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Foliar nutrient contents and yield performance of blackberry with potassium fertilization

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Abstract – The objective of this work was to evaluate the yield performance and foliar nutrient contents of blackberry (*Rubus* sp.) cultivars in response to the increase in potassium fertilization. The experiment was carried out in a soil with pH 5.2 and 22 mg dm^{-3} K content in the fourth and fifth years of production of the Brazos, Guarani, BRS Tupy, and BRS Xavante cultivars, grown in the state of Minas Gerais, Brazil. The tested K_2O rates were distributed in a 4x4 factorial arrangement, which consisted of four rates of K_2O per plant (10, 20, 30, and 40 g) and of the four blackberry cultivars, distributed in four randomized complete block designs. The maximum economic efficiency (MEE) yield, the formation of primocanes, and the critical level of foliar nutrients were evaluated. The K fertilization recommended for blackberry cultivation in Brazilian conditions is not sufficient to maintain foliar nutrient contents at an adequate level. Fertilization with 20 g per plant per year of K_2O, twice the recommended amount, favors the MEE yield, compatible with the yield performance of the cultivars. Foliar nutrient contents should be evaluated to recommend the proper fertilization for the orchard to reach its maximum yield potential.

Index terms: *Rubus*, mineral nutrition, yield.

Teores de nutrientes foliares e desempenho produtivo de amoreira-preta com fertilização potássica

Resumo – O objetivo deste trabalho foi avaliar o desempenho produtivo e os teores de nutrientes foliares em cultivares de amoreira-preta (*Rubus* sp.), em resposta ao aumento na adubação potássica. O experimento foi realizado em solo com pH 5,2 e 22 mg dm^{-3} de K, no quarto e no quinto ano de produção das cultivares Brazos, Guarani, BRS Tupy e BRS Xavante, cultivadas no estado de Minas Gerais, Brasil. As doses de K_2O testadas foram distribuídas em arranjo fatorial 4x4, que consistiu em quatro doses de K_2O por planta (10, 20, 30 e 40 g) e nas quatro cultivares de amoreira-preta, distribuídas em quatro delineamentos de blocos ao acaso. Foram avaliados a produtividade considerada de máxima eficiência econômica (MEE), a formação de hastes novas e o nível crítico de nutrientes foliares. A fertilização com K recomendada para o cultivo da amoreira-preta, nas condições brasileiras, não é suficiente para manter os teores de nutrientes nas folhas em nível adequado. A adubação com 20 g por planta por ano de K_2O, o dobro da recomendada, favorece produtividade de MEE compatível com o desempenho produtivo das cultivares. Os teores de nutrientes foliares devem ser avaliados para recomendação da fertilização adequada para o pomar alcançar seu potencial máximo de rendimento.

Termos para indexação: *Rubus*, nutrição mineral, produtividade.

Introduction

The use of fertilization rates recommended in other countries in Brazilian conditions creates problems for the blackberry (*Rubus* sp.) production system, such as a slow or excessive plant development, susceptibility to pests and diseases, and a low yield and fruit quality (Pereira et al., 2015a). Therefore, information on blackberry fertilization needs to be improved based on the response of different cultivars in Brazilian regions, considering foliar nutrient contents and plant yield.

Fertilization, however, is currently recommended based only on soil analysis. Depending on the nutrient content of the soil, the recommended potassium rates for orchard maintenance range from 0 to 66.7 kg ha^{-1} K_2O (Manual…, 2016). In countries that consider soil and primocane K contents, the applied amount may be as high as 112 kg ha^{-1} K_2O (Hart et al., 2006).

In plants, potassium performs an important function in regulating the osmotic potential of cells, acting as an activator of many enzymes involved in respiration and photosynthesis (Castaño et al., 2008). Therefore, high quantities of the nutrient have been applied to blackberry in high-yield situations, especially since K can also induce growth, increase yield, and influence fruit firmness when nitrogen is not limiting (Pereira et al., 2015b).

Research conducted with blackberry cultivars in Brazil has shown that the current K fertilizer recommendation is low. Pereira et al. (2015b), for example, observed that K foliar content stays below normal for optimal plant growth and yield, which is an indicative that K fertilization may be limiting the yield potential of the cultivars.

