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Soil salinity and yield of mango fertigated with potassium sources

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semi-arid region

A B S T R A C T

Irrigated fruit crops have an important role in the economic and social aspects in the region of the Sub-middle São Francisco River Valley. Thus, the aim of this study was to evaluate soil salinity and the productive aspects of the mango crop, cv. Tommy Atkins, fertigated with doses of potassium chloride (KCl) and potassium sulfate (K_2SO_4) during two crop cycles (from January to March 2014 and from January to March 2015). The experiment was carried out in a strip-split-plot design and five potassium doses (50, 75, 100, 125 and 150% of the recommended dose) as plots and two potassium sources (KCl and K_2SO_4) as subplots, with four replicates. Soil electrical conductivity (EC), exchangeable sodium (Na^+) and potassium (K^+) contents and pH were evaluated. In addition, the number of commercial fruits and yield were determined. The fertilization with KCl resulted in higher soil EC compared with K_2SO_4 fertigation. Soil Na^+ and K^+ contents increased with increasing doses of fertilizers. K_2SO_4 was more efficient for the production per plant and yield than KCl. Thus, under the conditions of this study, the K_2SO_4 dose of 174.24 g plant^{-1} (24.89 kg ha^{-1} or 96.8% of recommendation, spacing of 10 x 7 m) was recommended for a yield of 23.1 t ha^{-1} of mango fruits, cv. Tommy Atkins.

Palavras-chave:
condutividade elétrica
nutrição de plantas
Mangifera indica L.
semiárido

Salinidade do solo e produtividade de mangueira fertigada com fontes de potássio

R E S U M O

A fruticultura irrigada tem papel importante quanto aos aspectos econômicos e sociais da região do Vale do Submédio São Francisco. Assim, objetivou-se avaliar a salinidade do solo e os aspectos produtivos da mangueira cv. Tommy Atkins fertigada com doses de cloreto de potássio (KCl) e sulfato de potássio (K_2SO_4) durante dois ciclos de produção (janeiro a março de 2014 e janeiro a março de 2015). O delineamento experimental foi em faixas no esquema de parcelas subdivididas utilizando-se cinco doses de potássio (50, 75, 100, 125 e 150% da dose recomendada) nas parcelas e duas fontes de potássio (KCl e K_2SO_4) nas subparcelas com quatro repetições. Foram determinados os teores de sódio (Na^+) e potássio (K^+) trocável, a condutividade elétrica (CE), o pH do solo, o número de frutos comerciais e a produtividade da mangueira. A fertilização com KCl resultou em maior CE do solo em relação ao K_2SO_4. Os teores de Na e K no solo aumentaram com o incremento das doses dos fertilizantes. O K_2SO_4 apresentou maior eficiência quanto à produção por planta e produtividade de mangueira em relação ao KCl, sendo recomendada a dose de 174,24 g planta^{-1} (24,89 kg ha^{-1} ou 96,8% da recomendação, espaçamento de 10 x 7 m) de K_2SO_4 para a produtividade de frutos da mangueira cv. Tommy Atkins de 23,1 t ha^{-1}.

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Introduction

The Sub-middle São Francisco River Valley is considered as the largest national producer of mango in irrigated regime, producing approximately 120 thousand tons of mango in 2014, which corresponded to more than 93% of the Brazilian exportations of mango fruits (CEPEA, 2015).

The Sub-middle São Francisco River Valley is found in the semi-arid region, which, due to its climatic characteristics, such as poorly drained soils, low rainfall, high evapotranspiration and inadequate use of irrigation and fertilizers, can aggravate the salinization of agricultural areas, interfering with the development and production of the plants, because of the increase in the osmotic pressure of the soil solution, which reduces the water absorption potential of the plants (Filippou et al., 2014).

Potassium sulfate (K_2SO_4) has salt index per unit of K_2O of approximately half (46) the salt index of potassium chloride (KCl) (116), which makes it more indicated for soils prone to salinization. In addition, K_2SO_4 is generally more recommended for the application in the mango crop, due to the sensitivity of this crop to salinity and excess of chloride (Zuazo et al., 2003).

