. As mudas utilizadas foram do cultivar Oso Grande cultivadas em vasos de 10 L; as variáveis analisadas foram: altura das plantas; massa da matéria fresca dos frutos, número de folhas, número de frutos; sólidos solúveis totais e acidez titulável. A adubação com nitrogênio e fósforo aumentou os valores na maioria das variáveis estudadas enquanto nas maiores doses de nitrogênio e fósforo o potássio estimulou o rendimento das plantas.

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Introduction

The strawberry crop (*Fragaria x ananassa* Duch.) is considered an important commodity in the global scenario and has, mainly in the United States, most of the consumers of fresh strawberry in the world (Banaeian et al., 2011). Although Brazil is not in the group of the main producing countries, its strawberry production is in full expansion. Currently, the Brazilian production centers are spread in producing regions in the states of Minas Gerais, Rio Grande do Sul, São Paulo, Paraná and Distrito Federal, which have 41.4, 25.6, 15.4, 4.7 and 4% of the national production, respectively (Calvete et al., 2007).

Strawberry has a fast growth (two to three months) and is highly influenced by environmental conditions, such as light, salinity, water quality, temperature and nutrients (Li et al., 2010). Due to its development speed, the crop needs sufficient absorption of macronutrients in order to meet the photosynthetic demand and adequate fruit growth (Li et al., 2010). Although the specialized literature on the importance of these elements for the crop is still scarce, the results of some studies, such as Deng & Woodward (1998), bring important information on this issue.

Deng & Woodward (1998) claim that, when there is low availability, nitrogen (N) affects strawberry total biomass, besides reducing the size of fruits and severely limiting crop yield. Kirschbaum et al. (2010) mentioned that, when there is N surplus, the exaggerated growth is evident, with excess of leaves, increase in the susceptibility to pathogens and a poor overall performance of the plant.

With respect to phosphorus (P), which is an essential and important nutrient for crop propagation, health and vigor (Li et al., 2010), strawberry plants show an intensification in the tonality of the leaves to a dark green under deficiency. This occurs due to the reduction in the leaf blade area and, consequently, higher concentration of chlorophyll per unit of area (EPAMIG, 2007).

Choi et al. (2013) indicated that a deficient P nutrition causes retardation in the development of branches, reduction in stem elongation and a decrease in the capacity to withstand the weather, such as low or high temperatures, and the stress caused by pathogens. These authors, as well as Choi & Lee (2012), also show that the excess of P in strawberry tissues reduces the size of shoots, favors the yellowing of leaves and decreases the contents of Fe and Zn in plant tissue.

Potassium (K) is also highly demanded by the crop for directly favoring fruit quality and increasing the contents of total soluble solids and ascorbic acid, besides improving aroma, taste, color and firmness of fruits (Pettigrew, 2008). Rodas et al. (2013) indicated that physical and chemical properties of the cultivar 'Aromas', such as external color, titratable acidity, pH and soluble solids, were influenced by combined doses of N and K applied through fertigation. On the other hand, the use of K outside the recommended range can cause damages, especially to fruits, as reported by Andriolo et al. (2010), when evaluating the effects of Ca and K on fruit quality. In this study, the increase in K concentration in the nutrient solution decreased growth, production and the organoleptic quality of strawberry fruits. This result is corroborated by Sousa et al. (2014), who observed that mean weight and percentage of fruits of the variety 'Oso Grande' were affected by high contents of K available in the soil, and Sousa et al. (2014), who observed yield reduction in the cultivars 'Oso Grande' and 'Verão', with the increase in the doses of K fertilization.

Considering not only the low availability of information on the crop in this region, but also the expressive economic potential of strawberry, further researches are necessary. Therefore, this study aimed to evaluate growth and yield of the strawberry cultivar 'Oso Grande' in response to different doses of N, P and K in the region of "Brejo da Paraíba".

Material and Methods

The experiment was carried out from July to September 2013, at the Olericulture Sector of Federal University of Paraíba (UFPB), Areia, PB, Brazil. The local altitude is 575 m. The climate of the region, according to Köppen's classification, is 'As' (hot and humid), with rainy season from March to July and mean annual rainfall of 1200 mm. The mean air temperature is 23 °C, with the highest values in February (25.7 °C) and the lowest values in July (21.6 °C). The mean relative air humidity is about 80%.

