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EFFECT OF NITROGEN AND POTASSIUM FERTIGATION ON THE QUALITY OF ITALIAN ZUCCHINI FRUIT

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ABSTRACT

The objective of this study was to evaluate the effect of nitrogen and potassium fertigation on the quality of 'Novita Plus' Italian zucchini fruit. The experiment was conducted under greenhouse conditions at the Technical Center of Irrigation, Department of Agronomy of the State University of Maringá. The drip irrigation system was used such that each plant was irrigated by a dripper operating at a nominal flow of 4 L h^{-1} and a service pressure of 10 m.c.a., which was controlled by means of a pressure gauge of glycerin installed in the control head of the system. A completely randomized design was used. The experiment was arranged in a factorial design (4 × 4) with three replicates. The treatments applied to the plants were in the combination of four N doses (0 kg ha^{-1} N, 90 kg ha^{-1} N, 180 kg ha^{-1} N, and 270 kg ha^{-1} N) with four doses of K (0 kg ha^{-1} K_2O, 90 kg ha^{-1} K_2O, 180 kg ha^{-1} K_2O, and 270 kg ha^{-1} K_2O). The following fruit variables were evaluated: pH, titratable acidity, fruit diameter, and fruit length. The N and K doses applied through irrigation water significantly influenced the fruit variables. However, no significant effects of N and K fertigation were found in the interaction between the N and K doses applied.

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INTRODUCTION

The family Cucurbitaceae, to which the zucchini (*Cucurbita pepo* L.) belongs, has about 20 genera and more than 800 species, constituting one of the most important families of plants cultivated by man. Zucchini is known in Brazil as squash, Italian zucchini, and trunk zucchini (Filgueira, 2013). According to Correa and Cardoso (2016), it is a crop that generates many jobs, both directly and indirectly, because there is a great need of manpower in the various phases of the production process of the crop. N is one of the main nutrients required to obtain high productivity as it has important structural functions and participates in biochemical and physiological processes that occur in the plant such as photosynthesis, respiration, root development and activity, ionic absorption of other nutrients, and cell growth and differentiation (Taiz and Zeiger, 2013). However, N fertilization is currently a controversial issue, because when applied excessively it can result in reduced nutritional quality and safety owing to nitrate accumulation (Pôrto, Puiatti, Fontes, Cecon and Alves, 2014). According to Pittela (2003), K is required by plants in large quantities and its function is related especially to the enzymes that participate in almost all reactions of the plant. In the period of fruiting, it assists in the filling and growth of the seeds. In contrast, its deficiency is characterized by slow growth, plants with poorly developed roots, weak and very flexible stems, plants more susceptible to disease attacks, and the formation of seeds and undeveloped fruit. Vegetables are demanding of K, this being the macronutrient most extracted by most of them. In addition to influencing productivity, it improves product quality, and consequently, market value (Filgueira, 2013). Therefore, although K is considered by many as the most important nutrient in the quality of vegetables, there is no consensus in previous studies conducted with different species (Araújo, Cardoso, Evangelista, Takata and Silva, 2014). According to Araújo, Cardoso, Oliveira Junior and Magro (2015), studies aimed at the validation of fertilization recommendations are of

fundamental importance to guarantee adequate doses and timing, avoiding excess or scarcity of nutrient availability to the plant, and contributing to a sustainable agricultural practice. The nutritional imbalance in zucchini or any plant, either due to the lack or excess of nutrients, directly influences the production and final quality of the product, because it is a stress factor (Vidal *et al.,* 2013). According to Schwerz (2018), the conditions of planting and cultivation can affect physical, chemical, and physical-chemical quality indexes which are determinants of the maturity of fruits and vegetables. Chitarra and Chitarra (2005) state that pH, acidity, soluble solids, sugars, vitamin C, and carotenoids are some of the indices that characterize the morphological, physiological, and biochemical transformations that vegetables pass through. Such transformations may interfere with the quality of the final product. Currently in the literature, there are few studies that relate the conduction of plants in fertigated crops with fruit quality. Thus, the objective of this study was to evaluate the effect of N and K fertigation on the production and quality of Italian zucchini fruit.