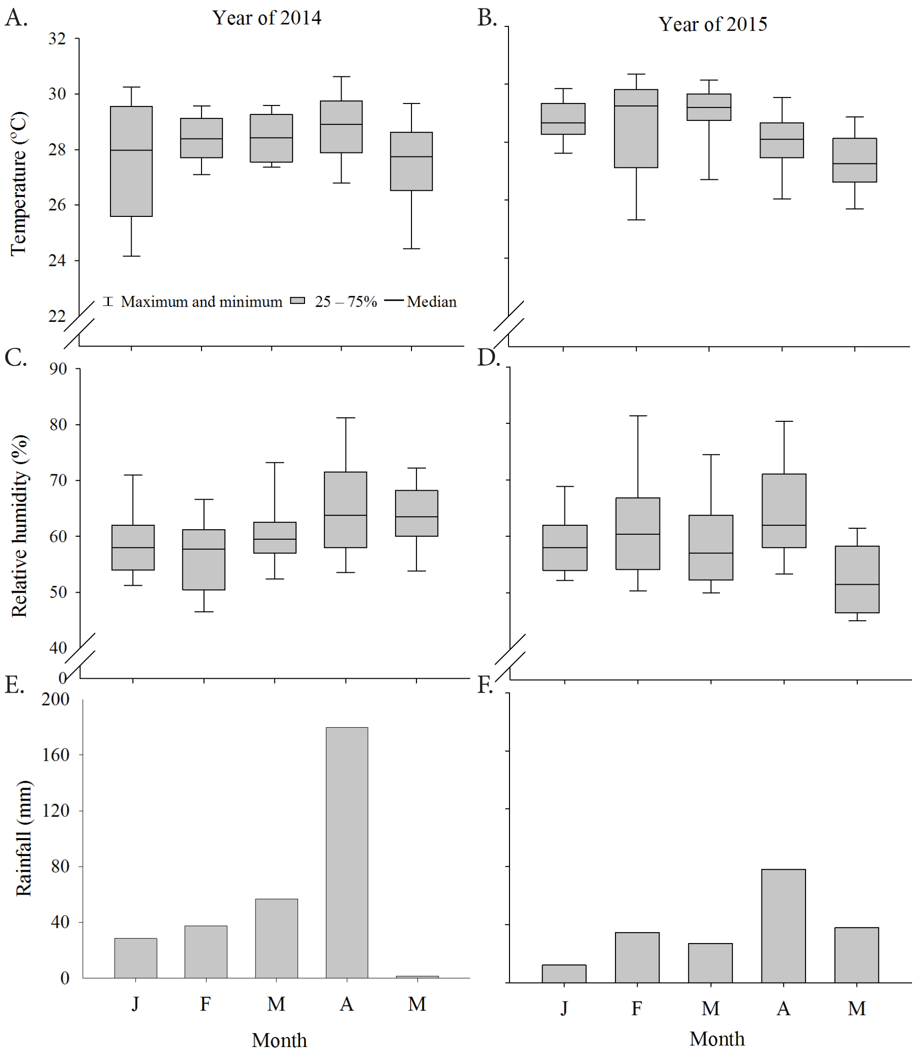
Potassium (K) is extremely important for the production and quality of the fruit, because it is one of the macronutrients most absorbed by the crop, especially in fruiting, participating in the initial formation of the fruits (Ganeshamurthy et al., 2011). K has an essential role in enzymatic activation, photosynthesis, water use efficiency, formation of starch and protein synthesis (Stino et al., 2011; El-Razek et al., 2013). On the other hand, the excess of K can cause imbalance in the levels of calcium and magnesium (Almeida et al., 2015), which evidences the importance of a good fertilization program.

The present study aimed to evaluate soil salinity, number of commercial fruits and yield of mango, cv. Tommy Atkins, fertigated with two K sources (KCl and K_2SO_4) and five K doses (90, 135, 180, 225 and 270 g plant^{-1} of K_2O) in Casa Nova-BA.

