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Growth, nutrition and production of dry matter of rubber tree (*Hevea brasiliensis*) in function of K fertilization

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Abstract

The rubber tree crop (*Hevea brasiliensis*) is raw material used for the production of rubber. However, the Brazilian production accounts for only a third of the demand, resulting in large cultivation areas concomitantly concerned with aspects related to production system. Hence, this study aims to evaluate the effects of potassium fertilization on the growth, nutrition and dry matter production of *Hevea brasiliensis* seedlings up to 35 days after planting. Potassium rates were 0 (control), 0.25, 0.5, 0.75 and 1 kg m^{-3} of K_2O soil. Biometric evaluations such as rootstock diameter, leaf number and plant height, as well as dry matter production and potassium accumulation in shoots and roots of rubber tree seedlings were evaluated up to 85 days after transplanting. The efficiency of absorption, transport and use of potassium by rubber tree seedlings were also assessed. Potassium rates influenced plant height, stem diameter and number of leaves. However, with the increase in rates these parameters decreased. Plants obtained a maximum production of total dry matter of 141.72 g $plant^{-1}$ at a rate of 0.2 kg m^{-3} of K_2O, suggesting that it is the best rate to be applied to plants during seedling stage. Absorption and transportation efficiencies were not affected by potassium application in the soil, while the use efficiency was lower as the rate applied was higher.

Keywords: Plant nutrition; seedling production; macronutrients.
Abbreviations: AB_{ef}_Absorption efficiency; DM_Dry matter; K_Potassium; TR_{ef}_Transport efficiency; UT_{ef}_Use efficiency; NL_Number of leaves; H_Plant height; SD_Stem diameter; RDM_Root dry matter; SDM_Shoot dry matter.

Introduction

Some plant species have a potential for latex production, especially species from the Euphorbiaceae family. However, the worldwide latex production mostly uses rubber tree (*Hevea brasiliensis*) (Nogueira et al., 2015). The latex from rubber trees is the raw material for the production of rubber. It is obtained from a coagulation process. This product supplies a portion of the worldwide tire industry (Nogueira et al., 2015). The Brazilian production supplies a third of the national demand, and the marketing is influenced by product price fluctuations on the international market (Nogueira et al., 2015). Some authors suggest that the rubber tree crop is increasing and that this may change natural ecosystems at different scales, either spatial or temporal, particularly affecting the socio-economic conditions of farmers (Häuser et al., 2015). In addition to aspects inherent to the production of latex and wood from *Hevea brasiliensis*, this crop can store large amounts of carbon (C) in the soil (Diniz et al., 2015; Blagodatsk et al., 2016). Thus, some authors compare the storage of C by rubber tree growing areas with natural and planted forests, and consider this type of crop a good alternative for increasing C levels in the soil (Diniz et al., 2015). However, some aspects concerning production systems must still be clarified, especially those inherent to plant nutrition, considering the need to increase crop productivity. Potassium (K) is one of the nutrients required by plants at higher levels because it acts in various physiological functions (Anschütz et al., 2014). It is estimated that 98% of K comprises the structure of primary and secondary minerals (Sparks, 2000), followed by a lower portion in exchangeable or readily available forms, occupying or not preferred sites in the colloidal complex. In tropical soils, K may reach concentrations from 0.9 to 19 g kg^{-1} (Fassbender, 1994). This concentration may vary depending on the degree of moisture in the soil and in source materials, which consequently will comprise its mineralogical composition (Shaikh et al., 2007). Thus, the need for management fertility of tropical soils is relevant in order to optimize agricultural production, as well as K-based fertilization using external sources. K acts on the activation of enzyme systems related to photosynthesis and respiration (Ashraf et al., 2001; Cakmak et al., 2005; Ahmad et al., 2012), especially the synthesis of proteins (Ashraf et al., 2001), carbohydrates, adenosine triphosphate (ATP) (Pettigrew, 2008). It also acts on osmotic regulation, regulating water loss from opening and closing stomata (Arquero et al., 2006; Ahmad et al., 2012). In addition, it provides greater resistance conditions to plasma membranes, and thus a greater plant resistance to pests and diseases (Zörb et al., 2014). K deficiency leads to a decrease in plant growth (Pettigrew, 2008), size of internodes, apical dominance. It especially delays fruiting. It may result in smaller fruits with less intense colors (Ernani et al., 2007). Due to its mobility in the phloem, the deficiency symptoms occur on older leaves, characterized as chlorosis on leaf edges followed by necrosis (Ernani et al., 2007).