MATERIALS AND METHODS

The experiment was installed and conducted between August and December 2018 in a greenhouse located at the Technical Center of Irrigation, an institution linked to the Department of Agronomy of the State University of Maringá, in the city of Maringá, State of Paraná, Brazil (23°25′ south and 51°57′ west). The greenhouse was built in a north–south direction, with an arc cover of 30 m in length, 5.7 m in width, and 2.5 m right foot. The facades were wrapped with an anti-aphid screen and had a masonry skirting board 0.25 m in height. The ceiling was covered with a 150-micron thick low-density polyethylene plastic film with anti-UV treatment. The climate of the experimental area is of the type Cfa Mesothermic Moist, characterized by abundant rains in the summer and dry winters, according to the Koppen climate classification (Sala, 2005). The annual rainfall averages 1500 mm. The average minimum and maximum temperatures are 10.3 °C and 33.6 °C, respectively. The average annual temperature is 21.8 °C and the average relative air humidity is 66%. The soil of the area belongs to the class Typical Dystroferric Red Nitosol with moderate A horizon, clay texture, and perennial forest phase (EMBRAPA, 2013). This soil has the following chemical characteristics: pH in $CaCl_2$, 4.9; P: 3.19 mg dm^{-3}; K^+: 0.16 $cmol_c$ dm^{-3}; Ca^{2+}: 2.00 $cmol_c$ dm^{-3}; Mg^{2+}: 0.60 $cmol_c$ dm^{-3}; Al^{3+}: 0.62 $cmol_c$ dm^{-3}; $H^+ + Al^{3+}$: 3.74 $cmol_c$ dm^{-3}; organic matter: 17.97 g dm^{-3}; CTC: 6.50 $cmol_c$ dm^{-3}; and base saturation (V%): 42.46%. According to Trani (2007), limestone was applied to raise the base saturation to 80%, using 0.29 t ha^{-1}. At the time of planting, 26.66 kg ha^{-1} N, 213.3 kg ha^{-1} P_2O_5, and 80 kg ha^{-1} K_2O were applied as fertilization. In addition, organic fertilization was performed with 30 t ha^{-1} of bovine manure applied about 30 days before transplanting the seedlings to the experimental area. Subsequently, the soil in the area was prepared for the construction of the beds. For this, a rotating hoe was used to incorporate the correctors of acidity and organic and mineral fertilizers to a depth of 20 cm before application to the soil. Then, the demarcation of the experimental area was performed, such that seven beds, 1 m apart, were prepared and the beds at the extremities were 0.45 m away from the wall of the greenhouse. All the beds were handmade using hoes. Simultaneously, 'Novita Plus' Italian zucchini seeds were sown in three 72-cell styrofoam trays. These trays were first sanitized with bleach solution (1%). After drying the trays, commercial substratum was applied in each of the cells and the 'Novita Plus' Italian zucchini seeds were sown. Seedlings were transplanted to the experimental area 21 days after sowing with the seedlings presenting three definitive leaves with a spacing of 1.0 m between rows and 0.7 m between plants according to the methodology of Filgueira (2013). During the period between sowing and transplanting irrigations were performed in the trays thrice a day, with 10 L of water per application. After transplanting the Italian zucchini seedlings to the experimental area, irrigations were performed daily, aiming to favor the establishment of the seedlings. This procedure was adopted for ten days. Afterwards, the irrigations and fertigations were performed according to the voltage values recorded in the tensiometers. When they recorded critical voltages of 20 KPa according to the method described by Marouelli (2008) the nitrogen and potassium applications were performed. Irrigation management was performed based on the estimation of the maximum evapotranspiration of the crop, according to the method proposed by FAO, in Bulletin 56 (Allen, Pereira, Raes and Smith, 2006), applying the dual Kc methodology. The basal Kc of culture values recommended by FAO 56 were equal to 0.15, 0.95, and 0.70 for Italian zucchini, in the initial and intermediate stages and at the end of the crop cycle, respectively.

