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Electrical Conductivity Helps Determine the N and K Concentrations in the Soil Solution in Watermelon Production in a Fertigated System

Condutividade Elétrica Auxilia na Determinação das Concentrações de N e K na Solução do Solo na Produção de Melancia em Sistema Fertirrigado

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Abstract

This study aimed to determine the electrical conductivity and nitrogen and potassium concentrations in the soil solution suitable for watermelon production in a fertigated system. The work was divided into two experiments installed in May (autumn) and September (spring). In both experiments, nitrogen and potassium fertilization was carried out in topdressing in order to achieve different electrical conductivities of the soil solution (0.6; 1.2; 1.8; 2.4; 3.0 and 3.6 dS m^{-1}). Each plot consisted of two eight-meter rows containing 10 plants each. Soil samples were collected weekly, and electrical conductivity and N-NH_4^+, N-NO_3^- and K^+ contents were determined. The productive characteristic evaluated was commercial fruit production. The results showed that each fertigation should restore the electrical conductivity of the soil solution to 2.3 dS m^{-1}. In autumn plantings, it is recommended to maintain the concentrations of N-NH_4^+, N-NO_3^-, K^+ in the soil solution close to 50.8; 77 and 251.8 mg L^{-1}, respectively. In spring plantings, it is recommended to maintain the concentrations of N-NH_4^+, N-NO_3^-, K^+ in the soil solution close to 57.1; 83.9 and 145.5 mg L^{-1}, respectively. The evaluation of electrical conductivity in field experiments allows to estimate the concentration of N-NH_4^+, N-NO_3^-, K^+ in the soil solution.

Keywords: *Citrullus lanatus*. Fertilization. Irrigation. Soil Salinity.

Resumo
Neste estudo, objetivou-se determinar a condutividade elétrica e as concentrações de nitrogênio e potássio na solução do solo adequadas para a produção de melancia em sistema fertirrigado. O trabalho foi dividido em dois experimentos instalados em maio (outono) e setembro (primavera). Nos dois experimentos foi realizada a adubação nitrogenada e potássica em cobertura visando atingir diferentes condutividades elétricas da solução do solo (0,6; 1,2; 1,8; 2,4; 3,0 e 3,6 dS m^{-1}). Cada parcela foi constituída por duas linhas de oito metros contendo 10 plantas cada uma. A coleta de amostras do solo foi realizada semanalmente, sendo a partir dela determinada a condutividade elétrica e os teores de N-NH_4^+, N-NO_3^- e K^+. A característica produtiva avaliada foi produção comercial de frutos. Como resultado foi evidenciado que a cada fertirrigação, deve-se restabelecer a condutividade elétrica da solução do solo para 2,3 dS m^{-1}. Nos plantios de outono recomenda-se a manutenção das concentrações de N-NH_4^+, N-NO_3^-, K^+ na solução do solo próximas de 50,8; 77 e 251,8 mg L^{-1} respectivamente. Nos plantios de primavera recomenda-se a manutenção das concentrações de N-NH_4^+, N-NO_3^-, K^+ na solução do solo próximas de 57,1; 83,9 e 145,5 mg L^{-1} respectivamente. A avaliação da condutividade elétrica em experimentos de campo permite estimar a concentração de N-NH_4^+, N-NO_3^-, K^+ na solução do solo.

Palavras-chave: *Citrullus lanatus* Adubação. Irrigação. Salinidade do Solo.

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1 Introduction

To achieve high fruit productivity, many growers have adopted irrigation practices in their watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) cultivation, with drip irrigation being one of the most widely used methods (Villas Bôas *et al.*, 2001). In 2021, Brazil produced 2 million tons of watermelon, with the Northeast region accounting for the highest share (802 thousand tons) (IBGE, 2021). The increase in production capacity is associated with the widespread adoption of irrigation, which offers greater water use efficiency and a lower risk of disease spread compared to sprinkler and furrow irrigation systems (Nunes *et al*., 2024).