The soil is a non-saline Regolithic Neosol, with sandy texture. Soil physical, chemical and salinity parameters before treatment application (Table 1) were determined according

Table 1. Soil physical and chemical characterization with respect to fertility and salinity in the layer of 0-20 cm

Attributes	Value
Physical	
Ds (kg dm^{-3})	1.44
Dp (kg dm^{-3})	2.68
Pt (m^3 m^{-3})	0.46
Sand (g dm^{-3})	872.6
Silt (g dm^{-3})	60.4
Clay (g dm^{-3})	67.0
WC_{FC} (%)	13.57
WC_{PWP} (%)	5.64
WC_A (%)	7.93
Fertility	
pH in water (1: 2.5)	6.60
OM (g dm^{-3})	24.3
P (mg dm^{-3})	47.7
K^+ (mg dm^{-3})	62.56
Ca^{+2} ($cmol_c$ dm^{-3})	4.2
Mg^{+2} ($cmol_c$ dm^{-3})	1.11
Na^+ ($cmol_c$ dm^{-3})	0.16
H^+ + Al^{+3} ($cmol_c$ dm^{-3})	0.13
Al^{+3} ($cmol_c$ dm^{-3})	0.00
Salinity	
ECse (dS m^{-1})	0.63
pH	6.47
Ca^{2+} ($mmol_c$ L^{-1})	0.10
Mg^{2+} ($mmol_c$ L^{-1})	2.75
Na^+ ($mmol_c$ L^{-1})	2.10
K^+ ($mmol_c$ L^{-1})	0.71
Cl^- ($mmol_c$ L^{-1})	3.50
CO_3^{2-} ($mmol_c$ L^{-1})	0.00
HCO_3^- ($mmol_c$ L^{-1})	3.00

Ds - Soil bulk density; Dp - Soil particle density; Pt - Total porosity; WC_{FC} and WC_{PWP} - Respectively, soil water content at field capacity (0.33 atm) and permanent wilting point (15.0 atm); WC_A - Available water content; OM - Organic matter; SB - Sum of bases (Na^+ + K^+ + Ca^{2+} + Mg^{2+}); CEC - Cation exchange capacity = SB + (H^+ + Al^{3+}); V - Base saturation (100 x SB/CEC); ECse - Electrical conductivity in the saturation extract; SAR - Sodium adsorption ratio = Na^+x $[(Ca^{2+} + Mg^{2+})/2]^{-1/2}$; ESP - Exchangeable sodium percentage (100 x Na^+/ CEC) to the methodologies suggested by Richards (1954) and EMBRAPA (2011).

The treatments, using Box's central composite design, were arranged in randomized blocks, with four replicates, and consisted of five N doses (0.16, 0.37, 0.88, 1.4 and 1.6 g plant^{-1}) and five P doses (0.3, 0.58, 1.2, 1.8 and 2.1 g plant^{-1}), in the presence (1.67 g plant^{-1}) and absence of K, totaling 19 treatments with one plant per pot and 76 experimental units. For the experiment, 10-L polyethylene pots, perforated at the bottom and sides, were used. Urea, single superphosphate and potassium sulfate were used as sources of N, P and K, respectively.

Irrigation and fertilizer application were performed manually and the frequencies of fertilizer application according to the recommendation for the North of the Minas Gerais State; 40% as basal fertilization and the rest divided into monthly applications (EPAMIG, 2007).

Seedlings of the cultivar 'Oso Grande' were used, which is intended for fresh consumption due to its pleasant taste and, among other characteristics, good yield and large pseudofruits, with bright red external color. These seedlings are vigorous and have a semi-erect habit, besides being a short-day cultivar with great adaptability (EPAMIG, 2007).

Phytosanitary control was performed due to the appearance of dark sword-grass (*Agrotis ipsilon*) during the vegetative growth stage, at 35 days after transplantation, using an insecticide from the carbamate chemical group, recommended for the control of *Agrotis ipsilon* in vegetable crops (Ferreira & Barrigossi, 2006). The commercial product Sevin 850 PM was used, which is a contact/ingestion insecticide, at the concentration of 1.5 g L^{-1} of water (according to the manufacturer's recommendation), using a backpack sprayer (Guarani) with a flat-fan nozzle directed to the base of the plants.