In this study, the drip irrigation system was used such that each plant was irrigated by a drip irrigator, which operated at a nominal flow rate of 4 L h^{-1} and a service pressure of 10 m.c.a., which was controlled by a glycerin manometer installed in the system control head. The system comprised 144 drippers, 48 polyethylene tubes 16 mm in diameter and 2.1 m in length, 2 drawer registers, 48 butterfly registers, a 0.5 horsepower motor pump, and maximum reservoir capacity of 500 L. Seven shunt lines were each formed by 32 mm diameter PVC pipes. Each bypass line had seven side lines of polyethylene tubes 16 mm in diameter. N and P doses were defined based on the total nutrient requirement along the crop cycle according to Trani (2007). N doses were applied with the use of calcium nitrate fertilizer, while K was supplied by the application of potassium chloride to the 'Novita Plus' zucchini plants. A completely randomized design was used. The experiment was arranged in a factorial design (4 × 4) with three replicates. The treatments applied to 'Novita Plus' zucchini were a combination of four N doses (0 kg ha^{-1} N, 90 kg ha^{-1} N, 180 kg ha^{-1} N, and 270 kg ha^{-1} N) with four doses of K (0 kg ha^{-1} K_2O, 90 kg ha^{-1} K_2O, 180 kg ha^{-1} K_2O, and 270 kg ha^{-1} K_2O), resulting in 16 treatments with each having been applied in three experimental units, totaling 48 treatments in the experimental area. Fertilizer applications were applied twice a week for two months, totaling 16 applications following the irrigations defined by the management criterion. The N and K doses were injected into the main line of the irrigation system after the filtration system. A 1/2 cv centrifugal pump, installed with suction that pumped the fertilizer solution (calcium nitrate or potassium chloride) from a 500 L capacity tank where the mixture was produced, was used as the injector equipment. The fertigation duration was 54 min and as part of the management, the system was initialized and completed with the application of water, to ensure stabilizing the flow of the drippers and avoiding clogging. The cultural treatments and the phytosanitary control when necessary were executed according to the methods described

by Filgueira (2013). Harvests started 30 d after transplanting and were performed daily in the morning until the productive capacity of the plants was exhausted. For the comparison of the fruit quality of the 'Novita Plus' Italian zucchini plants between the different treatments, the following responses were evaluated in the culture:

- pH: determined by the potentiometric method, after calibrating the potentiometer with buffer solutions (pH 4.0 and 7.0) at 25 °C, then immersing the electrode in a beaker containing the sample and recording the value indicated on the display of the instrument, with the results expressed in units of pH.
- Titratable total acidity (TA): determined by titration of the sample with 0.1 M NaOH solution to pH 8.1, according to the methodology described by the Institute Adolfo Lutz (1985), and results expressed as percentage of malic acid.
- Fruit length (cm): the harvested fruit was measured using scales graded in centimeters.
- Fruit diameter (cm): digital calipers were used to determine the diameter of the fruit obtained from each plant.

Data were analyzed by analysis of variance and in the case of significant differences in the variables with N and K doses, regression analyses were applied. SISVAR was used for the statistical analyses. All applied tests had a significance level of 5%.

RESULTS

pH: N and K applications, through fertigation, significantly affected the pH of 'Novita Plus' zucchini fruit. Thus, the regression analysis was performed and the quadratic polynomial regression model was shown to have the best fit to express the relationship between applied fertilizer (calcium nitrate and potassium chloride) doses and the pH of the fertilized fruit (Figure 1). Figure 1A shows that as the N doses increased, there was also an increase in the pH of the 'Novita Plus' Italian zucchini fruit. The maximum estimated dose of 230 kg ha^{-1} N applied as calcium nitrate resulted in fruit with a pH of 6.7. In relation to K (Figure 1B), the increase in the pH value of the 'Novita Plus' Italian zucchini fruit increased with the application of the K doses, which was similar to the evaluation of the effect of N application. The application of the maximum estimated dose of 125.5 kg ha^{-1} K_2O resulted in fruit with a pH of 6.4, while the application of 180 kg ha^{-1} K_2O resulted in the production of fruit with a pH of 6.8.

TA: The N and K doses applied by fertigation also significantly influenced the TA of the 'Novita Plus' Italian zucchini fruit. The best fit of the data was obtained by the adoption of the quadratic polynomial regression model and the relationship between N and K applications through fertigation and the TA of the fruit of 'Novita Plus' Italian zucchini is shown in Figure 2. As the N doses (Figure 2A) increased, there was also an increase in fruit TA. The maximum estimated dose of 150 kg ha^{-1} N resulted in the production of 'Novita Plus' zucchini fruit with a TA of 0.2025% of malic acid. However, the dose of 180 kg ha^{-1} N resulted in the production of fruit with a TA of 0.21% of malic acid. The results obtained in the present study are different from those found by Araújo (2011) who reported total acid values ranging from 0.086 to 0.126% of malic acid when working with 'Aline' Italian zucchini fruit. Figure 2B confirms the increase in the doses of K provided to the 'Novita Plus' Italian zucchini fruit increased the TA. The maximum estimated dose of 150 kg ha^{-1} K_2O resulted in the production of 'Novita Plus' Italian zucchini fruit with TA of 0.1835% of malic acid, while zucchini fruit with TA of 0.19% of malic acid was obtained with the application of 180 kg ha^{-1} K_2O.