Alongside drip irrigation, fertigation-defined as the application of fertilizers through irrigation water—has also been implemented (Azevedo *et al.*, 2016). Fertigation has contributed significantly to yield improvement; however, under certain conditions, nutritional imbalances in plants have been observed due to nutrient leaching (caused by rainfall and excessive irrigation) and over-application of fertilizers (Abdel-All; Seham, 2013; Andrade Júnior *et al.*, 2007).

Proper fertigation management is crucial, as mineral nutrition is one of the key factors influencing both the yield and quality of watermelon fruits. Several studies have reported increased watermelon productivity as a result of modifications in fertigation management (Andrade Júnior *et al*., 2006, 2007; Azevedo *et al*., 2016; Gomes, 2020; Nunes *et al*., 2024). Alternative methods are necessary to ensure efficient fertigation without causing nutrient leaching problems. In this context, targeted nutrient monitoring represents a promising strategy.

Issues arising from inadequate fertigation management are common in watermelon crops (Azevedo *et al*., 2016). A frequent limitation is the lack of monitoring of soil fertility conditions throughout the crop cycle. Since nutrients are supplied more frequently via fertigation than with conventional fertilization, continuous monitoring becomes essential—yet it is often neglected (Nunes *et al*., 2024).

Monitoring soil conditions can be achieved through the use of soil solution extractors (Villas Bôas *et al*., 2001). By obtaining the soil solution, it is possible to indirectly assess the salt concentration near the root zone and the immediate availability of nutrients to plants. However, to generate meaningful recommendations, it is necessary to establish reference standards for electrical conductivity (EC) and nutrient concentrations in the soil solution suitable for crop development, as it has been done for crops such as tomato (Eloi *et al*., 2011; Lao *et al*., 2004), jitomate (Raya *et al*., 2005), eggplant (Silva *et al*., 2013), citrus (Souza *et al*., 2006), and watermelon (Abdel-All; Seham, 2013), among others.

Fertigation management based on the EC of the soil solution obtained from extractors is a simple and practical technique that can be applied at any stage of crop development. EC monitoring enables faster identification of the need for adjustments in fertilization before nutritional disorders manifest, unlike conventional management where fertilizer doses are predetermined prior to planting and adjustments are made only after problems are detected (Silva Júnior *et al*., 2010).

Additionally, the soil solution allows for estimation of nitrogen (N) and potassium (K) availability to plants using portable ion meters that provide instant concentration readings. Critical levels of N and K have been determined for crops such as orange (Souza *et al*., 2012), tomato (Lao *et al*., 2004), jitomate (Raya *et al*., 2005), and melon (Silva Júnior *et al*., 2010).

However, studies on electrical conductivity and suitable N and K concentrations in the soil solution for watermelon cultivation are still scarce, highlighting the need for further research on this topic. Therefore, the objective of this study was to determine the electrical conductivity and appropriate concentrations of nitrogen and potassium in the soil solution for watermelon production under fertigation systems.

2 Material and Methods

The experiments were conducted in the agricultural production sector of Universidade Estadual do Mato Grosso do Sul (UEMS), located in the municipality of Cassilândia, MS (19º 05’ S, 51º 56’ W, and altitude of 471 m). According to the Köppen classification, the predominant climate in the region is Tropical Savanna (Aw), with a dry winter.

Two experiments were carried out for this study. In the first experiment, watermelon was planted in May (autumn), and in the second, planting occurred in September (spring). Both experiments were conducted in the same year.

The soil at the site was classified according to the Brazilian Soil Classification System (Santos *et al*., 2013) as Orthic Quartzarenic Neosol. The results of the soil particle size analysis at depths of 0–20 cm and 20–40 cm revealed proportions of 855 g kg^{-1} of sand, 50 g kg^{-1} of silt, and 95 g kg^{-1} of clay.

The experimental design used in both experiments was a randomized block design with six treatments (levels of soil electrical conductivity) and four replications. Before treatment application, a soil salinization curve was determined to establish the quantities of ammonium nitrate and potassium chloride to be applied in the treatments to achieve the different soil electrical conductivity levels.

