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CROP PRODUCTION

Growing apples in tropical semiarid: N and K fertigation

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ABSTRACT. Apple tree has been experimentally grown Brazilian tropical semiarid. In these new regions, fertilizing management research for N and K is crucial to reach apple high yields. Therefore, an experiment was conducted to evaluate the effect of N and K fertilizing on fruit production, leaf chlorophyll and N and K nutritional status of apple cv. 'Julieta' grown in Brazilian tropical semiarid. The experimental design used was randomized blocks with treatments disposed in a factorial arrangement (4 x 4) referring to nitrogen doses (30, 60, 90, and 120 g of N plant^{-1}) and potassium doses (30, 60, 90, and 120 g of K_2O plant^{-1}), with three replications and three plants in each parcel. 'Julieta' apple trees propagated by grafting (with 'M9 filter and Maruba rootstock) and transplanted in 2013 were used in this study. The following variables were evaluated: i) fruit production (kg plant^{-1}); ii) number of fruits (in a plant); iii) leaf chlorophyll index ('a', 'b', and total); and iv) leaf N and K concentrations (g kg^{-1}). N and K doses effects depend on the consecutive production cycles of apple cv. 'Julieta' grown in tropical semiarid. An adequate N supply is very important for the subsequent production cycle. K fertilization until 120 g plant^{-1} of K_2O is not enough to supply K demand of apple cv. 'Julieta' grown in tropical semiarid. In tropical semiarid, 60-90 g plant^{-1} of N through fertirrigation is enough for 'Julieta' apple production.

Keywords: fruit production; *Malus domestica*; plant nutrition; nitrogen; potassium.

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Introduction

Apple is one of the most economically important fruiting species around the world, traditionally grown under temperate climate conditions (Food and Agriculture Organization [FAO], 2019). In Brazil, apples are grown in the South region, where the four seasons are well defined and more than 95% of all apple consumed is produced. In the 2017/18 harvest, Brazil produced 1.1 million tons of apple, and the main varieties were Gala and Fuji (Associação Brasileira de Produtores de Maçã [ABPM], 2018).

Recent experimental results have demonstrated that apples can be grown in non-traditional regions, with short or even no cold period, by cultivating little cold demand cultivars such as 'Julieta' and 'Princesa' (Lopes, Oliveira, Silva, & Cavalcante, 2012; Lopes, Oliveira, Silva, & Cavalcante, 2013; Miranda, Cavalcante, Oliveira, Lopes, & Assis, 2015a; Miranda, Cavalcante, Oliveira, & Lopes, 2015b).

Fertilization in apples, as in other fruit species, depends on soil physical and chemical properties, besides being crucial to achieve high yields over years and to maintain a commercial standard quality of fruits (Souza, Argenta, Nava, Ernani, & Amarante, 2013).

Nitrogen (N) and potassium (K) are the most demanded nutrients by apples; however, they must be balanced to ensure a nutritional balance of trees and achieve high yields and fruit quality (Nava & Dechen, 2009). Despite the high N demand of apple trees, there is still no fertilization pattern, especially under the new edaphoclimatic conditions, as in the tropical semiarid. It is important to note that N has high dynamics in soil and can be absorbed in both organic and inorganic forms (Pereira et al., 2020), highlighting the relevance of studying the theme.

According to Lu, Yang, Li, Li, and Tong (2015), adequate K management increases its concentrations in leaves and fruits, improving fruit mass and quality. On the other hand, K deficiency reduces fruit size and hence yield (Zhang et al., 2017). This element regulates lots of essential plant process such as photosynthesis, stomatal opening, water absorption, enzymatic activities, and production of starch and proteins (Wang & Wu, 2017). Moreover, fertigation systems have been used for fertilizing management (including for N and K) of some fruit crops, improving fertilizer use efficiency and consequently fruit production and quality (Lima et al., 2020).

Based on the above, an experiment was conducted to evaluate the effects of N and K fertilizing on fruit production, leaf chlorophyll content, and N and K nutritional status of apple trees cv. Julieta under Brazilian tropical semiarid conditions.

Material and methods

Plant material and growth conditions

'Julieta' apple (*Malus domestica*) trees propagated by grafting (with 'M9 filter and Maruba rootstock), transplanted in 2013 and in their second production season were used in this study.