The objective of this work was to evaluate the the yield performance and foliar nutrient content of blackberry cultivars in response to the increase in potassium fertilization.

Materials and Methods

The experiment was carried out in an orchard, located in the municipality of Diamantina, in the state of Minas Gerais, Brazil (18º14'56"S, 43º36'0"W, at an altitude of 1,387 m), during the fourth and fifth years of production after planting of blackberry cultivars. The climate of the region is Cwb, temperate humid, according to Köppen-Geiger, characterized by a well-defined dry and rainy season. Accumulated precipitation, temperature variations, and the number of cold hours at mild temperatures were recorded in the two evaluated cycles, between January 2016 and January 2018, at an automatic weather station, approximately 300 m from the orchard (Figure 1).

The soil in the experimental area is a Neossolo Quartzarênico (Santos et al., 2013), i.e., an Arenosol (IUSS Working Group WRB, 2015), with 830 g kg^{-1} sand, 100 g kg^{-1} clay, and 70 g kg^{-1} silt. At 0–20-cm depth, the organic matter content was 1.2 dag kg^{-1}. The soil analysis, prior to the start of experiment, showed the following characteristics: pH 5.1; 7.5 and 22.1 mg dm^{-3} P and K, respectively, both extracted by Mehlich-1; 1.0 $cmol_c$ dm^{-3} Ca; 0.4 $cmol_c$ dm^{-3} Mg extracted by KCl 1 mol L^{-1}; base saturation of 45.5%; and cation exchange

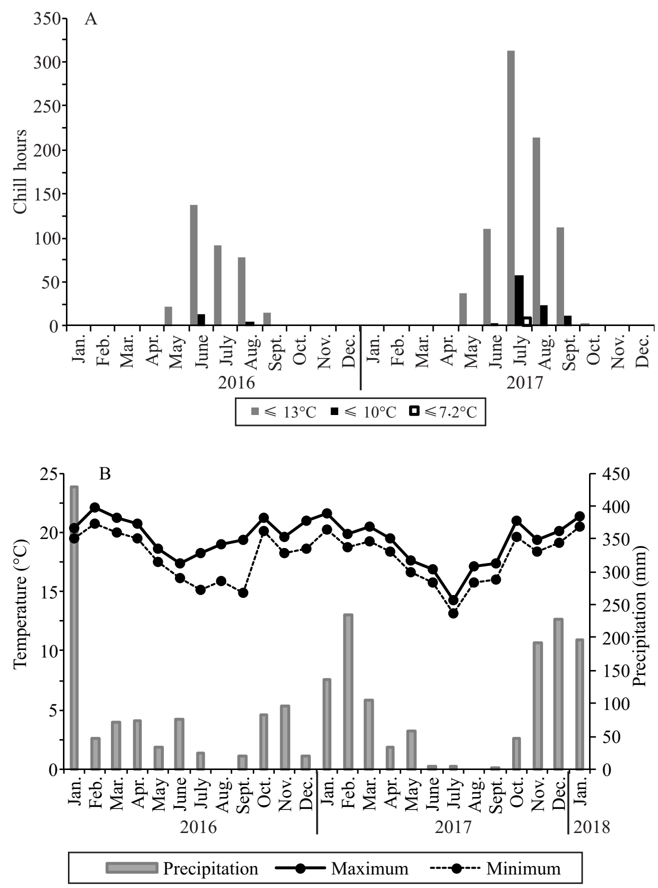

Figure 1. Chill-hours accumulated at temperatures below 13, 10, and 7.2°C (A) and monthly averages of the maximum and minimum temperatures (Ts) and of the precipitation (B) recorded in the blackberry (*Rubus* sp.) growing region, in the municipality of Diamantina, in the state of Minas Gerais, Brazil.

capacity at pH 7.0 of 5.5 $cmol_c$ dm^{-3} obtained by the Walkley-Black method.

The Brazos, Guarani, BRS Tupy, and BRS Xavante blackberry cultivars were evaluated at four and five years of age. These cultivars require a low chill of 200–300 hours (<7.2°C). The plants were conducted in a double espalier, with two wires parallel at 0.5 m, distanced 0.8 m from the soil, with a spacing of 0.8 m between plants and 2.5 m between rows, corresponding to a density of 5,000 plants per hectare.