To construct the soil salinity curve, 24 PVC rings with 30 cm diameter and 40 cm height were used, containing 28.26 dm^3 of soil with a bulk density of 1.48 g cm^{-3}, following a methodology adapted from Silva *et al.* (2000). Eight solutions with different electrical conductivities (0, 1, 2, 3, 4, 5, 6, 7 dS m^{-1}) were applied, using three rings for each solution (three replications). The solutions were prepared using ammonium nitrate and potassium chloride fertilizers, in a proportion of 47% N and 53% K. These proportions were based on the total nutrient uptake of watermelon crops, as presented by Grangeiro and Cecílio Filho (2004).

After solution application, a soil solution extractor and a tensiometer were installed in the rings at a depth of 20 cm (center of the capsule). Both devices were placed 7.5 cm from the ring edge. Twenty-four hours after solution application, a vacuum pressure of approximately -60 kPa was applied to the extractors, and the soil solution was collected four hours later. At the time of solution collection, the tensiometer was read to determine soil moisture.

After collecting the soil solution, its electrical conductivity was determined. Using the soil moisture at the time of collection and the saturated paste moisture (19 g 100 g^{-1} of soil), the electrical conductivity values of the soil solution were corrected according to the methodology proposed by Silva *et al.* (2000).

With the corrected electrical conductivity values (for saturated paste moisture), the following equation was developed: $y = 1.3786x - 1.1012$ ($R^2 = 0.99$),which determines the amount of salt required to reach the desired soil electrical conductivity, where "x" is the corrected soil solution electrical conductivity in dS m^{-1} and "y" is the amount of salt to be used in g L^{-1}.

The N and K doses to be applied were calculated using Equation 1, based on the soil salinization curve and the experimental area's characteristics:

QS = (QSS – QSN) * [MS * (UP/100)] Eq. 1

Where:

QS = Quantity of salt required to achieve the desired electrical conductivity (g);

QSS = Quantity of salt in the soil, obtained using the equation y = 1.3786x – 1.1012, where x is the corrected electrical conductivity of the soil solution (g);

QSN = Quantity of salt needed for the target soil EC of the treatment, using the same equation, where x = target EC (0.6; 1.2; 1.8; 2.4; 3.0; and 3.6 dS m^{-1}), in grams;

MS = Mass of irrigated soil (15,913 kg);

UP = Saturated paste soil moisture in g 100 g^{-1} (19 g 100 g^{-1} soil).

The irrigated soil mass (15,913 kg) was calculated by multiplying the wet bulb depth, width, drip line length of each treatment, and the soil bulk density. The wet bulb reached 40 cm in depth and 42 cm in width, with a drip line length of 6400 cm and soil bulk density of 1.48 g cm^{-3}.

After developing the equation to determine the amount of ammonium nitrate and potassium chloride to be applied, two experiments were conducted to evaluate watermelon production and mineral N and K concentrations in the soil solution under fertigation management for different soil EC levels. Experiment I was planted in May 2014 and Experiment II in September 2014.

During Experiment I (May), average daily temperatures ranged from 20 to 23°C, with total rainfall of 153 mm. In Experiment II (September), average temperatures ranged from 24 to 28 °C, with rainfall totaling 462 mm.

Each plot consisted of two 8-m rows with 10 plants per row. The usable area included the 16 central plants. Plant spacing was 2.8 m between rows and 0.8 m between plants.

The soil for Experiment I was prepared in May 2014 using harrowing, turning the soil to a depth of about 10 cm to control weeds. Soil samples (0–20 cm depth) showed: pH ($CaCl_2$) = 5.0; OM = 16 mg dm^{-3}; P (resin) = 4 mg dm^{-3}; K = 1.7 mmolc dm^{-3}; Ca = 14 mmolc dm^{-3}; Mg = 10 mmolc dm^{-3}; H+Al = 22 mmolc dm^{-3}; CEC = 47.7 mmolc dm^{-3}; V = 54%.