The study was carried out from August 2015 to January 2016 (first trial) and from June 2016 to December 2016 (second trial) on an experimental orchard in Serenissima farm, in Lagoa Grande (09°21' S and 40°34' W; at an altitude of 375 m above sea level), Brazil.

The climate of this region is classified as Bswh (Köeppen), which corresponds to a semiarid region. The climatic data for average air temperature and air humidity (thermo-hygrometer Instrutemp®, Brazil) during the experiments are in Figure 1.

The soil physical and chemical characteristics (Red-Yellow Oxisol) where the experiment was carried are in Table 1.

The apple trees were pruned and treated with 0.08% hydrogen cyanamide and 3.0% mineral oil (Assist®) and 3.0% of color fix (Hi-Light®), immediately after hand defoliation, which was performed in August 2015 (first trial) and June 2016 (second trial), according to instructions of Lopes et al. (2012). Fruit thinning also was performed when fruit measured approximately 2.0 cm in diameter, maintaining just one or two fruits in each floral bunch.

The plants, spaced with 4.0 m between the rows and 1.25 m between the plants, were set up with a central leader and daily drip-irrigated with five self-regulated emitters per tree for a flow of 2 L hour^{-1} each. Irrigation water management was performed based on daily evapotranspiration corrected through apple Kc value.

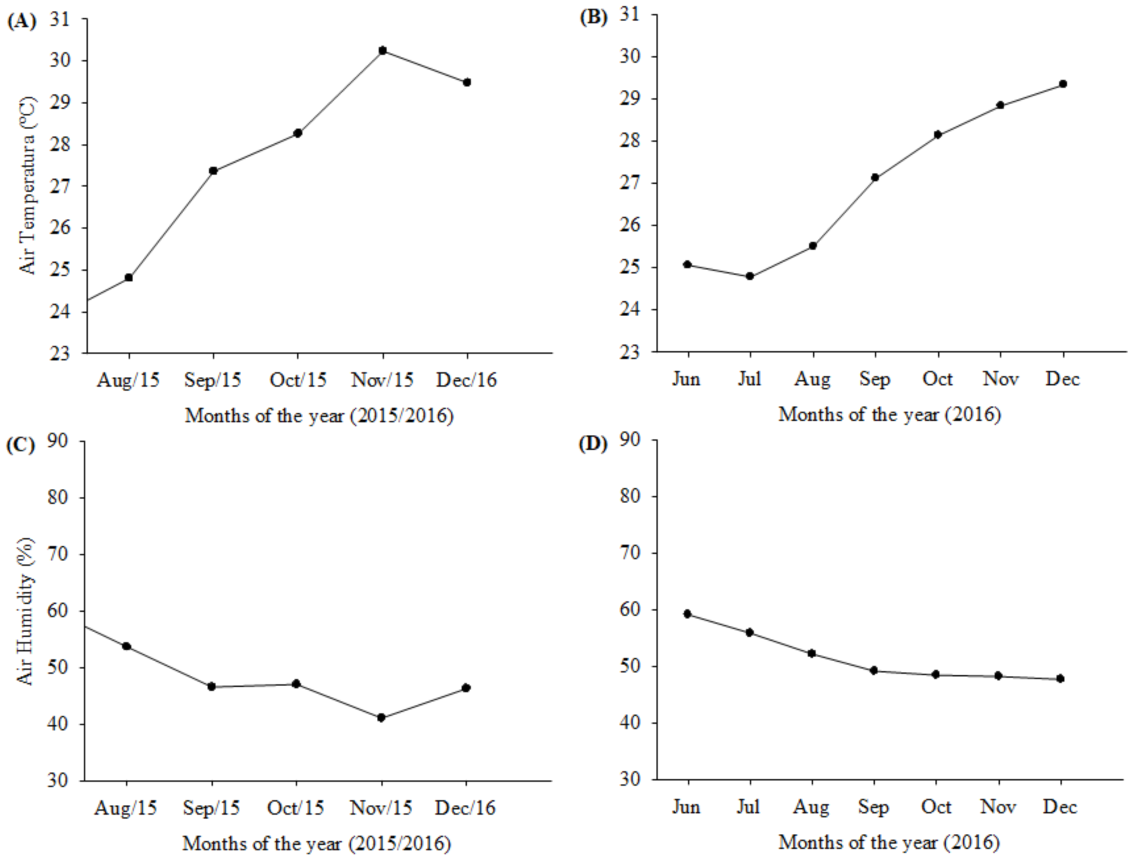

Figure 1. Average temperature and air humidity during the execution of the experiments. (A and B – first trial; C and D – second trial).