Fruits were weekly harvested from late July until the end of September, totaling 11 applications. The evaluated variables were: number of leaves and fruits per plant, determined by manual counting; total soluble solids, through manual refractometer graduated in the °Brix scale (0-32%); titratable acidity, measured by the concentration of organic acids in 100 g of dry fruits; and fresh mass of ripe fruits, harvested with at least ¾ of the surface showing a red color, which indicates the maturation stage (EPAMIG, 2007).

The results were subjected to analyses of variance and regression using the software SAS 9.3.

Results and Discussion

The increments in N and P doses increased the number of fruits (NF), both in the presence and absence of K, but with higher intensity in those treatments receiving this nutrient (Figure 1). The N doses that most stimulated fruit production were 0.9 g plant^{-1}, with K, leading to 15 fruits plant^{-1} and decreasing from this point on, and 1.2 g plant^{-1}, without K, with 11.4 fruits plant^{-1} (Figure 1A). On the other hand, despite the behavior similar to that of N, P fertilization led to a slightly lower NF: 14.6 fruits plant^{-1} for the maximum dose (2.1 g), in the presence of K, and 11 fruits plant^{-1} for the dose of 1.8 g, in the absence of K.

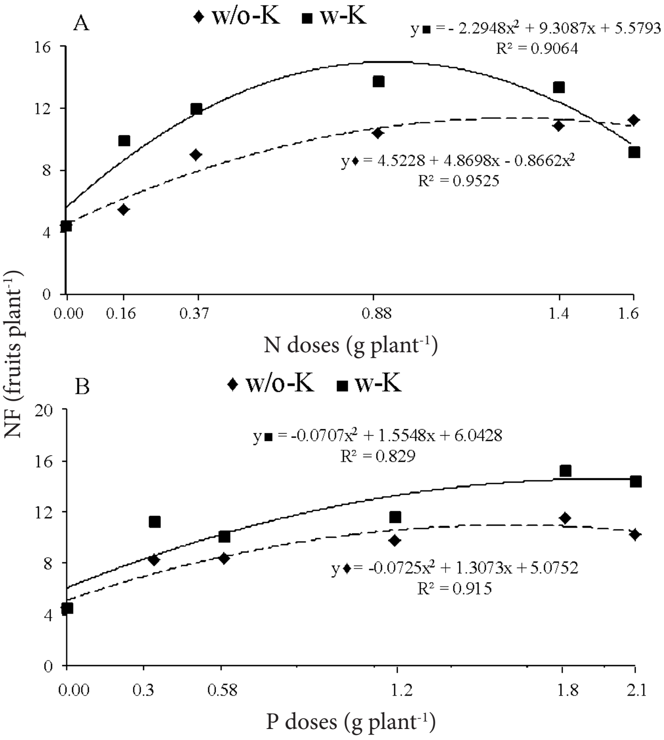

Figure 1. Number of fruits (NF) in 'Oso Grande' strawberry as a function of doses of nitrogen (N) and phosphorus (P), in the presence and absence of potassium (K)

The increase in NF as a function of the doses, especially those in the presence of K, is due to the positive influence of these elements in the various metabolic processes of the plant, since N and P participate in and are essential to the many plant mechanisms (Castellanos-Morales et al., 2012; Li et al., 2014). The substantial increase in NF for those plants treated with K, compared with the treatments without this nutrient, can be due to the positive interaction between these elements.

Recent studies with different crops have confirmed these results, such as Gonçalves Júnior et al. (2010), who observed positive relation between P and K. These authors found that, together, these nutrients influenced soybean production and number of legumes per plant, promoting an increase in the production with the increment in the doses. Rao et al. (2007) are also categorical when claiming that N and K fertilizers increased basil yield, pointing that the adequate use of these fertilizers is important for crop production.

For Sousa et al. (2014), the isolated application of K was not sufficient to increase the number of fruits in 'Oso Grande' strawberry, causing a linear decrease in NF as the doses increased. These authors claim that the decrease in NF with the increase in K concentration can be related to the saline stress in the substrate, caused by the high doses of the K fertilizer.

The values of total soluble solids (TSS) fitted to the regression model in the P treatments (Figure 2) and there was a superiority of the presence of K, compared with its absence, until the dose of 1.7 g plant^{-1}, after which the tendency inverted (Figure 2B). N-fertilized treatments, in the absence of K, showed linear behavior for TSS and mean value of 7.4 °Brix (Figure 2A), but they were superior to those receiving K, which showed a predominantly decreasing tendency ($TSS = 1.6x^2 - 3.0x + 7.9$ and $R^2 = 0.53$).

