RESPONSE OF BEET TO DOSES OF POTASSIUM IN OXISOL WITH HIGH CONTENT OF THE NUTRIENT[1]

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ABSTRACT – Fertiliser recommendation tables for beet culture have been prepared based on the response to potassium (K) doses in soils with a low nutrient content. However, there is little research that evaluates potassium fertilisation for beet crops in soil with high K content, a condition commonly found, which allows a better understanding of the crop's response to the nutrient. The objective was to evaluate the response of beet to doses of K in Oxisol with a high K content. The experiment was carried out in the field, with an experimental design in randomised blocks, in a 4 x 2 factor scheme with four replications. The doses of K were 0, 60, 120 and 180 kg ha^{-1} of K_2O, and the cultivars were 'Early Wonder' and 'Kestrel'. At 50 days after transplantation, the levels of nitrogen (N), phosphorus (P), K and boron (B) in the diagnostic leaf were evaluated. Beet yield and accumulation of these four nutrients were analysed at harvest. The doses of K positively influenced the leaf content of K; however, without an effect on beet yield. Therefore, in Oxisol with a high K content available, potassium fertilisation is not recommended. To maintain soil fertility at a high potassium content, fertilisation with 162 and 126 kg ha^{-1} of K_2O is recommended for 'Early Wonder' and 'Kestrel', respectively; doses equivalent to the quantities exported by the beet root.

Keywords: *Beta vulgaris* L.. Potassium fertilization. Mineral nutrition. Nutrient accumulation.

RESPOSTA DA BETERRABA A DOSES DE POTÁSSIO EM LATOSSOLO COM ALTO TEOR DO NUTRIENTE

RESUMO – Tabelas de recomendação de adubação para a cultura da beterraba foram elaboradas com base na resposta a doses de potássio (K) em solos com baixo teor do nutriente. Contudo, são escassas as pesquisas que avaliam a adubação potássica para a cultura da beterraba em solo com alto teor de K, condição comumente encontrada, o que permite melhor compreensão da resposta da cultura ao nutriente. Objetivou-se avaliar a resposta da beterraba a doses de K em Latossolo com alto teor do nutriente. O experimento foi realizado em campo, em delineamento de blocos ao acaso, em esquema fatorial 4 x 2, com quatro repetições. As doses de K foram 0, 60, 120 e 180 kg ha^{-1} de K_2O e as cultivares foram 'Early Wonder' e 'Kestrel'. Aos 50 dias após o transplante avaliaram-se os teores de nitrogênio (N), fósforo (P), K e boro (B) na folha diagnose. A produtividade e o acúmulo destes quatro nutrientes foram analisados na colheita. As doses de K influenciaram positivamente o teor foliar de K; contudo, sem efeito na produtividade da cultura. Portanto, em Latossolo com alto teor de K disponível, não se recomenda a fertilização potássica. Para a manutenção da fertilidade do solo em nível alto de K, recomenda-se a fertilização com 162 e 126 kg ha^{-1} de K_2O para 'Early Wonder' e 'Kestrel', respectivamente, doses equivalentes às quantidades exportadas pela raiz de beterraba.

Palavras-chave: *Beta vulagaris* L.. Adubação potássica. Nutrição mineral. Acúmulo de nutrientes.

INTRODUCTION

Mineral nutrition is one of the most important factors in vegetable production, since they are plants that have a short cycle, fast growth, superficial root system and high demand for nutrients (TIVELLI et al., 2011). According to these authors, fertilisers correspond to 56% of the total cost of input and 28% of the operational cost of beet crops. Therefore, the rational use of fertilisers is a preponderant factor to achieve high yield, but it also greatly impacts the profitability of cultivation (CECÍLIO FILHO et al., 2014).

Among nutrients, due to the functions described by Hawkesford et al. (2012), potassium (K) is an important element to increase the crop yield. In beet plants, it is the nutrient demanded in greater quantity (CARDOSO et al., 2017; SILVA; SILVA; KLAR, 2017).