Thus, the deficiency of this nutrient may lead to several physiological problems, which it will consequently result in a reduced crop yield. In this sense, this study aimed to evaluate the effects of potassium fertilization on growth, nutrition and production of dry matter of rubber tree seedlings (*Hevea brasiliensis*).

Results and discussion

Height, stem diameter and number of leaves

Potassium rates (K_2O) significantly affected plant height (H), stem diameter (ST) and number of leaves (NL) (Table 1). There was a quadratic fit for all growth parameters. Plant height and number of leaves were significant at 1% probability ($p \leq 0.01$), while stem diameter was significant at 5% probability ($p \leq 0.05$). The maximum height of seedlings was 125.32 cm when a rate of 0.29 kg m^{-3} of K_2O (Fig 1) was used, followed by a maximum stem diameter of 57.29 mm achieved when using a rate of 0.10 kg m^{-3} of K_2O (Fig 2). The number of leaves was 32.44, with a rate of 0.22 kg m^{-3} of K_2O (Fig 3). The most representative coefficients of variation were observed when rates were related to the diameter of plants, suggesting a wider variation of this parameter due to K_2O rate. Potassium deficiency may reduce the number and size of leaves, hence the photosynthetic rate at the expense of a decreased leaf area unit of plant (Pettigrew, 2008).

All growth parameters decreased with the increase in applied rates. This behavior may be a result from inhibition of other nutrients (Virgens Filho et al., 2001), antagonists of this mineral, as well as salinization of K (Pottosin and Dobrovinskaya, 2014). A considerably higher rate was applied in a small volume of soil. Plant growth is influenced by K, since this nutrient affects osmotic regulation, respiration, photosynthesis, stomatal movement and protein synthesis (Ashraf et al., 2001; Cakmak et al., 2005; Arquero et al., 2006; Ahmad et al., 2012). K deficiency causes a severe decrease in photosynthesis rate at the expense of CO_2 fixation (Cakmak et al., 2005), reducing the production of photoassimilates and consequently plant development (Zörb et al., 2014). Murbach (1997) observed the influence of K on the growth and productivity of the PB 235 clone (*Hevea brasiliensis*), so that the nutrient availability resulted in an increased number of leaves and productivity.

Dry matter production

The production of dry matter was influenced by K_2O rates applied to the soil although the coefficients of variation were less pronounced, with low standard deviation values, expressed as mean percentage, ranging from 4.94 to 7.51% (Table 2) and suggesting a greater homogeneity of data. The production of shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM) showed a significant quadratic fit at $p \leq 0.05$, where SDM reached the maximum value of 90.97 g $plant^{-1}$ when a rate of 0.15 kg m^{-3} of K_2O was used. RDM showed a maximum yield of 51.29 at a rate of 0.27 kg m^{-3} of K_2O (Fig 4), respectively.

The maximum production of total dry matter was 141.72 g $plant^{-1}$ at a rate of 0.2 kg m^{-3} of K_2O (Fig 4), with values tending to decrease, followed by a coefficient of determination of 0.96 (R^2) under using a quadratic equation, suggesting the best rate to be applied to rubber tree seedlings. K regulates protein synthesis, transport of photoassimilates and control of metabolic processes (Pettigrew, 2008). In addition, K potentiates the increase in leaf area and dry matter accumulation (Ahmad et al., 2012.). It mainly increased productivity and improved the production quality (Pettigrew, 2008; Zörb et al., 2014). According to Zörb et al. (2014), the production of photoassimilates directly affects productivity and quality of production. These aspects are associated to a more efficient use of potassium by plants (Pettigrew, 2008). Deprivation of K causes negative responses regarding the development of roots (Pettigrew, 2008). Thus, the optimization of K in the soil is crucial to increase the response of plants to water stresses at the expense of a greater root system, providing improvements on the mechanisms of adaptation and resistance of plants (Zörb et al., 2014).