Table 1. Chemical and physical characteristics of the soil (0-20 cm and 20-40 soil depths) where the experiment was carried out.

Soil characteristic	Soil depth	
	0 – 20 cm	20 – 40 cm
pH (in water)	5.9	5.7
	$cmol_c dm^{-3}$	
Ca^{2+}	3.20	3.50
Mg^{2+}	1.00	1.10
Al^{3+}	0.00	0.00
$H + Al^{3+}$	0.64	1.12
K^+	0.58	0.41
Na	0.09	0.09
CEC	5.51	6.22
P –Melich (mg dm^{-3})	26.00	18
OM (%)	4.00	4.10
E.C.	0.86	1.36
	g kg^{-1}	
Clay	12.00	18.60
Silt	3.00	10.60
Sand	83.00	69.70
	mg dm^3	
Cu	1.40	1.10
Fe	42.50	31.60
Mn	45.70	29.90
Zn	23.80	104.00

Note: OM = Organic matter; CEC = cationic exchangeable capacity [$Ca^{2+} + Mg^{2+} + Na^+ + K^+ + (H^+ + Al^{3+})$]; E.C. = electrical conductivity; P, K: Melich 1; H + Al: calcium acetate (extractor) 0.5M, pH 7; Al, Ca, Mg: KCl 1 M extractor.

The N and K fertigations were performed twice a week for 40 days, thus reaching 12 fertilizings. The first fertigation was performed at 40 days after breaking dormancy. Calcium nitrate (15.5% of N) and urea (44% of N) were alternately applied for N sources, while the potassium sulphate (50% of K_2O) was used as a K source.

The fertilizing management of the other nutrients was performed through irrigation water using triple superphosphate (45% of P_2O_5), magnesium sulphate (15% of Mg), boric acid (17% of B). Zinc (10.4% of Zn), magnesium (6.6% of Mg) and iron (2.0 of Fe; 1.0 of Zn; and 10% of amino acid) were applied through foliar sprays. The fertilizing management followed instructions of Nava, Nuernberg, Pereira, and Dechen (2007).

All agronomic treats performed in the experiment followed the instructions of Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina [Epagri] (2006).

Treatments and experimental design

The experimental design used was randomized blocks with treatments disposed in a factorial arrangement (4 x 4) referring to nitrogen doses (30, 60, 90, and 120 g of N $plant^{-1}$) and potassium doses (30, 60, 90, and 120 g of K_2O $plant^{-1}$), with three replications and three plants in each parcel. N and K doses followed the previous studies of Ernani, Dias, and Flore (2002) and Miranda et al. (2015a).

Data gathered and statistical analysis

During fruit production the leaf chlorophyll readings (‘a’, ‘b’, and total) were measured using a chlorophyll meter (Falker®, Brazil) in four leaves in each plant from the canopy middle part at each cardinal point, as previously performed by Cavalcante, Silva Junior, Santos, and Lima (2016).

After leaf chlorophyll readings the same leaves were collected and chemically analyzed for total N concentrations using the Kjeldahl method and K concentrations through flame absorption spectrophotometry method, following Bataglia, Furlani, Teixeira, Furlani, and Gallo (1983) methodology.

The accumulated number of fruits per plant and the fruit production (kg $plant^{-1}$) were recorded. Statistical analyses included analysis of variance and regression analysis (simple or multiple) of N and K doses of each trial. All calculations were performed using the software SigmaPlot 12.5, and terms were considered significant at $p < 0.05$ or $p < 0.01$.