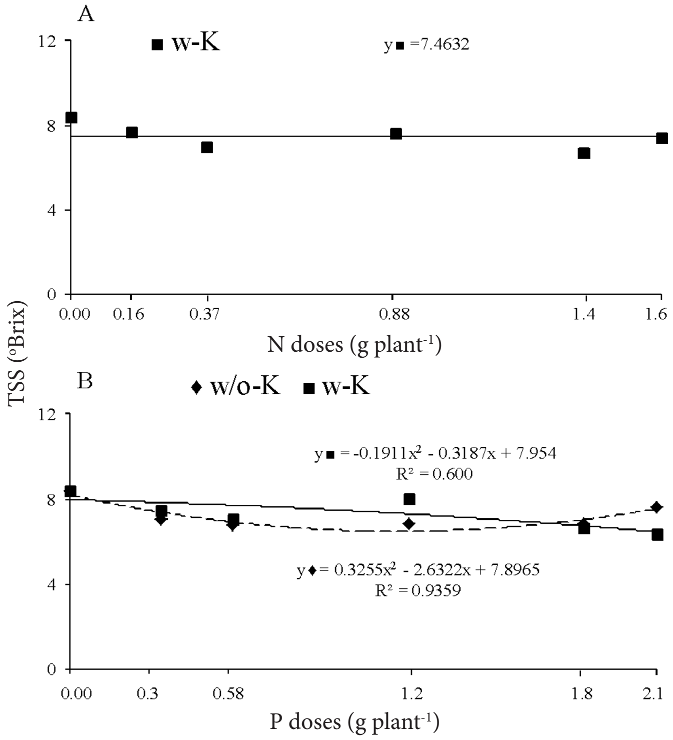

Figure 2. Total soluble solids (TSS) in fruits of 'Oso Grande' strawberry as a function of doses of nitrogen (N) and phosphorus (P), in the presence and absence of potassium (K)

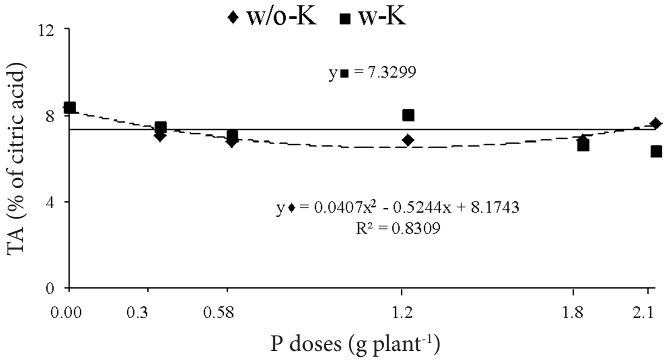

Figure 3. Titratable acidity (TA) in fruits of 'Oso Grande' strawberry as a function of the doses of phosphorus (P), in the presence and absence of potassium (K)

The superiority of the fertilizers in the absence of K could be widely contested, since the literature is emphatic when it claims that K is an important element for the concentration of solutes in plants (Pettigrew 2008; Taiz & Zeiger, 2013). However, this behavior might be related to the fertilizer source used in this experiment (potassium sulfate), its potential to salinize the soil (Grattan & Grieve, 1999) and the sensitivity of the crop to salts, as described by Saied et al. (2005), although further evaluations are still necessary.

Sousa et al. (2014) observed similar results when evaluating K fertigation in strawberry, and found reduction in the mean weight and percentage of fruits of the variety 'Oso Grande', with the increase in K doses. Andriolo et al. (2010) also observed that the increase in K concentration in the nutrient solution caused a decrease in growth, production and the organoleptic quality of strawberry fruits.

The titratable acidity (TA) of fruits (Figure 3) decreased and fitted to the quadratic polynomial regression model in the plants treated with P without K. In plants receiving K, no change was observed with the increase in P doses, with a mean value of 7.3% of citric acid. In the other cases, the increase in N doses caused a decreasing response in both situations (with and without K). The equations expressing this behavior are: citric acid (%) = $0.83x^2 - 3.51x + 9.45$ and $R^2 = 0.51$ and citric acid (%) = $0.15x^2 - 1.23x + 9.77$ and $R^2 = 0.49$, respectively for the absence and presence of K.