The efficient use of K by plants improves water use and drought tolerance due to a better stomatal conductance, enhancing the photosynthesis process (Ahmad et al., 2012) and therefore increasing productivity.

K content in roots and shoots

K content accumulated in the plant tissue ranged according to K_2O rates applied to the soil. There was a significant quadratic fit at $p \leq 0.01$ regarding the K accumulation on shoots, roots and the total plant, followed by average values of 18.23, 10.90 and 15.31% for variation coefficients (Table 3), suggesting homogeneity of data. The maximum value of K accumulation in shoots was 0.83 g $plant^{-1}$ observed at a rate of 0.33 kg m^{-3} of K_2O. In roots, the highest accumulation of K was 0.48 g $plant^{-1}$ at a rate of 0.38 kg m^{-3} of K_2O (Fig 5). The highest accumulation of K found in seedlings, regarding the total tissue evaluated, was 1.35 g $plant^{-1}$ at a rate of 0.48 kg m^{-3} of K_2O, with a decrease tendency observed for the significant quadratic function at $p \leq 0.01$.

Potassium and phosphorus are the nutrients with the highest redistribution rate from leaves to stems in rubber trees (Murbach et al., 2003). Some authors associate the highest rubber tree productivity to nitrogen and phosphorus levels on leaves (Bataglia et al., 1988). K can be accumulated in vacuoles, with a variable content regarding nutrient availability (Pottosin and Dobrovinskaya, 2014). Some authors also describe cytosol as a K reservoir in plant tissues (Walker et al., 1996). The behavior of K concentration in these reservoirs is important in order to understand how this nutrient affects plant development.

According to Walker et al. (1996), K activities in vacuoles linearly decreased with K content decrease in tissues, while the K activity in cytosol initially remained constant in epidermal and cortical cells, tending however to decrease.

The decrease of K contents in plants may be associated to the dynamics of other nutrients. Reis et al. (1984) observed decreases in K contents in leaves of plants in liming treatments and increases in Ca contents, while Bataglia and Santos (1999) associated the low K concentration in leaves to N application as urea.

Efficiency indexes: absorption, transport and utilization

The absorption and transport efficiency of K are not associated with K_2O rates applied to the soil. The values of ANOVA by F test were not significant, in contrast with plant

Table 1. Height (H), stem diameter (SD) and number of leaves (NL) of rubber tree seedlings in relation to the application of potassium in the soil. GT1 clone seedlings transplanted 35 days after planting.

Treatments	Height	Stem diameter	Number of leaves
Rates (kg m^{-3} of K_2O)	cm	mm	$plant^{-1}$
0	112.25	56.34	30.10
0.25	140.25	55.66	34.11
0.50	117.50	52.06	33.01
0.75	100.00	30.13	21.19
1.00	92.25	15.80	20.53
F	52.19**	11.62**	14.20**
Linear regression	98.76**	40.01**	34.56**
Quadratic regression	48.08**	5.24*	9.68**
C.V.	4.54	25.38	12.41

**, * and ns significant at 1 and 5% and not significant at 5% probability by F test, respectively.

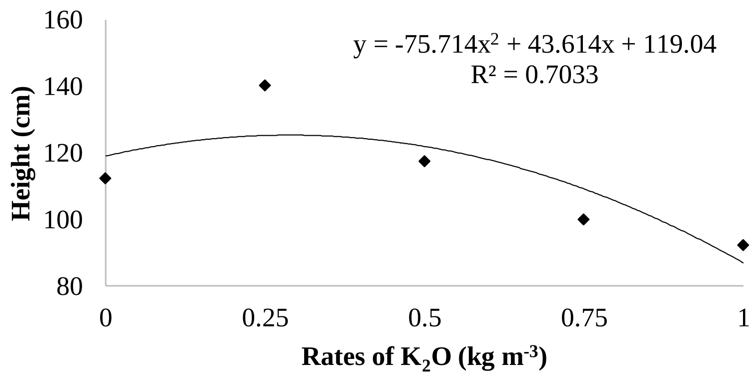

Fig 1. Height of rubber tree seedlings in relation to the application of potassium in the soil. ** Significant at 1% probability by F test.

Table 2. Aerial Part, root and total dry matter of rubber tree seedlings in relation to the application of potassium in the soil.