Material and Methods

The experiment was carried out in a commercial mango orchard at the Herculano Agrícola Farm, along two production cycles (2014 and 2015), located in the municipality of Casa Nova-BA, Brazil (9º 11’ 43.5” S; 41º 01’ 59.2”W; 400.3 m). According to Köppen’s classification, the local climate is Bswh” (semi-arid), with rainfall lower than 500 mm concentrated in three or four months of the year. The soil of the area is ‘Argissolo Amarelo’.

The means of temperature, relative air humidity and cumulative rainfall in the experimental period (first cycle: January to March 2014; second cycle: January to March 2015) are presented in Figure 1A, B, C, D, E and F. Minimum, mean



Baixa Grande Station – Brazilian Geological Service (CPRM) (January, J; February, F; March, M; April, A; May, M)

Figure 1. Temperature, relative air humidity and rainfall along the experimental period (2014-2015)

and maximum values of evapotranspiration (ETo) calculated by the FAO-56 Penman-Monteith method were 3.94, 6.06, 7.27 and 3.2, 6.02, 7.66 mm day^{-1} for the years 2014 and 2015, respectively.

Mango plants of variety Tommy Atkins were evaluated, with 11 years of age, planted at the spacing of 10 x 7 m, irrigated by a localized sprinkler system (one emitter per plant), with flow rate of 60 L h^{-1}. Irrigation management was conducted based on crop evapotranspiration (ETc, mm), determined by the multiplication of reference evapotranspiration (ETo, mm) and crop coefficient (kc), defined by Soares et al. (2006).

Eleven years before planting, soil pH was corrected with the application of dolomitic limestone. The mango trees were planted in 80 x 80 x 80 cm holes, each of which received 20 L of goat manure. Fertilizations have been applied through fertigation, considering the contents of nutrients determined in the soil analyses performed after harvest in each production cycle and according to the requirement of the crop. Flower induction was performed using calcium nitrate and water stress, while weeds were controlled using a mechanical mower between the crop rows.

Prior to experiment installation (January 2014), soil samples were collected under the canopy projection in the layer of 0-40 cm, removing 20 single samples to obtain one composite sample for an area of approximately 1.4 ha. The soil sample was air-dried, pounded to break up clods, homogenized and sieved through a 2.0-mm mesh, to obtain the air-dried fine earth (ADFE).

Chemical characterization was based on the determinations of electrical conductivity in the saturation paste extract (EC), pH (H_2O), potential acidity (H + Al) (extraction in 0.5 mol L^{-1} calcium acetate at pH 7.0), exchangeable acidity (Al^{3+}) (extraction in 1.0 mol L^{-1} KCl) and soil organic matter content (OM), according to the methodology proposed by Silva (2009) (Table 1). In addition, the contents of phosphorus (P), potassium (K^+) and sodium (Na^+) (Mehlich-1) and calcium (Ca^{2+}) and magnesium (Mg^{2+}) (1.0 mol L^{-1} KCl) were determined. Then, the cation exchange capacity (CEC) and base saturation (V) were calculated according to the methodology proposed by Silva (2009). Additionally, the contents of Fe, Mn, Cu and Zn were determined through atomic absorption spectrophotometry. Physical characterization consisted in the granulometric analysis of the soil through the pipette method (Ruiz, 2005).

The experiment was set in a strip-split-plot design, using five K doses (50, 75, 100, 125 and 150% of the recommended dose, corresponding to 90, 135, 180, 225 and 270 g plant^{-1} of K_2O, respectively) in the plots and two K sources (potassium chloride - KCl and potassium sulfate - K_2SO_4 with the respective concentrations of 60 and 50% of K_2O) in the subplots, with four replicates. The recommended dose according to the soil analysis was 180 g plant^{-1} of K_2O (Genu & Pinto, 2002). Each experimental plot was composed of five plants and the central plant was used for evaluation. The K doses were split and supplied through irrigation; 45% before induction, 20% in flowering, 20% after fruit setting and 15% fifty days after fruit setting, according to Genu & Pinto (2002).