The reduction in the contents of titratable acidity is due to the higher accumulation of liquids in the fruits, promoted by the increasing N doses. This element is known to cause various negative effects on both yield and fruit quality, stimulating the excessive production of liquids in the fruits, which leads to the dilution of the cell content.

Based on this information, it is possible to infer that the contents of organic acids are reduced with the increase in N doses. Although predominantly decreasing, the contents were high only when K was applied. K is related to lower water losses by the plant, because it regulates stomatal opening and closure (Taiz & Zeiger, 2013). This tendency is contrary to that observed by Castellanos-Morales et al. (2012). These authors observed reduction in the contents of organic acids in strawberry fruits when different N levels were applied.

As to P-fertilized plants, a decrease in organic acids was also observed, although less expressive, which was readily changed with the presence of K, similarly to the first case.

The analysis of variance showed that the different doses of N and P, combined with K, did not show significant effect on plant height, which presented mean value of 13.3 cm. Presumably, the organic matter content during the experiment, which was equal to 24.3 g dm^{-3} (Table 1), masked the efficiency of the fertilizers, especially N, since this is the main element responsible for plant growth in height (Kirschbaum et al., 2010).

Thus, plant height was not a determinant factor for N fertilization, as also observed by Venâncio et al. (2013), in an experiment evaluating the production components of yellow passion fruit under N fertilization. Under these conditions, the soil fertility evidenced by the presence of 15.2 g kg^{-1} of organic matter led to the inexpression of the N fertilizer with respect to fruit production.

The values of fruit fresh mass (FFM) fitted to the linear regression model and increased with N and P doses, except only for the doses of N without K, which were represented by a mean value of 90.3 g $plant^{-1}$. Nevertheless, when compared with the highest dose, the values were close (Figure 4A) and the difference was 15.7%. The increase in P doses, in the absence of K, stimulated FFM (Figure 4B), but with lower values compared with the treatments receiving K (FFM = $6.32x + 52.55$ and $R^2 = 0.46$), which were 19% higher.

In general, N and K are the most required nutrients and interact for the increment of production and improvement of plant nutrition (Epstein, 1975; Taiz & Zeiger, 2013). However, in the case of N doses in the presence of K (Figure 4A), the response was less than expected, with the lowest FFM value for the dose of 1.6 g of N $plant^{-1}$, which can have occurred, as explained by Lavres Júnior & Monteiro (2002), due to inadequate K levels, suggesting a relation between absorption and use of these elements.

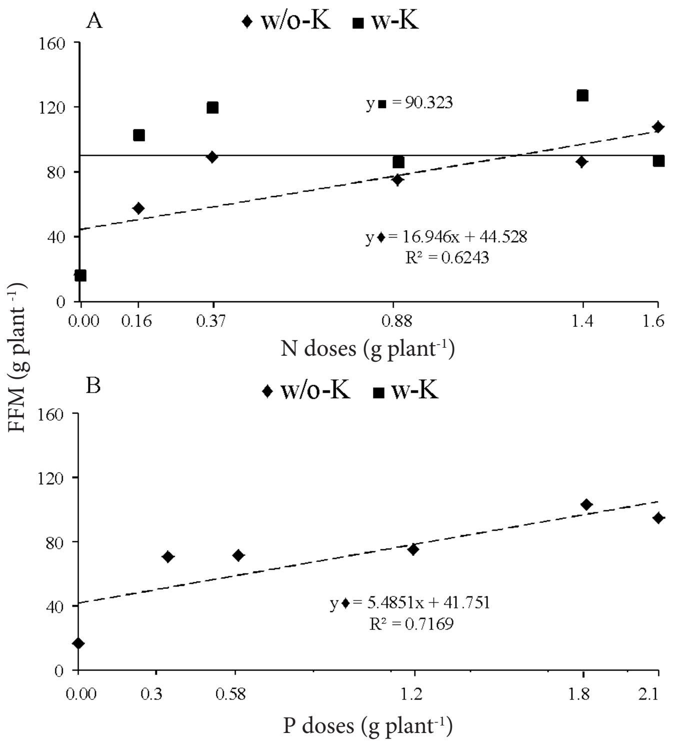

Figure 4. Fruit fresh mass (FFM) of 'Oso Grande' strawberry as a function of doses of nitrogen (N) and phosphorus (P), in the presence and absence of potassium (K)