Fruit length: The sources of variation (N and K doses) significantly influenced the length of the 'Novita Plus' Italian zucchini fruit. However, unlike the pH and TA, the best fit of the data in the regression analysis was obtained through the adoption of the linear polynomial regression model. Figure 3 shows the relationship between N and K doses applied by fertigation and fruit length. Data shown in figure 3A confirm that the increase in the length of the 'Novita Plus' Italian zucchini fruit is directly proportional to the increase in the doses of N applied. Each kg ha^{-1} of applied N resulted in increases of 0.0176 cm in the length of the evaluated fruit. Thus, with the application of 270 kg ha^{-1} N, fruit of greater length (19.8 cm) was obtained. Figure 3B shows that as K doses increased, the length of the 'Novita Plus' Italian zucchini fruit increased. The application of 270 kg ha^{-1} K_2O promoted the production of fruit with a maximum length of 17.8 centimeters, and for each kg ha^{-1} of K_2O applied, the fruit showed increments of 0.0027 cm in length.

Fruit diameter: Regarding the N rates, the fruit diameter data had a good fit to the quadratic polynomial regression model. This behavior was also observed in the evaluation of K doses. Figure 4 shows the relationship between the N and K rates applied by fertigation and the fruit diameter. Figure 4A shows the diameter of the fruit of 'Novita Plus' Italian zucchini plants increased with the application of 126.67 kg ha^{-1} N resulting in fruit production with a maximum diameter of 5.68 cm. With the dose of 270 kg ha^{-1} N, a decline was observed, that is, this nitrogen dose resulted in the production of fruit with smaller diameters. The diameter of the fruit of 'Novita Plus' Italian zucchini plants increased with the K doses supplied reaching the maximum value (5.16 cm) at the estimated dose of 175 kg ha^{-1} K_2O. However, with the dose of 270 kg ha^{-1} K_2O, a decrease was observed, that is, the production of fruit with smaller diameters, a behavior similar to that seen in the evaluation of the effect of the N doses.

DISCUSSION

In relation to pH, the results of this study differ from those reported by Antunes, Ferreira, Puiatti, Cecon and Silva (2014) in an experiment with the African cucumber. N applications did not significantly influence the pH of the fruit analyzed in the different treatments. Barros, Araújo, Neves, Campos and Tosin (2012) also did not find significant statistical differences related to the application of N doses when evaluating the physical and chemical characteristics of drip irrigated watermelon fruits. It is probable that the immediate transfer of harvested fruit for the determination of pH contributed to the values approaching pH considered neutral. In addition, the fruit did not suffer any type of injury during transfer, which could have contributed to the maintenance of its chemical characteristics. Durigan and Mattiuz (2007) confirmed the effect of different treatments of injury (cut, impact, and compression) on Italian zucchini fruit and reported the pH values of the fruit decreased considerably, obtaining average pH values of 4 and 5. According to Taiz and Zeiger (2013),