The need for high K availability in the soil for vegetables, compared to other agricultural crops, encourages producers to apply high doses of this nutrient. As a consequence, it has been observed that the continuous cultivation of vegetables in the same area over the years generates an increase in the soil K content (SEDIYAMA et al., 2011). Potassium fertilisers were the most commercialised in Brazil in 2017 (MAPA, 2018), in which the most used was potassium chloride because it has the lowest cost per K unit.

K rich soils contribute to greater absorption and accumulation of this nutrient by plants. However, although related to increased yield (OOSTERHUIS et al., 2014) and quality of beet (ZENGIN et al., 2009), both the high availability in the soil (FARIA et al., 2012) and the high accumulated quantity can negatively affect plants (ZANFIROV et al., 2012; ZÖRB; SENBAYRAMB; PEITER, 2014). The K excess symptom, which can be confused with the damage caused by salinity, can decrease magnesium and calcium absorption with negative implications for plant metabolism, such as impaired protein synthesis, ATP use and formation of the middle lamella, which causes leakage of solutes and instability in the functioning of the plasma membrane (HAWKESFORD et al., 2012).

Although there are fertiliser recommendations for beet cultivation, there is little research that evaluates potassium fertilisation in soil with a high K content, which is necessary to improve the fertilisation recommendation tables for the crop. Studies with this objective are important, since the participation of fertilisers in the production cost of crops is growing, together with the fact that mineral reserves are finite. For the State of São Paulo, Brazil, in soils with a high K content (> 3 mmol$_c$ dm^{-3}), Trani et al. (1997) recommend the application of 60 kg ha^{-1} of K$_2$O in planting and 30–60 kg ha^{-1} of K$_2$O divided into three applications as covering. For the State of Minas Gerais, also for a similar soil situation, Casali (1999) recommends 120 kg ha^{-1} of K$_2$O, without covering fertilisation.

Given the above, the objective was to evaluate the response of beet to doses of K in Oxisol with a high content of this nutrient.

MATERIAL AND METHODS

Location and characterisation of the experimental area

The experiment was carried out in the field from 26 May to 25 September 2017 at São Paulo State University, in Jaboticabal city (21° 14' 05" S, 48° 17' 09" W and 615 m.a.s.l.), in Brazil. The soil of the experimental area was classified as an Oxisol.

The values of minimum and maximum temperature and rainfall of the experimental period (Table 1) were obtained from the Agroclimatological Station of the university.

The experimental area soil is classified as a typical Eutrophic Red Latosol with a very clayey texture, a moderate kaolinitic-oxidic, smooth wavy to wavy relief (SANTOS et al., 2018).

Table 1. Weather data of the experimental period.

Month	maxT (^{0}C)	minT (^{0}C)	averT (^{0}C)	HR (%)	Rainfal (mm)	RDN
June	27.3	11.4	18.9	63.9	0	0
July	28.8	8.1	18.0	58.7	0	0
August	34.8	9.8	21.0	58.3	17.1	4
September	34.9	12.6	24.4	36.5	0	0
Average	31.5	10.5	20.6	54.4	-	-

maxT: maximum temperature; minT: minimum temperature; averT: average temperature; HR: humidity relative of the air; RDN: rainy days number.

Treatments and experimental design

Eight treatments were evaluated in randomised blocks with a 4 x 2 factorial scheme and four replications. The treatments resulted from two factors: K doses (0, 60, 120 and 180 kg ha^{-1} of K$_2$O) and beet cultivars ('Kestrel' and 'Early Wonder').

Each experimental unit was composed of six

rows, each row with ten pits with two plants, which provided 496,000 plants per hectare, considering 6,200 m^2 of beds in one hectare. The border of each unit corresponded to the plants located in the first and last rows of each experimental unit and by the first and last plant of each row.

Experiment management

The soil of the experimental area (layer of 0–20 cm) before planting was analysed according to Raij et al. (2001) and showed the following attributes: pH (CaCl$_2$) 5.4; 24 g dm^{-3} of organic matter, 49 and 14 mg dm^{-3} of P and S, respectively; 3.2, 31, 14, 1 and 72.5 mmol$_c$ dm^{-3} of K, Ca, Mg, Al and cation exchange capacity, respectively. The K content in the soil was considered high according to the classification of Trani and Raij (1997). The clay, sand and silt contents corresponded to 615, 253 and 132 g kg^{-1}, respectively.