Plants were subjected to the practices recommended for the mango crop under the regional conditions of cultivation, according to Genu & Pinto (2002). Thinning was performed by cutting the branches above the internode to stimulate new shoots from the axillary buds. When the new shoots were in the second vegetative flow, Paclobutrazol (PBZ) was applied in the soil, under the canopy projection, at the concentration of 1 g of active ingredient per linear meter of canopy to inhibit the biosynthesis of gibberellin and, therefore, result in the interruption of the vegetative growth and, consequently, promote the branch maturation (Genu & Pinto, 2002). One month after the inhibition, flower induction started, with applications of calcium nitrate.

Production fertilizations were applied based on the soil analysis and requirement of the crop. The production fertilizations along the experiment used, in the first and second cycles, the following fertigations: first application (post-thinning) - 7 g plant^{-1} of zinc sulfate, 60 g plant^{-1} of manganese sulfate, 500 g plant^{-1} of magnesium sulfate, 500 g plant^{-1} of calcium nitrate; second application (flowering) – 100 g plant^{-1} of zinc sulfate, 60 g plant^{-1} of boric acid, 600 g plant^{-1} of calcium nitrate. Weeds were controlled using a mechanical mower.

At the end of each production cycle, soil samples were collected. Four subsamples of soil were used in each composite sample per plot, under the influence area of the sprinkler in the layers of 0-20 and 20-40 cm. After preparing the samples and obtaining the ADFE, the values of electrical conductivity (EC) and pH in water and the contents of Na^+ and K^+ were determined (Silva, 2009).

To determine the number of fruits (fruits plant^{-1}) and yield (t ha^{-1}), the fruits were manually harvested in the morning period, with minimum size of 12 cm and cream-yellow color in the pulp, characterizing physiological maturation. These characteristics of fruit selection are recommended by the Brazilian Program for the Modernization of Horticulture for commercial fruits (PBMH, 2004).

At the end of each production cycle, leaf samples were collected in all quadrants of the plant, at a medium height of the canopy, in normal and recently matured branches, removing the leaves from the middle section of the branch to determine the K content in the plants, following the recommendations of Silva (2009).

Table 1. Chemical characteristics and soil texture in the layer of 0-40 cm, before the experiment

EC[1/] (dS m^{-1})	OM[2/] (g kg^{-1})	pH$_{(H_2O)}$ 1:2.5	P (mg dm^{-3})	K^+	Ca^{2+}	Mg^{2+}	Na^+ (cmol$_c$ dm^{-3})	$H^+ + Al^{3+}$	CEC[3/]	Al^{3+}	V[4/] (%)
0.18	11.0	6.8	41	0.63	4.3	1.7	0.04	0.80	7.47	0.00	89.00
Cu	**Fe**	**Mn**	**Zn**	**Sand**	**Silt**		**Clay**	**BD[5/]**	**PD[6/]**		**TP[7/]**
	(mg dm^{-3})				**(kg kg^{-1})**			**(g dm^{-3})**			**%**
2.0	39.4	51.7	18.9	0.65	0.14		0.21	1.46	2.41		37.63

[1/]Electrical conductivity. [2/]Organic matter. [3/]Cation exchange capacity. [4/]Base saturation. [5/]Soil bulk density. [6/]Soil particle density. [7/]Total porosity.