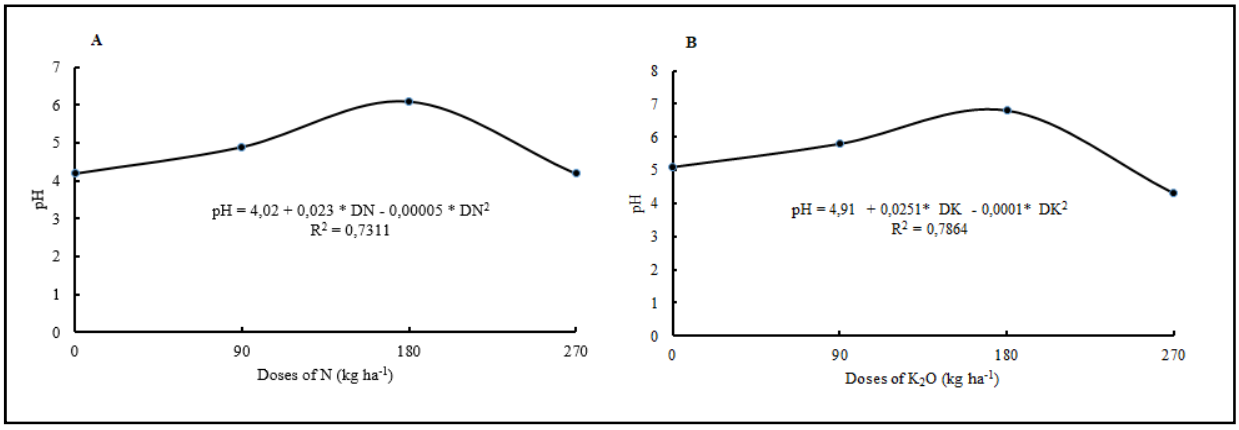

Figure 1. pH of 'Novita Plus' Italian zucchini fruit as a function of the application of different doses of nitrogen (A) and potassium (B) via fertigation

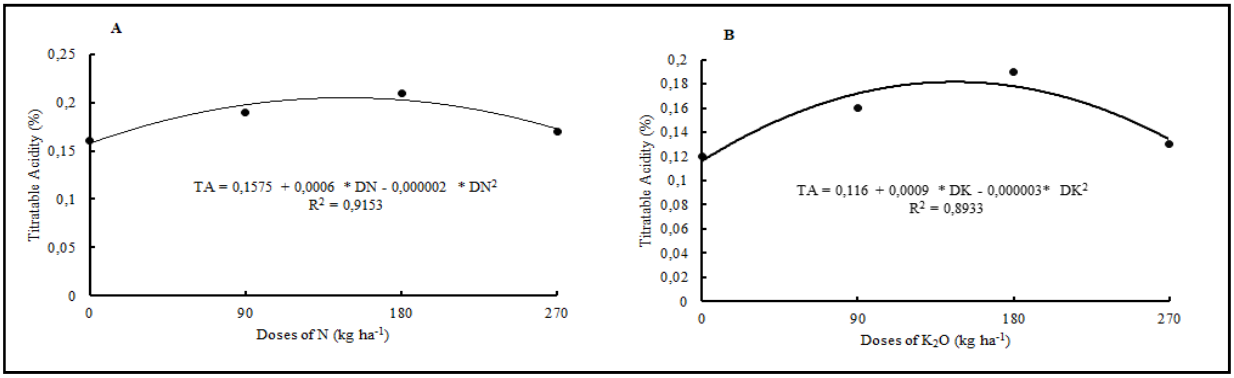

Figure 2. Titratable acidity (TA) of 'Novita Plus' Italian zucchini fruit with the application of different doses of nitrogen (A) and potassium (B) via fertigation

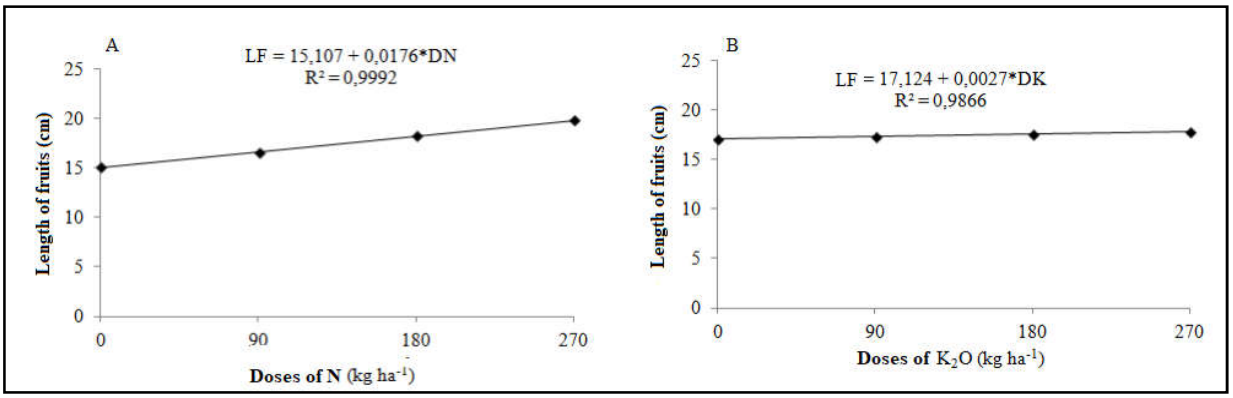

Figure 3. Length of 'Novita Plus' Italian zucchini fruit (LF) as a function of the application of different doses of nitrogen (A) and potassium (B) via fertigation