The preparation of the area and the application of liming before planting and fertilization up to the third production cycle were carried out according to Antunes & Raseira (2004) and to the chemical characteristics of the soil. Pruning was performed in summer, after harvest, by eliminating all the dry floricanes at soil level and reducing the primocanes to 1.2 m height. In winter, the canes and lateral shoots were reduced. Complementary irrigation was applied during fertilization, twice a week, if necessary.

Fertilization was split into two applications: one in March, during the growth of the primocanes; and the other in September, during the flowering period of the plants. The tested K_2O rates were distributed in a 4x4 factorial arrangement, which consisted of four rates of K_2O per plant (10, 20, 30, and 40 g) and of the four blackberry cultivars, distributed in four randomized complete block designs, with six plants per plot, leaving four plants as borders. Complementary fertilization was done with 30 g N and 50 g P_2O_5 per plant; the used sources were urea, potassium chloride with 60% K_2O, and monoammonium phosphate containing 50% P_2O_5 and 10% N, which was considered in the calculation of the tested N rates.

Fruit yield was obtained from the mass of fruits harvested per plant, multiplied by planting density. Fruit were harvested two or three times per week, from October to February, in the fourth and fifth production cycles.

Cane density was determined for all plants at the end of the harvest period, considering the number of primocanes and the spacing between plants. The number of primocanes was obtained by counting the total number per plant, in each plot.

Foliar nutrient contents were determined from samples of the sixth fully-expanded leaf from the apex of the floricanes. Samples of leaf dry matter were subjected to nitric-perchloric digestion to determine: P by colorimetry; K by flame photometry; calcium, magnesium, zinc, iron, copper, and manganese by atomic absorption spectrophotometry; and boron by incineration in a muffle furnace (Silva, 2009). Total N was obtained by the Kjeldahl method after sulfuric digestion (Malavolta et al., 1997).

Data were analyzed by the analysis of variance. Variables that differed significantly between the tested rates of K were subjected to regression analysis, and variables that differed significantly between cultivars were compared by Tukey's test, at 5% probability. From the equations for maximum technical efficiency (MTE) yield, the recommended K rates necessary for the cultivars to obtain a maximum yield of 90% were estimated and considered as being of maximum economic efficiency (MEE). The critical levels of foliar nutrients were estimated by substituting the K rate associated with the MEE yield in the equations.

Results and Discussion

The K rates applied to the soil increased blackberry yield in the two evaluated cycles (Table 1). The average rates of 30 and 20 g K_2O obtained for the MTE and MEE yields, respectively, are higher than that recommended for soils with a low K content of 10 g per plant (Manual…, 2016). With the rate for MEE, yield increased from 69 to 78%, varying according to the cultivar, in comparison with plants fertilized with 10 g K_2O.

The observed increase in yield is attributed to the increase in the availability of K for the plants. Used in high quantities, this nutrient activates the enzymes involved in plant respiration and photosynthesis, regulates stomatal opening and cell turgor, increases CO_2 fixation, promotes the transport of photoassimilates (Castaño et al., 2008), and favors the absorption of NO_3 and protein formation (IPI, 2013).

However, there was decrease in the yield performance of the blackberry cultivars that received the recommended fertilization of 10 g K_2O for soil with a low K content. At the lowest availability of K in the soil, the content of this nutrient in the leaves was below normal for a satisfactory plant growth and yield (Pereira et al., 2015b); this insufficient fertilization can cause impacts on the current and next crop cycles.

Therefore, it is necessary to adjust the currently recommended fertilization rates – that do not provide satisfactory yields in Brazilian conditions –, in order to meet the nutritional requirements of blackberry cultivars grown in soils with a low K content (Manual…, 2016). The need to adjust K fertilization to blackberry cultivars has already been verified for BRS Tupy and BRS Xavante, which have shown an increase in production with a K rate greater than the recommended (Pereira et al., 2015b). The problems caused by the existing fertilization recommendations may be primarily due to the fact they were developed in other countries (Pereira et al., 2013a, 2013b; Antunes et al., 2014).