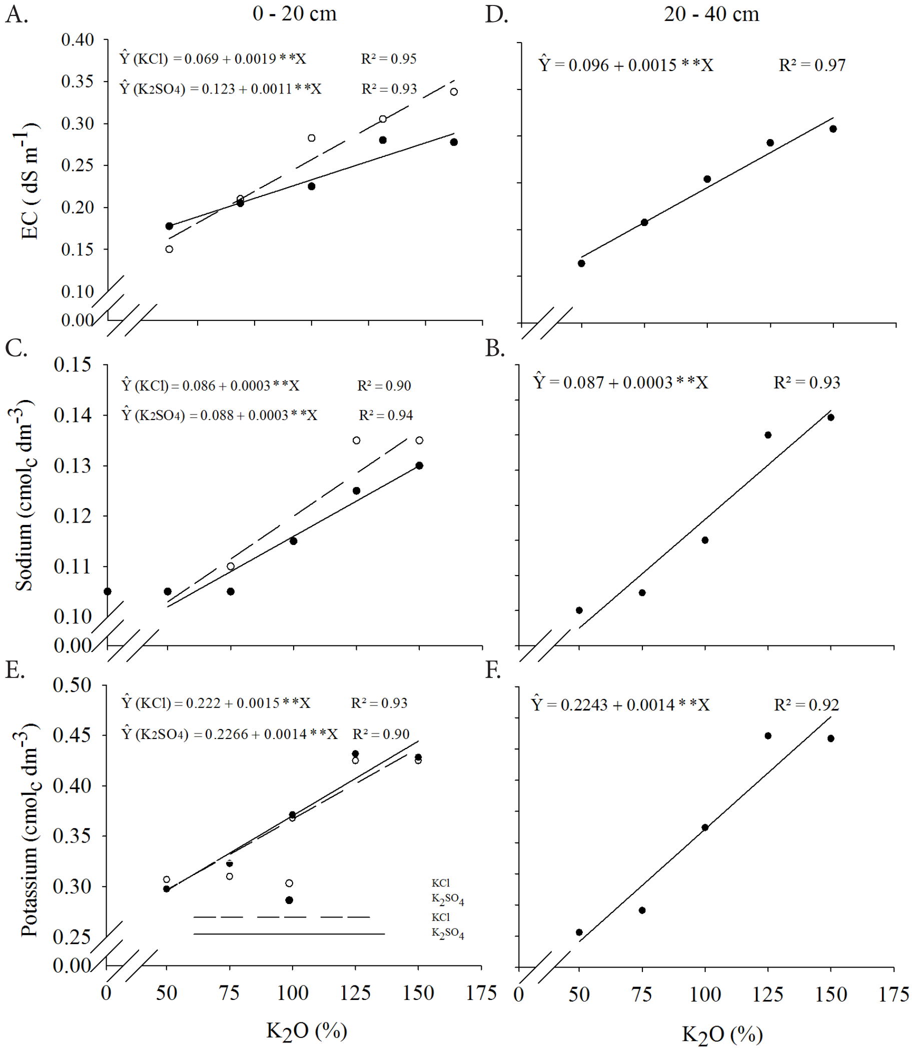
The obtained data of both production cycles (2014-2015) were subjected to analysis of variance by F test to diagnose the significant effects between the sources of K, while the doses were subjected to quantitative analysis of polynomial regression and the regression coefficients were analyzed using the t-test.

Results and Discussion

The analysis of variance for the soil attributes, such as electrical conductivity (EC) and contents of potassium (K^+) and sodium (Na^+), demonstrates that there was interaction between the doses and sources of K in the layer of 0-20 cm. As a function of the doses, there was significant difference only in the layer of 20-40 cm (Table 2). There was a significant linear effect ($p < 0.01$) of the KCl and K_2SO_4 doses on the EC in the layer of 0-20 cm (Figure 2A).

The increment in the EC value estimated for the maximum dose (270 g plant^{-1}) in relation to the minimum dose (90 g plant^{-1}) of K_2O applied through fertigation was 115.34% for KCl and 61.80% for K_2SO_4.

According to Litz (2009), besides the salt index and the accompanying ion (Cl^-, NO_3^-, SO_4^{2-}), the function of K in the plant and its availability in the soil are factors that must be considered in the selection of a K fertilizer. K_2SO_4 is usually the most recommended, because of the sensitivity of the mango crop to the excess of chloride, which is easily absorbed by roots



**Significant at 0.01 probability level ($p < 0.01$); * significant at 0.05 probability level ($p < 0.05$); ns not significant

Figure 2. Electrical conductivity (EC) and contents of sodium and potassium in the layers of 0-20 and 20-40 cm as a function of sources and doses of potassium applied through fertigation