Experiment II was conducted in the same area. Soil samples taken in September showed: pH ($CaCl_2$) = 4.9; OM = 23.1 mg dm^{-3}; P (resin) = 5 mg dm^{-3}; K = 2.4 mmolc dm^{-3}; Ca = 20 mmolc dm^{-3}; Mg = 11 mmolc dm^{-3}; H+Al = 37 mmolc dm^{-3}; CEC = 70 mmolc dm^{-3}; V = 47%. In both experiments, furrows 20 cm deep were opened on the planting line, and 40 kg N, 240 kg P_2O_5 ha^{-1}, and 20 kg S ha^{-1} were applied using MAP and single superphosphate as sources, along with 30 kg ha^{-1} of FTE-BR12.

In both experiments, the Explorer hybrid from Topseed was used, producing Crimson-type fruits. Seedlings were grown in 128-cell polystyrene trays using Bioplant Prata commercial substrate for vegetables.

Seedlings were transplanted when they had one true leaf, at 2.80 x 0.80 m spacing. The drip irrigation system had emitters spaced 0.30 m apart, with a flow rate of 1.5 L/h. Irrigation occurred every two days during the vegetative stage and daily during the reproductive stage to maintain field capacity.

Soil moisture was monitored using tensiometers installed at 20 cm depth, perpendicular to the drip line, halfway between the plant collar and the wet bulb edge (10 cm from the emitter and plant collar). One tensiometer per plot was installed next to the soil solution extractor. Water depth was calculated based on average tension readings and the soil water retention curve.

Fertilizer injection began seven days after transplanting, performed weekly until one week before harvest using a Dosatron injector. In the May planting, fertigation was applied until 70 days after transplanting (10 fertigations), and in the September planting, until 56 days (seven fertigations), due to a shorter crop cycle in spring.

Ammonium nitrate (33% N) and potassium chloride (60% K_2O) were used, maintaining the 53% K and 47% N ratio. Based on the EC of the soil solution and soil moisture from tensiometer readings, the amount of fertilizer was calculated using Equation 1.

Soil solution samples were collected after the irrigation preceding fertigation using two soil solution extractors per plot at 20 cm depth. A vacuum pressure of approximately -60 kPa was applied 14–18 hours after irrigation to draw in the soil solution, which was collected 2–4 hours later.

After each collection, EC and concentrations of N-NH_4^+, N-NO_3^-, and K were determined. Using the soil moisture at sampling (from tensiometers), values were corrected to saturated paste concentration using the method from Silva *et al.* (2000).

N-NO_3^- and NH_4^+ were determined by steam distillation, using a 1 ml aliquot of soil solution diluted with 9 ml of deionized water. The extract was then distilled and titrated. Potassium concentration was determined by flame photometry.

Fruits were harvested at physiological maturity, identified by the dried tendril near the fruit peduncle. In May, harvest started at 75 days and ended at 95 days after transplanting. In September, harvest began at 62 days and ended at 85 days after transplanting. Fruits were weighed and classified as marketable (>6 kg) and non-marketable (<6 kg), using only marketable yield data (CEAGESP, 2011). Non-marketable fruits included those that were stained, deformed, or weighed less than 6 kg.

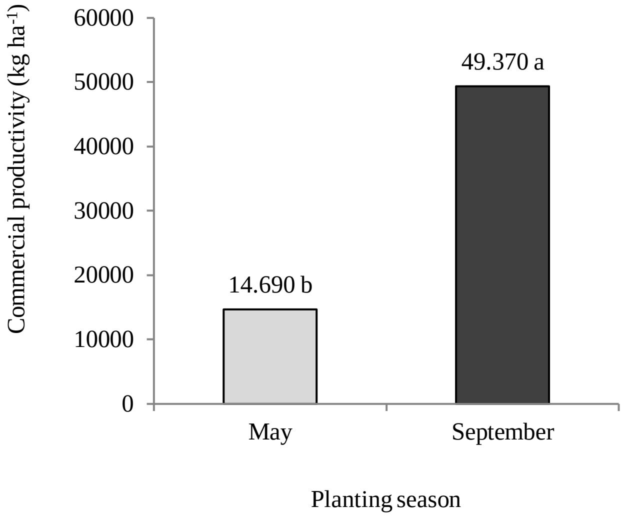
Data from each experiment were subjected to joint analysis of variance, considering two factors: planting season (May and September) and soil solution EC (0.6; 1.2; 1.8; 2.4; 3.0; and 3.6 dS m^{-1}).