Treatments	Aerial part	Root	Total
Rates (kg m^{-3} of K_2O)		------g $plant^{-1}$------	
0	88.08	44.68	132.76
0.25	89.70	52.52	142.22
0.50	85.07	51.88	136.95
0.75	51.32	27.52	78.84
1.00	26.70	15.67	42.37
F	148.62**	126.58**	279.61**
Linear regression	490.13**	330.68**	858.04**
Quadratic regression	89.81**	136.37**	215.26**
C.V.	6.75	7.51	4.94

**, * and ns: significant at 1 and 5% and not significant at 5% probability by F test, respectively.

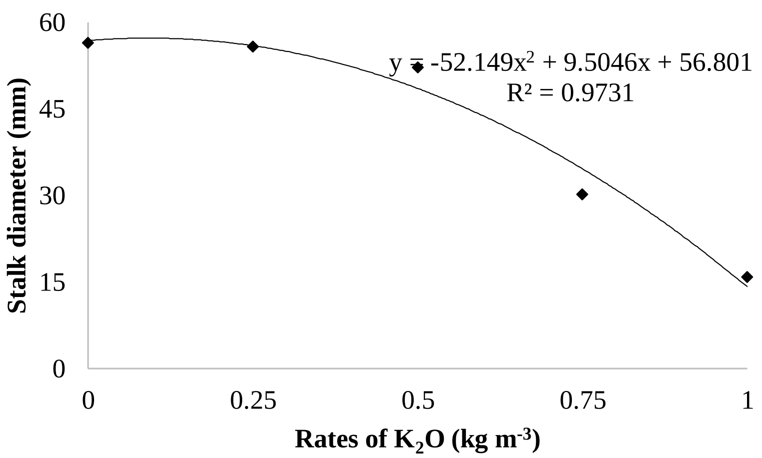

Fig 2. Stem diameter of rubber tree seedlings in relation to the application of potassium in the soil. * Significant at 5% probability by F test.

Table 3. Aerial part, root and total potassium accumulation of rubber tree seedlings in relation to the application of potassium in the soil.

Treatments	Aerial Part	Root	Total
Rates (kg m^{-3} of K_2O)	------------------------------g $plant^{-1}$---------------------------		
0	0.69	0.35	1.04
0.25	0.81	0.47	1.28
0.50	0.82	0.50	1.32
0.75	0.59	0.31	0.90
1.00	0.30	0.17	0.47
F	13.49**	44.56**	20.12**
Linear regression	29.77**	67.59**	39.27**
Quadratic regression	23.79**	100.50**	39.52**
C.V.	18.23	10.90	15.31

**, * and ^{ns}: significant at 1 and 5% and not significant at 5% probability by F test, respectively.

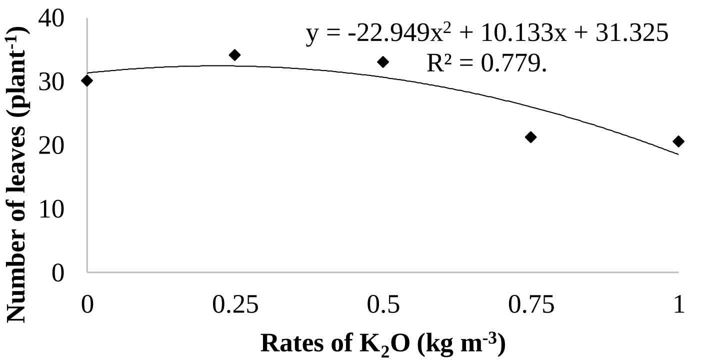

Fig 3. Number of leaves of rubber tree seedlings in relation to the application of potassium in the soil. ** Significant at 1% probability by F test.

Table 4. Absorption efficiency, transport efficiency and utilization efficiency of potassium of rubber tree seedlings in relation to the application of potassium in the soil.