Table 2. Summary of the analysis of variance (F value) for electrical conductivity (EC), contents of potassium (K^+) and sodium (Na^+) and hydrogen potential (pH) in the layers of 0-20 and 20-40 cm as a function of the sources and doses of potassium applied through fertigation in the mango crop

Source of variation	EC		Na^+		K^+		pH	
	Layer (cm)							
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Source (S)	2.23^{ns}	1.39^{ns}	0.24^{ns}	0.69^{ns}	0.00^{ns}	0.00^{ns}	1.82^{ns}	2.32^{ns}
Doses (D)	2.64^{ns}	3.24*	3.21*	4.44**	13.7**	3.55*	1.96^{ns}	2.71^{ns}
Interaction (S x D)	15.8**	1.25^{ns}	0.08*	1.33^{ns}	0.07*	1.84^{ns}	0.88^{ns}	2.22^{ns}
CV (%)	16.7	20.0	16.9	19.2	16.5	18.2	4.5	2.67

and translocated to the leaves, where it accumulates and can lead to leaf tip burn and premature fall (Litz, 2009).

For the layer of 20-40 cm, as the K_2O dose increased from 50% (90 g plant^{-1}) to 150% (270 g plant^{-1}), there was an increment of 87.39% in the EC value (Figure 2B). Potassium fertilization results in the increment of EC due to the increase in the concentration of ions in the soil solution and, consequently, in the increment of the electrolytic concentration (Marques et al., 2010). The EC values varied from 0.15 to 0.34 dS m^{-1} for KCl and from 0.18 to 0.28 dS m^{-1} for K_2SO_4, being much lower than the EC value in the soil considered as critical for the mango crop (> 4.0 dS m^{-1}), according to Amaral (2011). In experiment with 'Formosa' papaya, cv. 'Tainung Nº 1', conducted in the municipality of Russas-CE in a 'Neossolo Quartzarênico', Anjos et al. (2015) observed a linear behavior in soil EC with the increment in the KCl doses applied via fertigation, evidencing the saline effect of the fertilizer.

The Na^+ contents in the soil as a function of the doses of KCl and K_2SO_4 exhibited a linear behavior with increments of 30.01 and 27.45%, respectively, of the maximum dose in relation to the minimum dose of K_2O applied through fertigation, in the layer of 0-20 cm (Figure 2C)

For the layer of 20-40 cm, there was also significant linear effect ($p < 0.01$) of the K_2O doses on the contents of Na, with an increment of 30.24% (Figure 2D). The increase in the exchangeable K content in the soil with the increment in K_2O doses (KCl and K_2SO_4) probably inhibits Na absorption by plants, because of the competition between K and Na for the same absorption sites in the plasmatic membrane of the roots (Melloni et al., 2000), resulting in higher Na contents in the soil. However, despite the increments in Na contents with the K fertilization, the exchangeable sodium percentage (ESP = $[Na^+/CEC] \times 100$ = 1.77%) was much lower than the limit for sodic soils (ESP ≥ 15), indicating that there was no risk of sodification of the area, which could cause reduction of water infiltration (Assis Júnior & Silva, 2012).

K fertilization also influenced the soil contents of exchangeable K, fitting to a linear model in the layers of 0-20 and 20-40 cm (Figure 2E and F). For the layer of 0-20 cm, the estimated increments in the value of exchangeable K for the maximum dose (270 g plant^{-1}) in relation to the minimum dose (90 g plant^{-1}) of K_2O applied through fertigation were 47.30% for KCl and 50.03% for K_2SO_4. For the layer of 20-40 cm, the estimated increment of exchangeable K was 48.67% of the maximum dose in relation to the minimum dose of K_2O applied through fertigation. Evaluating the effect of K fertilization management on soil chemical characteristics and on the establishment and absorption of cations by rice plants in soil with different levels of sodium saturation, Carmona et al. (2009) observed increase in exchangeable K with higher doses of KCl. In a study evaluating the chemical characteristics of a 'Latossolo' fertilized with urea and KCl in a protected environment, Silva et al. (2001) observed that the exchangeable K was significantly higher according to its application in the soil, in the layers of 0-20 and 20-40 cm, confirming its permanence in the soil, especially adsorbed to the organic and inorganic colloids.