Brazos was the most productive cultivar in the two evaluated cycles, regardless of the applied K rate, as previously reported (Antunes et al., 2014; Oliveira et al., 2017). The difference in yield between cultivars is related to their genetic characteristics and ability to adapt to different growing regions. In the present study, the chill hours were insufficient to meet the required 200–300 hours (< 7.2°C) (Figure 1), showing how maximum yield is mainly related to climate and soil conditions and to plant nutrition, which influence plant growth, sprouting, and nutrient export (Pereira et al., 2013b, 2015a; Strik & Bryla, 2014).

The increase in K rates increased the foliar K content of the evaluated cultivars in both study years (Table 2). Plants fertilized with a K rate of 10 g K_2O showed a foliar K content lower than the range of 12.5 to 30 g kg^{-1}, considered sufficient for the optimal growth of blackberry (Freire, 2007; Manual…, 2016). However, with a rate of 20 g K_2O, sufficient to achieve MEE yield, a foliar K content from 12.0 to 12.1 g kg^{-1} was observed.

The low foliar K content found may be related to the availability of the nutrient in the soil (Table 2). With fertilization at the recommended rate of 10 g K_2O, the soil presented 45.2 to 53.9 mg dm^{-3} of the nutrient, indicating an average availability; however, with an increased fertilization of 20 g kg^{-1} K_2O, the availability in the soil was classified as good, ranging from 75.1 to 82.7 mg dm^{-3}.

The BRS Tupy and BRS Xavante cultivars also showed low foliar K contents when fertilized with the recommended rates for soils with average K contents. This is another indicative that the current K rates recommended for fertilization in Brazil are low and need to be updated, that is, increased (Pereira et al., 2015b).

Table 1. Fruit yield of the Brazos, Guarani, BRS Tupy, and BRS Xavante blackberry (*Rubus* sp.) cultivars in response to potassium fertilization, in the fourth and fifth production cycles(1).

Cultivar	Equation(2)	R^2	Fruit yield (Mg ha^{-1})		K_2O rate (g per plant)	
			MTE	MEE	MTE	MEE
Fourth production cycle						
Brazos	$\hat{y} = 3.45 + 0.554x - 0.0082x^2$**	94.4	12.8a	11.5a	34.4	21.0
Guarani	$\hat{y} = 2.4 + 0.403x - 0.0075x^2$**	98.5	7.8b	7.0b	26.9	18.0
BRS Tupy	$\hat{y} = 1.63 + 0.556x - 0.0106x^2$**	97.5	8.9b	8.0b	26.0	17.0
BRS Xavante	$\hat{y} = 1.72 + 0.231x - 0.0036x^2$**	93.2	5.4c	4.9c	32.0	21.0
Average	-	-			29.8	19.2
CV (%)			17.5			
Fifth production cycle						
Brazos	$\hat{y} = 4.46 + 0.466x - 0.0078x^2$**	90.0	11.4a	10.3a	30.0	18.0
Guarani	$\hat{y} = 3.063 + 0.456x - 0.0088x^2$**	92.8	8.9b	8.0b	26.0	17.0
BRS Tupy	$\hat{y} = 1.806 + 0.4499x - 0.0071x^2$**	97.7	8.9c	8.0a	32.0	21.0
BRS Xavante	$\hat{y} = 1.14 + 0.249x - 0.0037x^2$*	89.5	5.3c	4.8c	34.0	22.0
Average	-	-			30.5	19.8
CV (%)			15.4			

(1)Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. (2)Value of the independent variable in the equations corresponds to the yield estimate of the zero rate in the adjustment of the used models. MTE, maximum technical efficiency; and MEE, maximum economic efficiency. ** and *Significant at 1 and 5% probability, respectively. nsNonsignificant.

The foliar N contents in the present study varied from 24.8 to 26.3 g kg^{-1} in plants fertilized with 20 g K_2O in the two experimental years (Table 2). This range is within that of 22 to 30 g kg^{-1}, which is considered normal for the optimal growth of blackberry according to the standards followed in Brazil (Freire, 2007; Manual…, 2016). The increase observed in N content in the present study occurred because the plants were able to absorb more N because they were well supplied with K, which acts as a ion-charger in the transport of NO_3 when N is not limiting (IPI, 2013).