Treatments	Efficiency		
	Absorption	Transport	Utilization
Rates (kg m^{-3} of K_2O)	mg g^{-1}	%	mg g^{-1}
0	23.18	66.33	17.03
0.25	24.81	63.07	16.38
0.50	25.35	62.12	14.31
0.75	32.93	65.02	6.98
1.00	30.36	62.81	3.91
F	1.96^{ns}	1.39^{ns}	38.89**
Linear regression	5.83*	1.15^{ns}	141.04**
Quadratic regression	0.01^{ns}	1.62^{ns}	8.12*
C.V.	21.55	4.63	16.19

**. * and ^{ns}: Significant at 1 and 5% and not significant at 5% probability by F test, respectively.

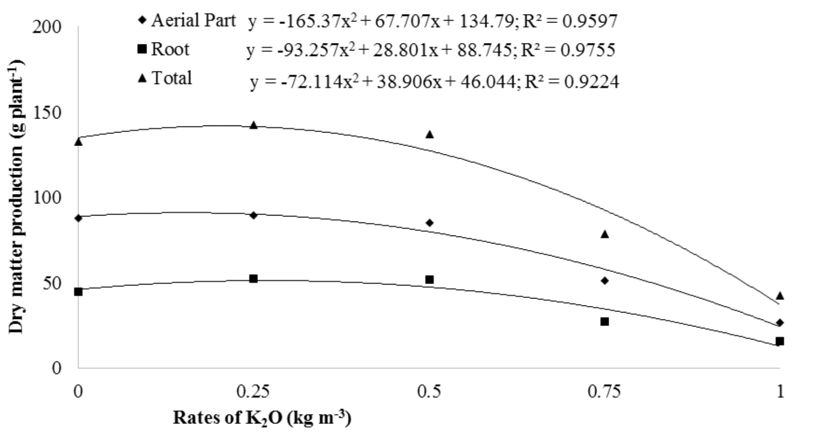

Fig 4. Aerial part, root and total dry matter production of rubber tree seedlings in relation to the application of potassium in the soil. ** Significant at 1% probability by F test.

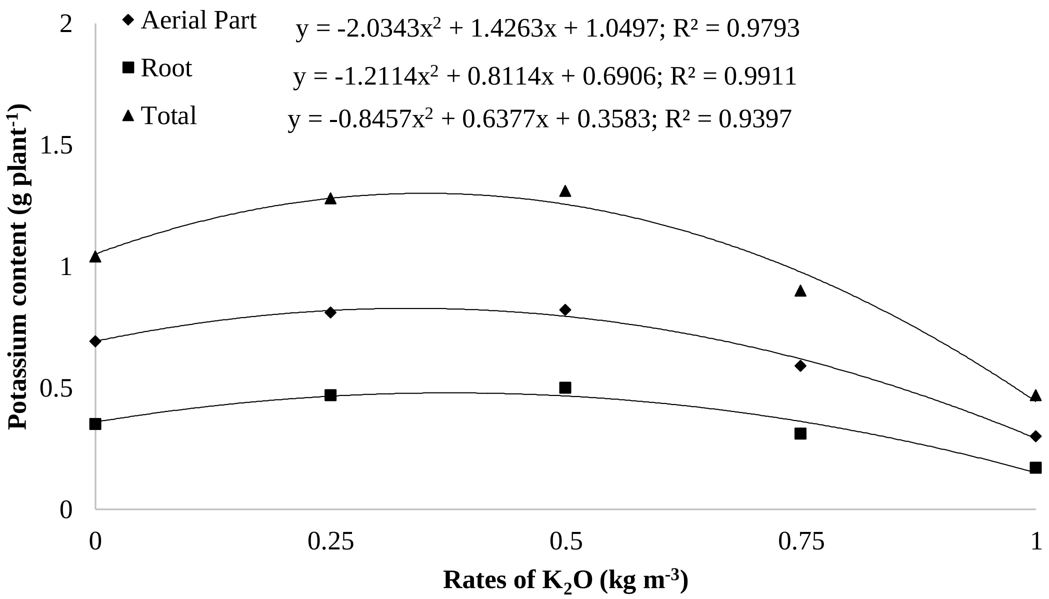

Fig 5. Aerial part, root and total potassium contents of rubber tree seedlings in relation to the application of potassium in the soil. ** Significant at 1% probability by F test.