The values of exchangeable K in the layer of 0-20 cm did not vary much and were from 0.31 to 0.43 $cmol_c\,dm^{-3}$ for the fertilization with KCl and from 0.30 to 0.43 $cmol_c\,dm^{-3}$ for the fertilization with K_2SO_4. These values are within the class of availability considered as good for the mango crop under irrigated conditions (0.31 to 0.45 $cmol_c\,dm^{-3}$) (Silva et al., 2004).

For the number of fruits per plant (NFP), yield (Y) and leaf K content (KL), there was significant interaction between the sources and doses of K applied through fertigation (Table 3).

The follow-up analysis of the interaction between doses and each K source for the characteristic NFP revealed a significant effect for the sources KCl and K_2SO_4, fitting to a quadratic model (Figure 3A). The highest number of fruits per plant was obtained with the fertilizer K_2SO_4 (306 fruits plant^{-1}) at the estimated dose of 161.1 g plant^{-1} of K_2O (89.5% of the recommended dose) applied through fertigation, while for KCl the highest number of fruits per plant was 253.6 for the maximum estimated dose of 180 g plant^{-1} (100% of the recommended dose).

According to the follow-up analysis of the effect of doses in each source for yield, the data fitted to a quadratic model (Figure 3B). The highest mango yield was obtained for K_2SO_4 (23.1 t ha^{-1}) at the maximum estimated dose of 174.24 g plant^{-1} (96.8%) in relation to the yield of 20.6 t ha^{-1} for the maximum estimated dose of 185.58 g plant^{-1} (103.1%) of KCl, superior to the national mean yield of the mango crop (16 t ha^{-1}) and compatible with the mean mango yield in the Sub-Middle São Francisco River Valley (20 t ha^{-1}) (IBGE, 2016).

Through an economic analysis of the application of the fertilizers K_2SO_4 and KCl. It is possible to reduce the amount of fertilizer to be applied to obtain 90% of the maximum estimated fruit yield by 22.57 and 26.86%, respectively, i.e., doses of 134.9 g plant^{-1} (58.69%) of K_2SO_4 and 135.74 g plant^{-1} (70.42%) of KCl lead to a reduction of only 10% in the mango yield in Casa Nova-BA. Although the doses of K_2SO_4 and KCl required to obtain 90% of the maximum estimated yield are close, for each kg of fertilizer applied through fertigation, it is possible to obtain a fruit yield of approximately 834 kg ha^{-1} for K_2SO_4 and 699 kg ha^{-1} for KCl, indicating higher efficiency of K_2SO_4 in comparison to KCl.

The SO_4^{2-} ions participate in the synthesis of chlorophyll and formation of the ferredoxin complex; this latter helps the transport of electrons during the production of reducing power in the photosynthetic process and favors the accumulation of carbohydrates and other N components (Lester et al., 2005), preponderant factors for the increment in mango yield. K

Table 3. Analysis of variance (F value) for the number of fruits per plant (NFP), yield (Y, t ha^{-1}) and leaf potassium content (KL, g kg^{-1}) as a function of the sources and doses of potassium applied through fertigation

Source of variation	NFP	Y	KL
KCl	223.9 b	17.63 b	6.97 a
K_2SO_4	272.7 a	21.23 a	7.10 a
Source (S)	27.52**	174.1**	1.13^{ns}
Doses (D)	4.20**	54.0**	13.8**
Interaction (S x D)	4.63**	7.31**	4.33**
CV (%)	6.24	19.4	5.65