Data were further analyzed using ANOVA, applying regression analysis for quantitative factors and Tukey's test ($p < 0.05$) for qualitative factors. Statistical analyses were performed using the SISVAR software (Ferreira, 2019).

3 Results and Discussion

When evaluating the ANOVA results, a significant difference was observed in marketable yield for both the planting season and the soil solution electrical conductivity factors. However, no interaction was found between these two factors. The highest marketable yield was obtained in the September planting, with an average of 49,370 kg ha^{-1}. In contrast, the May planting resulted in a marketable yield of 14,690 kg ha^{-1} (Figure 1).

Figure 1 - Marketable yield of watermelon fruits as a function of two planting seasons



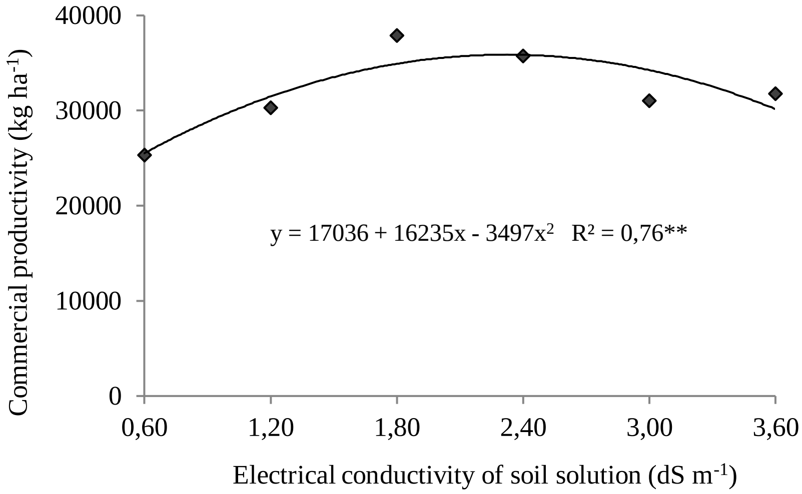
Source: research data.

The high marketable yield observed in the September planting is attributed to favorable temperatures and the presence of a large number of pollinators in the experimental area, which facilitated fruit production and consequently resulted in higher yield. During the May planting, average daily temperatures ranged from 20 to 23 °C, which, according to Andrade Júnior *et al.* (2007), are below the optimal range for crop development, which is 25 to 30 °C. In contrast, during the crop cycle in September, average daily temperatures ranged from 24 to 28 °C. Therefore, the results indicate that planting in May is not recommended for the region of Cassilândia, Mato Grosso do Sul, Brazil.

During the May planting, few pollinators were observed during the flowering period, and pollination was likely insufficient. In watermelon cultivation—as well as in cucumber and zucchini—the flowers require pollinators due to the plant's floral characteristics (monoecious flowers, with male and female flowers on the same plant) (Guimarães *et al.*, 2013). As a result, most of the fruits produced were classified as non-marketable due to their small size (< 6 kg) and deformities. In the September planting, a high number of pollinators were observed during flowering, including the European honeybee (*Apis mellifera*), jataí bee (*Tetragonisca angustula*), mandaçaia (*Melipona* sp.), and various dipteran species. This contributed to adequate pollination and the production of large fruits suitable for commercialization. According to Guimarães *et al.* (2013), entomophilous pollination in watermelon cultivation is a key factor for achieving high productivity.