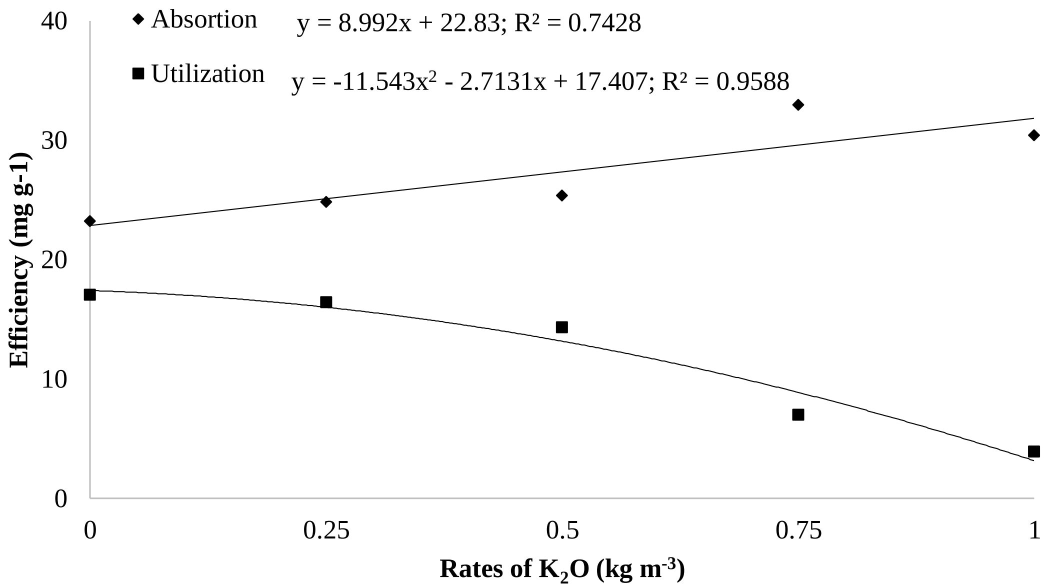

Fig 6. Efficiency of absorption and use efficiency of rubber tree seedlings. * Significant at 5% probability by F test.

use efficiency, in which F test values of 38.89, significant at $p \leq 0.01$, were observed (Table 4). The absorption efficiency showed a linear adjustment significant at $p \leq 0.05$, reaching 31.8 mg g^{-1} when 1 kg m^{-3} of K_2O was applied to the soil, presenting a tendency to increase possibly at the expense of higher contents of exchangeable K. The efficiency of K use tends to decrease with the increase in K_2O rates (Fig 6) due to the greater availability of nutrients in the soil. The efficiency of potassium use corresponds to the ability of plants to show a high productivity in an environment with low levels of available K (Yang et al., 2004). Thus, the behavior of rubber trees, when submitted to different K rates, suggests a responsivity of this species to potassium fertilization. The efficiency of absorption is due to the plant's ability to extract nutrients from the environment. Some authors report a high K absorption efficiency of rubber trees (Virgens Filho et al., 2001). The use efficiency suggests the plant's ability to convert absorbed nutrients into dry matter. This parameter was not associated with the K rates used here, which concerns the plant's ability to transport nutrients from roots to shoots.

Materials and Methods

Analysis and experimental design

The experiment was conducted in a greenhouse. Seedlings of rubber tree, GT1 clone, were grown at Federal Institute of Education, Science and Technology Tocantins (IFTO - Araguatins Campus) located at 05º38'56" S and 48º04'29" W, at 120 m of altitude. The regional average rainfall is 1,500 mm $year^{-1}$, and the average temperature is 28.5ºC.

The climate is Aw (megathermal), or tropical savannah, with dry winters and rainy summers distributed into two well-defined seasons: six months of rainy season and six months of dry season. The experimental unit comprised a pot with a capacity of 4 dm^3 filled with 3.5 dm^3 of Oxisol samples with a very clayey texture. Chemical and physical attributes were pH: 6.4, Organic matter: 10.25 g dm^{-3}, P: 2.2 mg dm^{-3}, K: 64 $mmol_c$ dm^{-3}, Ca: 5.2 $mmol_c$ dm^{-3}, Mg: 1.0 $mmol_c$ dm^{-3}, (H+Al): 0.66 $mmol_c$ dm^{-3}, CEC: 7.02 $mmol_c$ dm^{-3}, Base saturation (V%): 90.0%. The soil had 50 g kg^{-1} of sand, 100 g kg^{-1} of silt, and 850 g kg^{-1} of clay. The experimental design was randomized blocks composed of five treatments and six replications. The treatments consisted of five rates of potassium: 0, 0.25, 0.50, 0.75 and 1.0 kg m^{-3}. Potassium chloride (58% of K_2O) was used as source. Potassium chloride (KCl) has 60% of K_2O (50% K). When the soil is wet, the KCl dissolves in the first hours after application. Thus, a portion of the K goes into the soil solution, but most goes to the negative charges of the functional groups of clay and organic matter (Ernani et al., 2007).