** significant at 0.01 probability level ($p < 0.01$); ^{ns} not significant

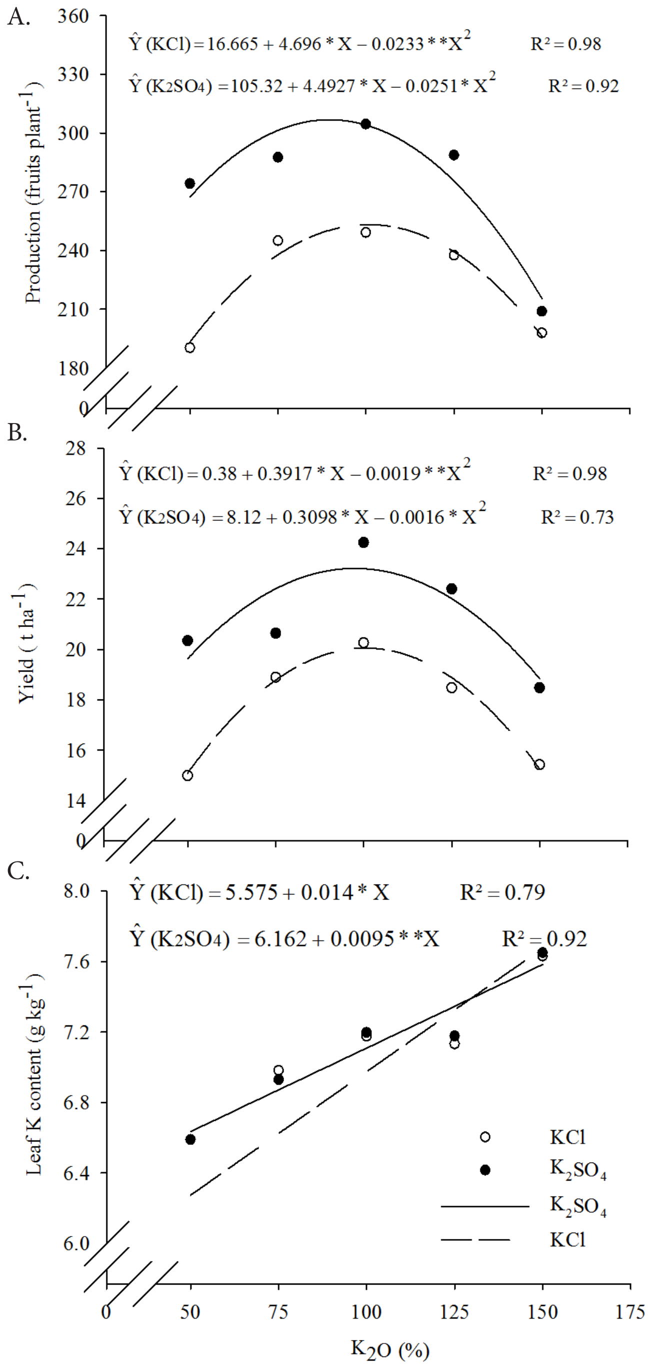


Figure 3. Production, yield and leaf K content as a function of the potassium doses applied through fertigation

plays a significant role in the translocation of photoassimilates from leaves to fruits, resulting in higher mass of fruits and, consequently, mango yield.

Leaf K contents increased with the increment in the doses of KCl and K_2SO_4 applied through fertigation (Figure 3C). For KCl, leaf K contents varied from 5.96 to 7.63 g kg^{-1} and for K_2SO_4 from 6.59 to 7.65 g kg^{-1}, being within the range considered as adequate for the mango crop (5 to 10 g kg^{-1}) (Genú & Pinto, 2002).

Conclusions

1. Fertilization with potassium chloride promotes higher soil electrical conductivity in relation to the fertigation with potassium sulfate, but not to the extent of making the soil saline (EC > 4.0 dS m^{-1}) under the conditions of soil, climate and management adopted in the present study.

2. The increase in the doses of potassium, in the form of potassium chloride and potassium sulfate, results in the increment of the exchangeable contents of sodium and potassium in the soil.

3. Fertilization with potassium sulfate has higher efficiency with respect to the production per plant and yield of mango, in comparison to the fertilization with potassium chloride, and the dose of 174.24 g $plant^{-1}$ of potassium sulfate is recommended for a fruit yield of 23.1 t ha^{-1} under the studied conditions.

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