Regarding the soil solution electrical conductivity factor, the highest marketable yield (35,880 kg ha^{-1}) was obtained with the application of nitrogen (176 kg ha^{-1} of N) and potassium (229 kg ha^{-1} of K_2O), aiming to maintain the soil solution electrical conductivity at 2.3 dS m^{-1} (Figure 2). An increase in watermelon fruit yield with higher nitrogen rates was also reported by Andrade Júnior *et al.* (2006) and Barros *et al.* (2012). The increase in marketable watermelon yield with higher potassium fertilization was also observed by Oliveira *et al*. (2012) and Abdel-All and Seham (2013).

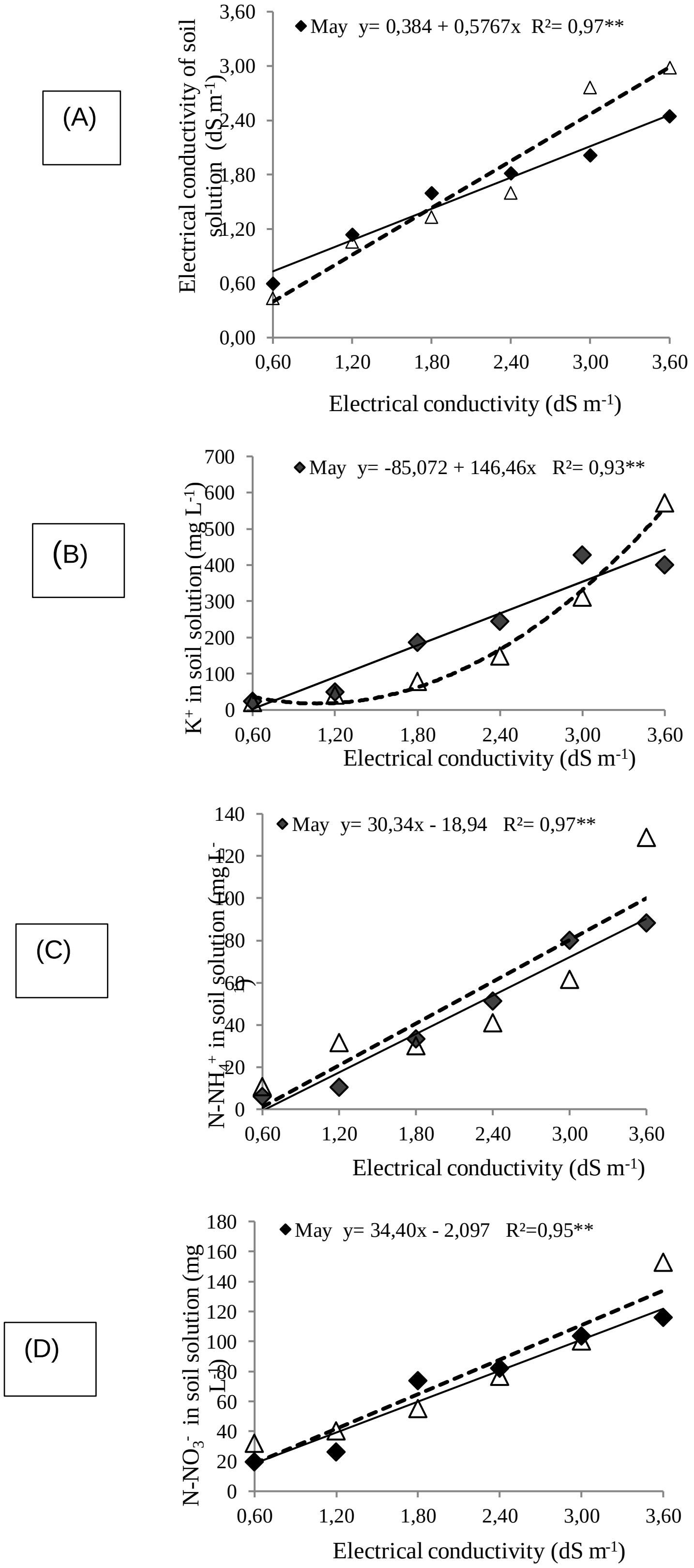
Figure 2 - Marketable yield of watermelon fruits as a function of fertigation management aimed at achieving different electrical conductivities



Source: research data.