Liming was performed three months before planting of beet aiming to increase the base saturation to 80% as recommended by Trani et al. (1997). Organic fertilisation was not performed. Beds were prepared to receive seedlings of the cultivars 'Kestrel' (Sakata) and 'Early Wonder Super Tall Top' (Top Seed/Agristar). Seedling thinning was performed leaving two plants per cell tray 30 days after sowing and the seedlings were transplanted into the beds. The spacing used was 0.25 m between rows and 0.10 m between plants in the row.

Planting fertilisation was performed as recommended by Trani and Raij (1997). Nitrogen (20 kg ha^{-1} N, urea), phosphorus (180 kg ha^{-1} P$_2$O$_5$, triple superphosphate), boron (2 kg ha^{-1} B, boric acid) and zinc (3 kg ha^{-1} Zn, zinc sulphate) were applied on bed. The K doses foreseen in the treatments were divided into two applications, at 20 and 40 days after transplantation, together with N (80 kg ha^{-1} of N, urea).

Weed control was performed by means of manual weeding. For phytosanitary control, the insecticide Acetamipride and the fungicide Azoxystrobin were used. Irrigation was carried out via a sprinkler according to the water requirements of the crop.

The harvest was performed when the tuberous root showed a commercial size (6-8 cm equatorial diameter).

Characteristics evaluated

i) N, P, K and B foliar content: At 50 days after transplanting, ten leaves were collected to evaluate the nutritional status (TRANI; RAIJ, 1997). The leaves were washed, dried, minced and the extract prepared in a laboratory to determine the nutrient contents according the methodology of Miyazawa et al. (2009).

ii) Accumulation of N, P, K and B in the shoot and tuberous root: At beet harvest, leaves and tuberous root were separated and the same method described above was carried out to determine the nutrient contents of each plant part. The nutrient accumulation was calculated by multiplying the dry mass for each plant part and the nutrient content of each part. The total for each nutrient corresponded to the sum of quantities of this nutrient presented in the shoot and tuberous root. As nutrient exportation, it was considered the amount present in the tuberous root.

iii) Yield: Firstly, the fresh mass of tuberous root of all plants in the useful area of the experimental unit was obtained. Next, the yield (kg ha^{-1}) was estimated considering that 6,200 m^2 of area was effectively cultivated in one hectare.

iv) Depletion of K content in the soil: Based on the accumulated amount of K in the tuberous root (nutrient export), the amount of K removed from the soil was calculated, expressed in mmol$_c$ dm^{-3}.

Statistical analysis

A variance analysis by F test (α ≤ 5%) and regression study for K doses were performed. The significant equations of higher order and coefficient of determination were chosen. The AgroEstat statistical program was used (BARBOSA; MALDONATO JÚNIOR, 2015).

RESULTS AND DISCUSSION

There was no interaction between the factors cultivar and K dose on leaf contents of the nutrients, but there was an isolated effect only for the factor cultivar (Table 2).

Table 2. Summary of the variance analysis for N, P, K and B foliar content and for yield as a function of cultivar and K dose.

Sources of variation	F values				
	N	P	K	B	Yield
Cultivar (C)	29.1**[1]	2.4[ns]	1.3[ns]	47.4**	8.35**
K dose (K)	3.7*	5.4**	6.0**	2.0[ns]	2.01[ns]
C x K	0.3[ns]	2.3[ns]	1.7[ns]	0.1[ns]	0.35[ns]
CV (%)	4.4	13.9	20.3	11.0	12.18
Cultivar	Means				
	------------------ g kg^{-1} ----------------			mg kg^{-1}	kg ha^{-1}
'Early Wonder'	28.7 a	8.1 a	71.2 a	45.4 a	29710.9 a
'Kestrel'	26.4 b	7.5 a	77.3 a	34.7 b	26230.5 b
MSD	0.9	0.8	11.1	3.2	2504.1
Dose of K$_2$O (kg ha^{-1})	Means				
	--------------- g kg^{-1} -----------------			mg kg^{-1}	kg ha^{-1}
0	28.8	6.9	71.2	42.2	27097.7
60	26.9	8.8	81.2	37.6	26140.6
120	27.5	7.2	78.3	41.5	30019.5
180	27.1	8.1	82.6	38.9	28625.0
MSD	1.7	1.5	21.0	6.1	4746.4