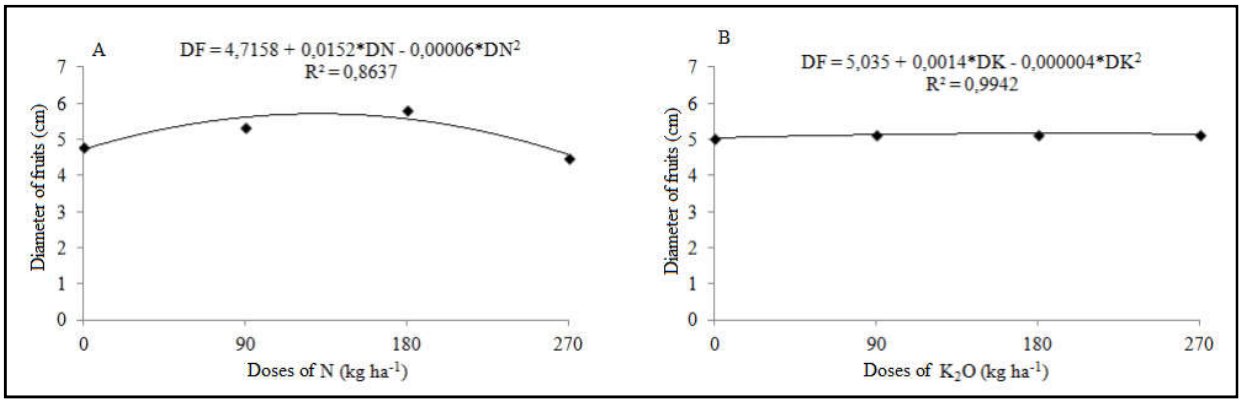

Figure 4. Diameter of 'Novita Plus' Italian zucchini fruit (DF) as a function of the application of different doses of nitrogen (A) and potassium (B) via fertigation

the increase in acidity and the decrease in pH are indicative of probable acceleration of the respiratory process (Krebs cycle) or solubilization of pectins, which makes the medium more acidic. These results can be explained by the fact that fertigation provides greater solubility of the nutrients that are supplied to the crops. In addition, it is noteworthy that fertilizer doses were distributed over the crop cycle. The use of fertigation has made it possible to optimize the use of fertilizers in different irrigated crops, both in relation to productivity and the quality of the products obtained; its adoption being more notable in crops irrigated by localized irrigation systems (Oliveira and Villas Bôas, 2008). The results of this study are partially divergent to those reported by Araújo *et al.,* (2014) of significant differences in the effect of the application of different doses of K on the physical and chemical characteristics of 'Aline' Italian zucchini fruit. However, the linear regression model was the most adequate to explain the relationship between K doses and pH of fruit. Titratable total acidity influences the taste and odor of food and is related to the amount of organic acids present (Cecchi, 2003). According to Chitarra and Chitarra (2005), the TA is among the attributes necessary for the post-harvest evaluation of vegetables, together with loss of fresh mass, color, firmness, soluble solids, total soluble solids, pungency, and pH. The results of this study were different from those reported by Araújo *et al.* (2014) of linear decreases with increased K doses provided to 'Aline' zucchini squash plants. Fruit TA can be explained by the presence of the organic acids that are dissolved in the vacuoles of the cells, in free form or in combination with ester salts (Nassur, 2009). They not only contribute to the acidity but also to the characteristic aroma, bearing in mind that some components are volatile. Organic acids serve as an energy reserve through their oxidation in the Krebs cycle and can be influenced by fertilization, since adequate levels of K may increase the TA owing to higher concentration of organic acids (Chitarra and Chitarra, 2005). Regarding fruit length, the results of this study differ from those obtained by Araújo, Andrade, Ramalho and Azevedo (2009) in an experiment evaluating the influence of the application of N doses (0, 100, 200, 300, and 400 kg ha^{-1} N) applied by fertigation in protected cultivation on the length, diameter, average fruit weight, and number of fruit per plant of 'All Big' chili. They concluded that N doses did not significantly influence fruit length.