There was an interaction between electrical conductivity and the concentrations of $N\text{-}NH_4^+$ (Figure 3C), $N\text{-}NO_3^-$ (Figure 3D), and K^+ (Figure 3B) in the soil solution, with a linear adjustment observed for most variables, except for electrical conductivity and K^+ concentrations (Figure 3B) in the month of September, which showed a quadratic behavior. As expected, an increase in the soil solution electrical conductivity was observed.

Figure 3 - Electrical conductivity and concentrations of K^+, $N\text{-}NH_4^+$, and $N\text{-}NO_3^-$ in the soil solution as a function of fertigation management aimed at achieving different electrical conductivities of the soil solution in two watermelon planting seasons



Source: research data.

The increase in $N\text{-}NH_4^+$ concentration is mainly due to the use of ammonium nitrate fertilizer, which contains around 16% nitrogen in the ammoniacal form. Souza *et al.* (2006) also observed an increase in $N\text{-}NH_4^+$ concentration in the soil solution, and one of the explanations proposed by the authors was that in drip-irrigated crops, the wet bulb is a poorly aerated environment. Since the nitrification process is strictly aerobic, it is hindered, resulting in high concentrations of $N\text{-}NH_4^+$ in the soil solution. Nitrogen should preferably be absorbed in the anionic form, as absorption in the cationic form may impair the uptake of other cations such as potassium, calcium, and magnesium (Souza *et al*., 2012).

The average $N\text{-}NH_4^+$ concentration in the soil solution corresponding to the desired electrical conductivity (2.3 dS m^{-1}), which resulted in the highest commercial yield in the May planting, was 50.8 mg L^{-1}. In the September planting, the average $N\text{-}NH_4^+$ concentration in the soil solution that resulted in the highest productivity was 57.1 mg L^{-1}. These values were close to those reported by Souza *et al.* (2012), who observed higher orange production when the average $N\text{-}NH_4^+$ concentration in the soil solution was 40 mg L^{-1}.

The increase in $N\text{-}NO_3^-$ concentration in the soil solution is attributed to the use of ammonium nitrate to raise the electrical conductivity of the soil solution, as it contains nitrogen in the nitric form. The increase in $N\text{-}NO_3^-$ concentration with the rising dose of ammonium nitrate was also observed by Souza *et al*. (2012) and Souza *et al.* (2006).

The average $N\text{-}NO_3^-$ concentration in the soil solution that resulted in the highest commercial productivity in the May and September plantings was 77 mg L^{-1} and 83.9 mg L^{-1}, respectively. These concentrations are close to the 64.9 mg L^{-1} recommended by Souza *et al*. (2012) for Hamilin orange. However, Lao *et al.* (2004) recommend maintaining 169 to 196 mg L^{-1} of $N\text{-}NO_3^-$ in the solution for tomato crops.

The increase in K^+ in the soil solution is due to the use of potassium chloride fertilizer to raise the electrical conductivity of the soil solution. Concentrations ranging from 20.2 to 572.4 mg L^{-1} of K^+ were observed in the soil solution. The average K^+ concentration in the soil solution that resulted in the highest commercial yield in the May planting was 251.8 mg L^{-1}, while in the September planting, it was 145.5 mg L^{-1}. These average concentrations of K^+ in the soil solution that led to the highest commercial productivity are close to the levels recommended by Lao *et al.* (2004), who suggest maintaining K^+ concentrations in the soil solution between 222 and 257 mg L^{-1}.

4 Conclusion

To achieve maximum commercial yield (35,880 kg ha^{-1}), the electrical conductivity of the soil solution should be maintained at 2.3 dS m^{-1}, regardless of the planting season.

For May plantings, it is recommended to maintain the concentrations of N-NH_4^+, N-NO_3^-, and K^+ in the soil solution at approximately 50.8, 77, and 251.8 mg L^{-1}, respectively.

For September plantings, it is recommended to maintain the concentrations of N-NH_4^+, N-NO_3^-, and K^+ in the soil solution at approximately 57.1, 83.9, and 145.5 mg L^{-1}, respectively.

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