The blackberry cultivars showed P content below normal for their optimal growth (Table 2). Therefore, K rates did not influence the content of this nutrient in the two evaluated years, considering the adequate range from 2.6 to 4.5 g kg^{-1} (Freire, 2007; Manual…, 2016). The low P contents can be attributed both to the long productive period of the cultivars in the growing region, which increased the demand of the plants for P, the third most exported nutrient by blackberry, as well as to the chemical and physical characteristics of the soil, which has low P contents and organic matter (Pereira et al., 2013b).

Foliar Ca and Mg contents varied during the two study years (Table 2). In the analysis performed during the fourth production cycle, the contents of both nutrients were not influenced by the K rates and were considered normal, ranging from 6.0 to 25 g kg^{-1}

Table 2. Foliar nutrient contents of the Brazos, Guarani, BRS Tupy, and BRS Xavante (*Rubus* sp.) cultivars in response to potassium fertilization.

Nutrient(1)	Equation(2)	R^2	Critical value(3) (MEE)	CV (%)
		Fourth production cycle		
N	$\hat{y} = 20.3 + 0.456x - 0.0079x^2$**	94.7	26.3	6.1
K	$\hat{y} = 8.25 + 0.175x$**	97.8	12.1	5.8
P	$\hat{y} = 1.83^{ns}$	-	1.83	9.4
Ca	$\hat{y} = 6.1^{ns}$	-	6.1	10.8
Mg	$\hat{y} = 3.6^{ns}$	-	3.6	8.6
B	$\hat{y} = 25.8^{ns}$	-	25.8	8.9
Fe	$\hat{y} = 146.9^{ns}$	-	146.9	11.1
Zn	$\hat{y} = 19.6^{ns}$	-	19.6	5.7
Cu	$\hat{y} = 4.97^{ns}$	-	6.0	8.5
Mn	$\hat{y} = 374.9^{ns}$	-	374.9	15.2
K availability in the soil (mg dm^{-3})(4)				
K	$\hat{y} = 25.24 + 2.874x$**	97.2	82.7	19.8
		Fifth production cycle		
N	$\hat{y} = 18.586 + 0.483x - 0.0086x^2$**	95.6	24.8	5.2
K	$\hat{y} = 7.66 + 0.216x$**	96.9	12.0	5.4
P	$\hat{y} = 1.63^{ns}$	-	1.63	11.6
Ca	$\hat{y} = 4.612 - 0.0242x$*	96.2	3.7	8.1
Mg	$\hat{y} = 1.2$	-	1.2	8.9
B	$\hat{y} = 25.767 - 0.156x$*	94.1	22.0	13.9
Fe	$\hat{y} = 126.4^{ns}$	-	126.4	10.6
Zn	$\hat{y} = 20.3^{ns}$	-	20.3	16.1
Cu	$\hat{y} = 19.2$	-	19.2	18.8
Mn	$\hat{y} = 747.5$	-	347.5	14.8
K availability in the soil (mg dm^{-3})(4)				
K	$\hat{y} = 15.245 + 2.994x$**	98.2	75.1	17.5

(1)The content of the macronutrients (N, K, P, Ca, and Mg) is given in g kg^{-1} and of the micronutrients (B, Fe, Zn, Cu, and Mn) in mg kg^{-1}. (2)The value of the independent variable in the equations corresponds to the yield estimate of the zero rate in the adjustment of the used models. (3)Value estimated by substituting the K rate by the maximum economic efficiency (MEE) obtained by the application of 20 g K_2O. (4)Extracted by Mehlich-1. ** and *Significant at 1 and 5% probability, respectively. nsNonsignificant.

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and from 3.0 to 10 g kg^{-1}, respectively (Freire, 2007; Manual…, 2016). In the fifth production cycle, a reduction was observed, with results lower than those of the previous cycle and below the ideal for plant growth and yield. These low contents may be related to the low availability of the nutrient in the soil and to the liming applied to improve the chemical attributes of the soil in the fifth production cycle. Although the relationship between K and Ca has been reported, under conditions of high K availability, there may be a decrease in Ca and Mg content likely due to the antagonistic effect of K (Castaño et al., 2008). In the present study, more representative decreases were verified from the fourth to the fifth production cycles, with a linear reduction of Ca in response to K rates only in the second year.