The results obtained in the length of the 'Novita Plus' Italian zucchini fruit can be explained by the practice of fertigation. Through this, the nutrients are supplied in readily soluble ionic forms contributing to the reduction in reaction time with the soil. In addition, nitrogen is highly soluble in the soil solution and mobile inside the plant. It may have been rapidly transported to the phloem, thus participating in the production of photoassimilates which are later translocated to produce the fruit (Marenco and Lopes, 2009). K is one of the nutrients most required in the culture of Italian zucchini. It is possible that the applications of macronutrients have contributed greatly to the improvement of the quality of Italian zucchini fruit owing to the optimization of transpiration and the carbohydrate formation process (Taiz and Zeiger, 2013), with consequent improvement in translocation and carbohydrate plants for fruit (Epstein and Bloom, 2006). The results of this study are consistent with those obtained by Melo *et al.* (2009) in an experiment to observe the effect of the application of K doses (0, 2,5,5,0,7,5,10,0 g K_2O $plant^{-1}$) by irrigation water in protected cultivation on the length of hybrid 'Zarco' yellow pepper fruit. They found significant differences and concluded the maximum dose of 7.0 g K_2O $plant^{-1}$ provided the fruit with the greatest length. The results presented in this study are consistent with those obtained by Medeiros, Duarte, Fernandes, Dias and Gheyi (2008) in an experiment studying the effect of the application of different N (45 kg ha^{-1} N, 91 kg ha^{-1} N, and 136 kg ha^{-1} N) and K (78 kg ha^{-1} K_2O, 156 kg ha^{-1} K_2O, and 234 kg ha^{-1} K_2O) doses by fertigation on the diameter of 'Mickylee' watermelon fruit. They concluded the maximum estimated dose of 96.66 kg ha^{-1} N contributed to the production of fruit with an estimated maximum diameter of 8.6 cm. In this case, there was also a quadratic effect of the N doses on the diameter of the watermelon fruit. It is possible that calcium nitrate improved the N availability in the soil owing to its high solubility and ionic form. The sources of fertilizers used must have high solubility so that the plant receives the nutrient dose adequately and the clogging of the emitters, especially the drippers, is prevented. When the plant absorbs N in the nitric form, it releases hydroxyls and carbonic acids in the rhizosphere, which cause the pH to increase, making the macronutrient more adequate (Borges and Silva, 2011).

The results obtained in this study are different from those reported by Albuquerque, Silva, Filho and Nunes (2011) in an experiment investigating the effect of K doses (80 kg ha^{-1} K_2O and 120 kg ha^{-1} K_2O) by fertigation and irrigation slides (80% ETc, 90% ETc, 100% ETc, 110% ETc, and 120% ETc) in the leaf area index, bark thickness, diameter and length of fruit, number of fruit per plant, average mass of fruit, and yield of 'Maxima F1' chili fruit. Regarding fruit diameter, no significant differences were found related to K doses, irrigation slides, and even with the interaction between these sources of variation. It is probable that with the application of 270 kg ha^{-1} K_2O the zucchini plants have the luxury of consuming unlimited K. In this case, plants absorb the chemical element in excess of their needs which does not improve the development of the plant (Brady and Weil, 2012), affecting the absorption of bivalent calcium and magnesium ions owing to the competition that occurs along with K at the site of cationic absorption located in the cells in the region of the plant root system. K is also involved in the activation of H^+-ATPases. Thus, the monovalent K ions leave the external solution and enter the plasma membrane of the root cells. In addition, with the activation of the H^+-ATPases, energy and H^+ ions are released, creating an electric and pH gradient. The nitrate ions (NO_3^-) are charged into the transport cells along with H^+ ions that are expelled from the cells and can carry other nitrate ions again. These ions may be stored in the cell vacuole or transported to other organs such as leaves (Taiz and Zeiger, 2013). The transport of the products generated in photosynthesis (photoassimilates) to the phloem depends on energy and is characterized as active transport. This energy comes from the activation of H+-ATPases, a process dependent on the presence of potassium (K^+) cations. The nitrate ions are transported in the xylem towards the aerial part of the plants along with K^+, which act as accompanying ions (Marenco and Lopes, 2009). A correct functioning of the processes explained above may have contributed to the success of N and K fertilization, mainly owing to the synergistic relationship between N and K.

Conclusion

The N and K fertigation allowed maximizing the quality of the 'Novita Plus' Italian zucchini fruit. As the N and K fertilizer

doses increased simultaneously, there was an increase in the performance of the fruit quality variables analyzed, and it was possible to determine in each case, the most adequate N and K dose to be applied. It was not possible to evaluate the effect of the interaction between N and K doses applied by fertigation on fruit quality, as no significant statistical differences were observed associated with this source of variation.

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