Results and discussion

Table 2 shows that, in the first trial, interactions of N and K doses had no significant effect on leaf chlorophyll indexes (‘a’, ‘b’, and total), while individual effects of N and K doses were registered for fruit yield and number of fruits per plant. In the second trial, interactions of N and K doses were identified for fruit yield and number of fruits per plant, while leaf chlorophyll indexes were affected only by N doses.

In the second trial (Figure 2A, B, and C), leaf chlorophyll indexes (‘a’, ‘b’, and total) had a linear fit to data as a function of N doses applied, with a minimum fit of 0.88 (leaf chlorophyll ‘a’ index), 0.91 (leaf chlorophyll ‘b’ index), and 0.89 (leaf total chlorophyll index), and a peak at the highest N dose studied (120 g plant^{-1} N).

Table 2. Variance analysis resume for leaf chlorophyll index (Chlo ‘a’, Chlo ‘b’ and Total Chlo.), fruit production (Fp), number of fruits per plant (NFP), leaf N concentration (Leaf N) and leaf K concentration (Leaf K) of apple cv. ‘Julieta’ as a function of N and K fertigation in tropical semiarid.

	Chlo ‘a’	Chlo ‘b’	Chlo total	Fp	NFP	Leaf N	Leaf K
	Index						
First trial							
N doses (‘F’ value)	1.80^{ns}	0.72^{ns}	1.07^{ns}	14.66**	8.12**	17.2**	1883.8**
K doses (‘F’ value)	0.30^{ns}	0.39^{ns}	0.20^{ns}	1.77^{ns}	2.68*	12.5**	1174.4**
N x K (‘F’ value)	0.49^{ns}	0.75^{ns}	0.63^{ns}	1.16^{ns}	1.20^{ns}	6.17**	1163.6**
V.C.%	9.61	31.65	15.74	19.37	22.46	13.43	1.05
Second trial							
N doses (‘F’ value)	6.26**	8.05**	8.71**	23.63**	13.35**	52.8**	115.5**
K doses (‘F’ value)	0.76^{ns}	0.88^{ns}	0.76^{ns}	0.26^{ns}	0.81^{ns}	10.5**	350.8**
N x K (‘F’ value)	0.91^{ns}	0.62^{ns}	0.68^{ns}	2.26*	2.72**	8.9**	331.8**
V.C.%	4.23	17.89	8.56	15.14	13.07	20.08	2.26

Note: V.C. = variation coefficient; **significant at p < 0.01 probability error; *significant at p < 0.05 probability error; ^{ns}non-significant.