GT1 clone seedlings were used. They were transplanted 35 days after planting. Subsequently, fertilization of macronutrients was performed at the following rates: 2.5 kg dm^{-3} of phosphorus (P) as triple superphosphate (41% of P_2O_5) (Benesi, 1999) and 300 mg dm^{-3} of nitrogen (N) as ammonium nitrate (34% of N) (Malavolta, 2006). In addition, the following micronutrient rates were applied to the soil: 0.5 mg dm^{-3} of B (H_3BO_3 p.a.) and 2.0 mg dm^{-3} of Zn ($ZnSO_4$ p.a.) (Malavolta, 2006). At this point, the potassium levels were applied to the standard treatment. The evaluations were performed every 30 days. Diameter parameters of rootstock (3 cm above soil level), number of leaves and plant height were measured. Irrigation was made with deionized water by weighing the pots, keeping the moisture at 60% of the retention capacity.

Plants were collected eight months after transplanting. Then, shoots and roots were separated and properly washed under running water. Subsequently, all the vegetative material was washed with a hydrochloric acid solution (0.01M) and deionized water. They were then dried in a forced-air circulation oven at 65°C for 72 hours to determine the dry mass of roots and shoots. Then, the K was analyzed in these sections of the plant.

Treatment measurements and nutritional indexes

Plants were daily evaluated for nutritional disorder symptoms. The cutting was performed at 85 days after transplanting. Plant height was recorded by measuring the largest tiller from the base of the plant to the last leaf insertion. Stem diameter was measured using a digital caliper and the total number of leaves was determined. Plant tissue samples were washed with a 0.1% detergent solution, a 0.3% acid solution and distilled water, and dried in oven at 65°C for 48 hours to determine for shoot and root dry mass. The potassium contents from shoots and roots were determined following the methodology described by Bataglia et al. (1983).

Using dry matter and nutrient contents data, the calculation of the nutritional indexes was performed, determining absorption efficiency (AB_{ef}), translocation efficiency/transport (TR_{ef}) and efficiency of use of nutrients for conversion into dry matter (UT_{ef}). The calculation of these indexes is presented below.

Equation: Swiader et al. (1994):

$$AB_{ef}=\frac{\text{total nutrient contents in plant}}{\text{root dry matter}}$$

Equation: Li et al. (1991):

$$TR_{ef}=\frac{\text{nutrient contents in shoots}}{\text{total nutrient contents of the plant}}$$

Equation: Siddiqi and Glass (1981):

$$UT_{ef}=\frac{(\text{total dry matter produced})^2}{\text{total nutrient contents in the plant}}$$

Statistical analysis

Results were subjected to analysis of variance using the software Sisvar®, Brazil (Ferreira, 2014) and to polynomial regression analysis. Linear and quadratic mathematical models were tested to select the sample that provided the best data adjustment based on the magnitude of regression coefficients at 5% probability by the t test. The maximum points were calculated by deriving significant equations. Variables were correlated using the Pearson linear correlation test (Sigma-plot In., USA), considering correlation significances ($p \leq 0.01$ and 0.05).

Conclusion

Potassium rates influenced plant height, stem diameter and number of leaves. However, when rates were higher than 0.25 kg m^{-3} of K_2O, the parameters were decreased. The highest production of total dry matter, 141.72 g $plant^{-1}$, was obtained using the rate 0.2 kg m^{-3} of K_2O, suggesting that this is the best rate to be applied to seedlings. Absorption and transportation efficiencies were not affected by the application of potassium in the soil at the seedling stage. Use efficiency tends to decrease the rate to be applied.

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