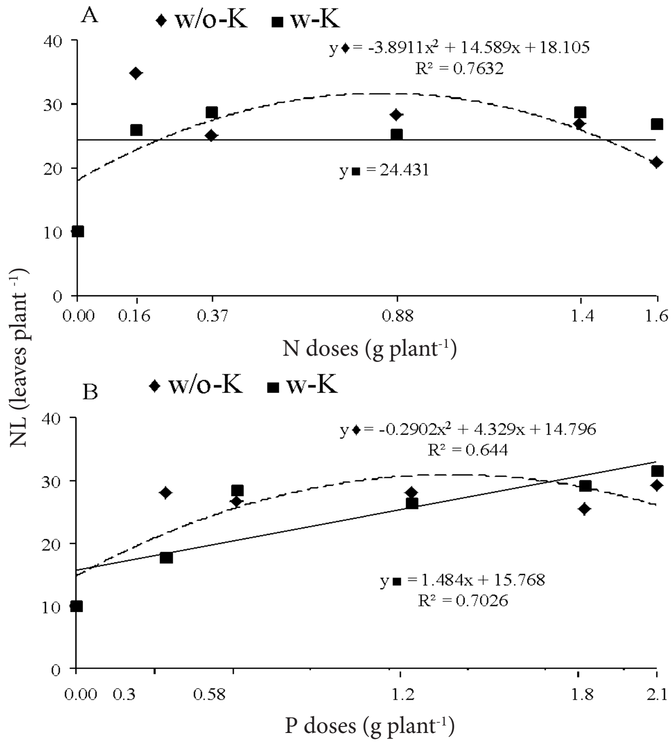

Figure 5. Number of leaves (NL) of 'Oso Grande' strawberry as a function of doses of nitrogen (N) and phosphorus (P), in the presence and absence of potassium (K)

These results agree with those observed by Pereira et al. (2012), who applied increasing doses of N and K and did not observe significant effect of the fertilizers on the variable mean fruit mass of blackberry plants. In strawberry, Nam et al. (2006) showed a positive relation between N and K in the increment of dry matter; however, these authors warn about the unbalanced use, which can pose risk of diseases like anthracnose. These authors recommend low contents of these elements in the plant.

The number of leaves (NL) increased significantly with the increment in the doses, in both situations (Figure 5). However, under N fertilization in the presence of K, NL data did not fit to the regression models like the other treatments and showed a mean value of 24.4 leaves plant^{-1} (Figure 5A). In the absence of K, N treatments reached the maximum of 30.7 leaves for the dose of 0.9 g plant^{-1}, decreasing from this point on until reaching 21 leaves for the highest dose. The same occurred for P fertilization, where NL increased until the dose of 1.36 g plant^{-1} and 30.7 leaves, subsequently decreasing until 26 leaves.

In both cases and considering the highest value of N and P (1.6 and 2.1 g plant^{-1} respectively), the presence of K promoted better results in the treatments. In percentage, this difference was 15.6% (Figure 5A) and 17.9% (Figure 5B).

N, P and K are essential to metabolic processes such as synthesis of proteins, nucleic acids, coenzymes, secondary metabolism products, enzyme activation, osmotic regulation, energy transfer, respiration and photosynthesis, among many other important processes (Castellanos-Morales, 2010; Taiz & Zeiger, 2013). Therefore, the application of these nutrients significantly increases plant growth and development, in this case evaluated by the number of leaves.

The high number of leaves in the P treatment may have occurred because strawberry plants were cultivated in a soil with good content of organic matter, associated with the applications of K, as occurred with plant height. The number of leaves was also higher in the plants receiving N, the main element responsible for plant growth. In this specific case, it is probable that the better use of K by the plants can stimulate more leaf production, but the dose of K did not promote this improvement. Lavres Júnior & Monteiro (2002) claimed that N fertilization has often shown productive responses below the expectations, because of inadequate K levels.

Similar behavior was observed by Lima et al. (2010), who evaluated the N/K ratio on the nutrition of coffee seedlings in nutrient solution. These authors confirm that K significantly influenced N contents, besides other nutrients, in the plant tissue, concluding that incompatible doses of N/K promote changes in the nutritional status of coffee plants.

Conclusions

1. Nitrogen fertilization increased the values of all the analysed variables.
2. The phosphorus dose of 2.1 g plant^{-1} maximized most of the analysed variables.
3. At the highest doses of nitrogen and phosphorus fertilizers, the greatest stimuli for the increase of the variables occurred in the presence of potassium.

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