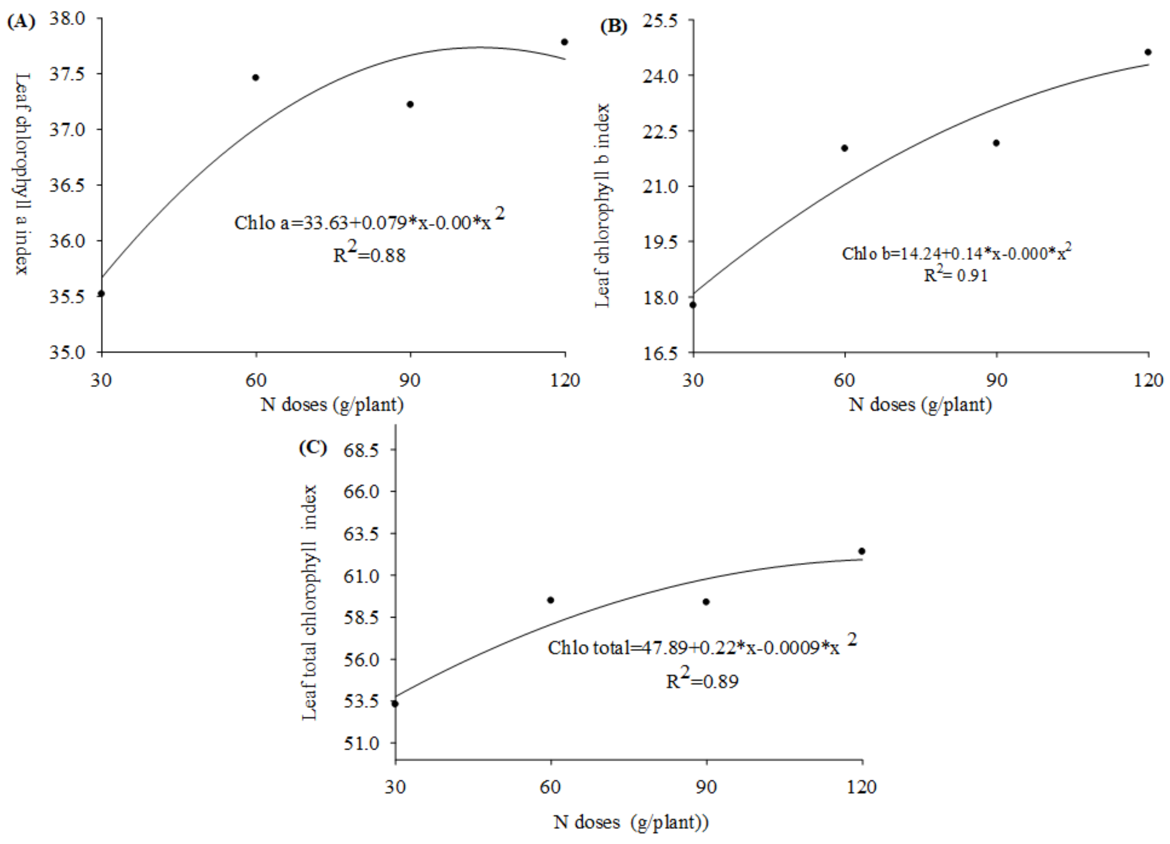

Figure 2. Leaf indexes of chlorophyll ‘a’ (A), ‘b’ (B) and total (C) of apple cv. ‘Julieta’ as a function of N and K fertigation in tropical semiarid.

Higher leaf chlorophyll indexes (‘a’, ‘b’, and total) were recorded for higher N fertilization doses (Figure 2), which is in agreement with Cavalcante et al. (2016). In this context, Römheld and Kirkby (2010) explained that N is a crucial structural component of chlorophyll in porphyrin ring, therefore its leaf contents could be proportional to chlorophyll contents. Furthermore, chlorophyll ‘a’ and ‘b’ in chloroplasts are the most important photosynthetic pigments as they absorb light at varying wavelengths for photosynthesis. According to Gutiérrez-Gamboa et al. (2018), chlorophyll ‘a’ is the most abundant, while ‘b’ is an accessory pigment in light-harvesting chlorophyll complexes that traps light energy. It also channels the light energy to chlorophyll 'a', which is present in plants in a normal a/b proportion of 3/1. In this study, an average ranging from 2.4/1 to 2.9/1 (a/b) was found.

In the first trial, N doses significantly affected apple yield (Figure 3A), peaking at the lowest N dose (4.47 kg plant^{-1}). In the second trial, fruit yield had a quadratic fit to data, with a minimum fit of 0.99 and peak at 23.25 kg (Figure 3B), which was followed by a consecutive decay.