Foliar Fe, Zn, Cu, and Mn contents were unaffected by K fertilization in the two evaluated years (Table 2) and were considered normal for optimal growth (Freire, 2007; Manual…, 2016). Mn contents were above normal and higher than 300 mg kg^{-1} during both years. Generally, in acid soils, Mn contents are more common above the adequate range than below it. This is due to the increase in the solubility and availability of this nutrient when soil pH is low (Hue & Mai, 2002). Similar results have been reported for blackberry cultivars planted in soil with a pH of 5.9 (Pereira et al., 2015b). Although B content reduced in response to the K rates applied during the fifth production cycle (Table 2), it was considered insufficient in both experimental years, being <30 mg kg^{-1} (Freire, 2007; Manual…, 2016). This difference in B content with increasing K fertilization may be attributed to the higher yield of the cultivars, since B is one of the most used micronutrients during flowering and fruit set (Dechen & Nachtigall, 2006).

Cane density was influenced by K fertilization (Table 3). In the plants fertilized with 20 g K_2O, cane density increased from 59 to 69%. However, the densities observed for the BRS Tupy and BRS Xavante cultivars were low, considering the ideal recommendation for the crop, varying from 5.7 to 13.1 canes per linear meter (Pagot et al., 2007). The low emission of new canes, at each production cycle, interferes with the yield performance of the cultivars, which may cause lower yields. To adjust cane density, as well as yield, the fertilization management must be balanced with the increase in N availability. In blackberry, N is the element used in the largest quantities and plays a major role in plant growth and development (Pereira et al., 2013a; Strik, 2008).

The increases in cane density were probably due to the structural and metabolic role of K, which induces increased photosynthesis (Castaño et al., 2008) and, among other processes, favors N absorption (Table 2), which is important for cane growth.

The obtained results show that it is necessary to adjust K fertilization rates for the management of blackberry orchards growing in soils with a low K content, mainly because the current K fertilizer

Table 3. Number of new canes emitted by the Brazos, Guarani, BRS Tupy, and BRS Xavante blackberry (*Rubus* sp.) cultivars in response to potassium fertilization(1).

Cultivar	Equation(2)	R^2	Canes (MME)	
			Number per plant	Density per meter
		Fourth production cycle		
Brazos	$\hat{y} = 0.914 + 0.137x - 0.0014x^2$*	98.2	3.1b	3.9b
Guarani	$\hat{y} = 1.56 + 0.118x$*	95.2	4.0a	5.0a
BRS Tupy	$\hat{y} = 2.1^{ns}$	-	2.1c	2.6c
BRS Xavante	$\hat{y} = 1.1 + 0.093x$**	98.7	3.0b	3.7b
CV (%)		18.5		
		Fifth production cycle		
Brazos	$\hat{y} = 0.55 + 0.419x - 0.0081x^2$**	92.3	5.7a	7.1a
Guarani	$\hat{y} = 1.5 + 0.15x$**	93.7	4.5b	5.6b
BRS Tupy	$\hat{y} = 0.703 + 0.175x - 0.0023x^2$**	98.9	3.3c	4.1c
BRS Xavante	$\hat{y} = 0.6 + 0.133x$ **	97.4	3.3c	4.1c
CV (%)		15.8		

(1)Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. (2)Value estimated by substituting the K rate by the maximum economic efficiency (MEE) obtained by the application of 20 g K_2O. ** and *Significant at 1 and 5% probability, respectively. nsNonsignificant.

recommendation does not promote an adequate plant growth and foliar K content.

Conclusions

1. The recommended potassium fertilization for the cultivation of blackberry (*Rubus* sp.) under Brazilian conditions is not sufficient to maintain an adequate nutrient foliar content, which should be evaluated to recommend the proper fertilization for the orchard, considering the higher plant demand to reach maximum fruit yield potential.

2. Potassium fertilization with 20 g per plant per year of K_2O favors maximum economic efficiency yield, compatible with the yield performance of the studied cultivars.

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