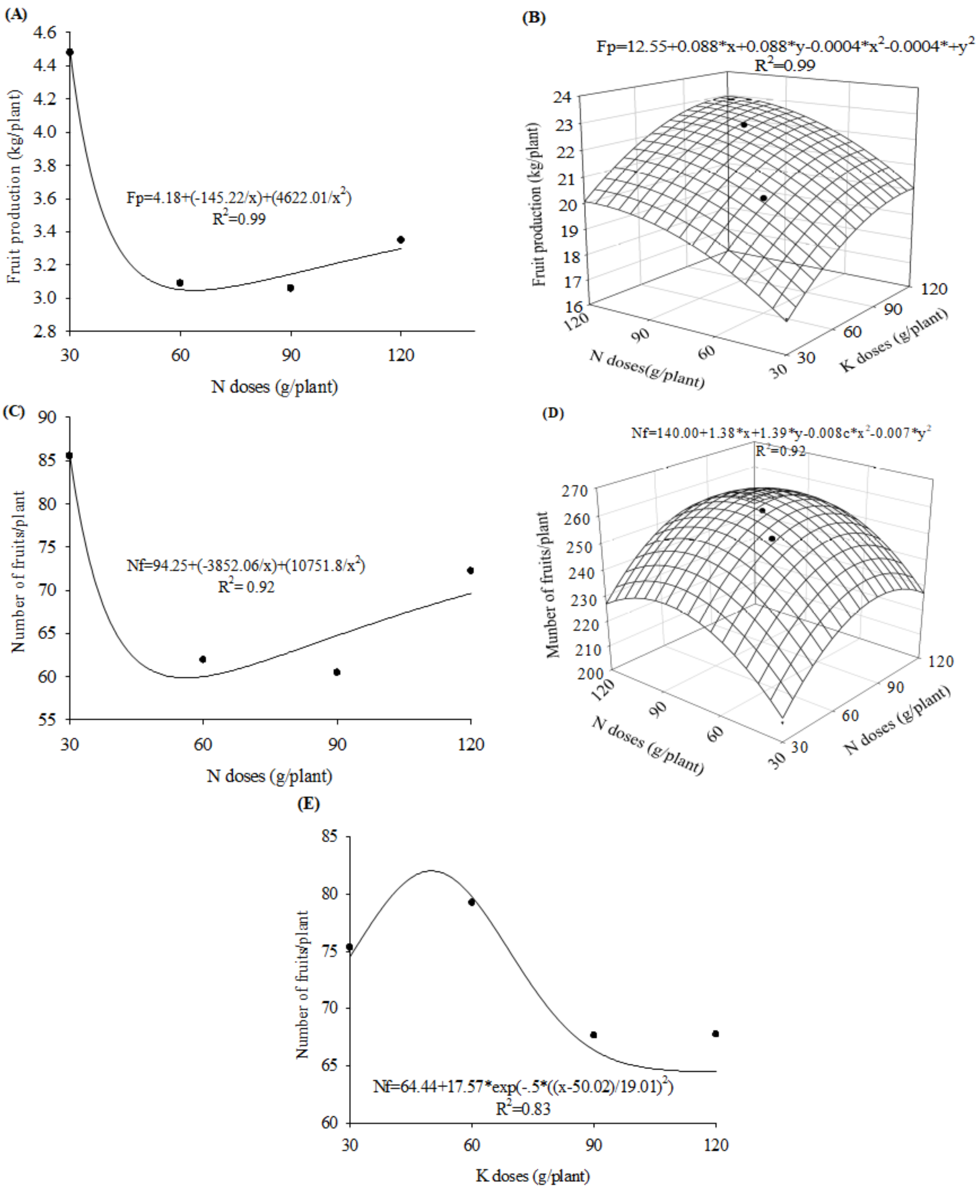

Figure 3. Fruit production (A – first trial; B – second trial) and the number of fruits per plant (C and E– first trial; D – second trial) of apple cv. 'Julieta' as a function of N and K fertigation in tropical semiarid.

From the first to the second trial, there was an increase in maximum yields from 4.47 kg plant^{-1} (Figure 3A) to 23.23 kg plant^{-1} (Figure 3B). It may be related to plant capacity to store N, mainly as proteins, which can be used in the following cycle (Nava & Dechen, 2009). Castro, Micheloud, Buyatti, and Gariglio (2015) studied optimal fruit production of apple cv. Princess and observed variation in the number of fruits per plant, ranging from 10 to 25 kg plant^{-1}.

The number of fruits per plant (Figure 3C) had the same trend as fruit yield per plant (Figure 3A), that is, there was a peak at the lowest N dose (85 fruits plant^{-1}). Yet for K doses in the first trial (Figure 3E), we observed a peak of 81.92 fruits plant^{-1} for plants fertilized with 49.25 g plant^{-1} K, differing in 8.8% with non-fertilized plants. Conversely, in the second trial, the highest mean number of fruits per plant (252.2 fruits plant^{-1}) was recorded in plants fertilized with 60 g plant^{-1} of N and K (Figure 3D).

Our results (Figure 3) dissent from that of Nava et al. (2007), who reported a linear increase in fruit number per plant as N doses were raised. Notably, N has effects on brunch growth and sprouting, thus directly affecting fruit production (Nava et al., 2007). According to Wang and Wu (2017), apart from the direct effect of K on plants, it also enhances N root uptake. Also, Ernani et al. (2002) described a linear effect of K fertilization on N leaf concentration.

Miranda et al. (2015a) and Nava (2010) observed no N effect on apple fruit production. However, it is known that such an effect may vary with N fertilization method. Pereira et al. (2020) clarified that N fertilization affects its availability in soil and fertigation makes it available for plants faster.

A higher number of fruits was registered in plants fertilized with a calculated peak of 49.25 g plant^{-1} of K. This may be due to a better K nutrition of buds which, according to Nava and Dechen (2009), enhances the number of fruits per floral bunch. Several studies have focused on achieving the best fruit yield per apple tree (Treder, 2010); however, it has to be defined on a cultivar level. Such production level may range from 4.7 to 16.0 fruits per square centimeter of trunk cross-sectional area (Serra, Leisso, Giordani, Kalcsits, & Musacchi, 2016) since a very high load of fruits can decrease their quality and alternate bearing.

In both trials (Figure 4A, B, and C), N and K leaf concentrations had quadratic fits to data as a function of N and K doses. Increasing N and K doses enhanced N and K leaf concentrations in the first trial, reaching a calculated peak of 20.5 g plant^{-1} (N) in plants fertilized with 90 g plant^{-1} of N and K. In the second trial, the lowest N and K dose (30 g plant^{-1} of N and K) promoted a leaf concentration of 13.1 g kg^{-1} of N, which is lower than that in the first trial.

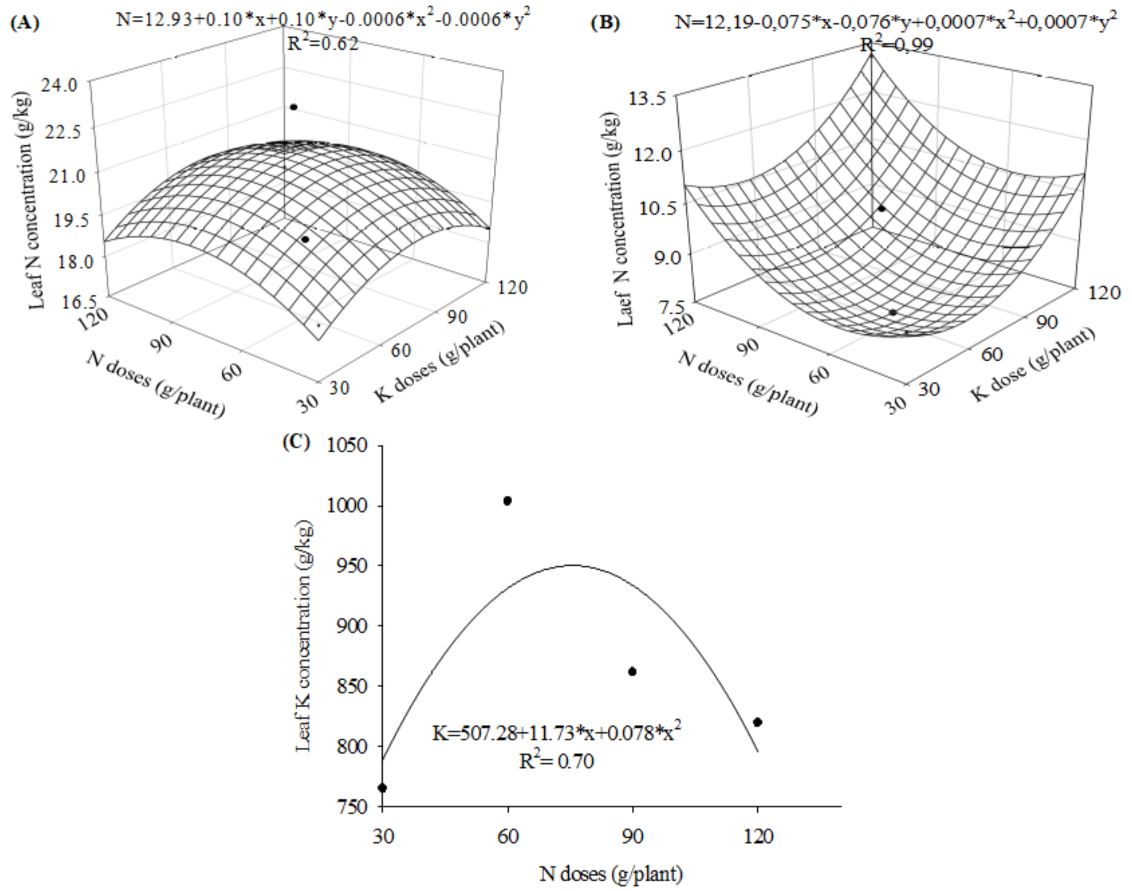

Figure 4. Leaf concentrations of nitrogen (A – first trial; B – second trial) and potassium (C – first trial) of apple cv. 'Julieta' as a function of N and K fertigation in tropical semiarid.

Leaf N concentrations showed different trends between the first and second trials. In the second trial, it decreased as a function of N and K doses. Yet in the first trial, it occurred from the maximum N and K calculated peak onwards (Figure 4A and B). Such a trend might have occurred due to low soil organic matter contents before the beginning of the study (Table 2), combined with the high N demand of apple, which has N as the second most demanded nutrient (Nachtigall, Basso, & Freire, 2004).

Under a semiarid climate, Miranda et al. (2015a) also observed averages of leaf N contents of 24.6 and 29.5 g kg^{-1} for 'Eva' and 'Princesa' apples, respectively, thus higher than our findings (Figure 4). Whether compared with the standardized foliar levels of nitrogen established by Malavolta, Vitti, and Oliveira (1997), we may infer that when fertilized with 90 g $plant^{-1}$ of N and K (first trial), plants had an adequate N supply (20 g kg^{-1} of N); however, in the second trial, none of the treatments supplied N properly. An adequate N nutrition is crucial to reach high apple yields, especially because this nutrient acts on several biochemical plant processes as part of amino acids, proteins, and nucleic acids (Römheld & Kirkby, 2010). Mainly for apples, N nutrition has particular importance because high leaf concentrations promote russeting, a physiological disorder characterized by lower fruit firmness, intense green color in fruits, and reduction in phosphorus, potassium, and boron contents (Nachtigall et al., 2004).

In the first trial, K leaf concentration increased with N and K doses, but only N doses had fit to data (Figure 4C). Increasing N doses enhanced K leaf concentrations until 60 g $plant^{-1}$ of N, with a consecutive drop at higher N doses (Figure 4C). In contrast, from the lowest to the highest K doses applied, K leaf concentrations ranged from 0.85 to 0.97 g kg^{-1}. In the second trial, although no data fit was observed in the regression model, leaf K concentrations ranged from 8.17 and 12.28 g kg^{-1}. Furthermore, average leaf K concentrations decreased by 62.43% from the first to the second trial.

Leaf K concentrations recorded in our study (8.17-12.28 g kg^{-1}) are below the standardized foliar levels of potassium (12-15 g kg^{-1}) established by Nachtigall et al. (2004). We also observed very low leaf K concentrations and these decreased by 62.43% from the first to the second trial. It can be explained by K remobilization from leaves to fruits, as this nutrient is mobile in the phloem, and fruits represent a strong drain, especially of K, which is the most exported nutrient by apple fruits (Brunetto, Melo, Toselli, Quartieri, & Tagliavini, 2015).

According to Römheld and Kirkby (2010), K is absorbed by apple trees at high levels, greater than the required for growth and production. However, proper K nutrition is crucial to reach high apple yields, since the physiological basis of K effects on fruit quality is well known. Potassium increases photosynthesis as a consequence of a higher photosynthetic efficiency, which increases leaf number and size, improving translocation of photoassimilates.

Conclusion

Nitrogen and potassium fertilization doses have effects on the following production cycles of apple cv. Julieta grown in tropical semiarid. Proper nitrogen supply is quite important for the subsequent production cycles. Potassium fertilization doses up to 120 g $plant^{-1}$ of K_2O are not enough to supply potassium demands of apple cv. Julieta grown in tropical semiarid, when considering reports in the literature. In tropical semiarid, nitrogen doses from 60 to 90 g $plant^{-1}$ of N through fertigation are enough apple 'Julieta' production.

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