1 F test, **: $p \leq 0.01$; *: $p \leq 0.05$; ns: no significant; CV: coefficient of variation; MSD: minimum significant difference.

The K doses influenced the leaf contents of N and K. The N content decreased and K content increased as the K doses increased (Figure 1). The third-degree adjustment for P content as a function of K dose was not considered, as there is no biological explanation.
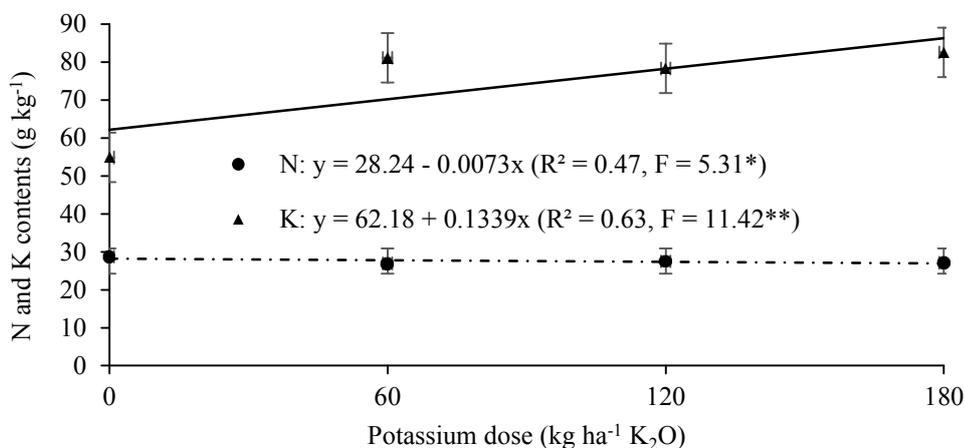
Figure 1. Nitrogen and potassium leaf content as a function of potassium doses.

The N contents were below the range recommended by Trani et al. (2018), which is 30-50 g kg^{-1}. However, no visual symptoms of N deficiency were observed. It was also observed that even with significant adjustment of the equation for N content, the values found were very close and had a low standard deviation, which in practical terms was not relevant

The maximum estimated K content (82.6 g kg^{-1}) was obtained at a dose of 180 kg ha^{-1} of K$_2$O and was 51% higher than the content obtained in the control treatment. The K content found in all treatments was above the 20–40 g kg^{-1} range, considered adequate by Trani et al. (2018). The high leaf content of K in beet confirm the importance of this nutrient for this species, which stores reserves in an underground organ. According to Hawkesford et al. (2012), K has an important role for translocation of photosynthesised sugars and starch biosynthesis. Even with a high K content in the soil (3.2 mmol$_c$ dm^{-3}) and fertilisation of up to 180 kg ha^{-1} of K$_2$O, symptoms of direct (salinity) or indirect (tipburn) K excess were not observed.

The P foliar content ranged from 6.9 to 8.8 g kg^{-1} (Table 2), that is, all P levels were above the range recommended by Trani et al. (2018), of 2-4 g kg^{-1}. These high values found are probably related to the P content found in the soil, which is

considered as medium, and also the phosphate fertilisation performed.

The B leaf content varied from 37 to 42 mg kg^{-1} (Table 2), with no significant difference between K doses. When using 60 and 180 kg ha^{-1} of K$_2$O, the B content was below that recommended by Trani et al. (2018), of 40–80 mg kg^{-1}. These results are similar to the B content (33-49 mg kg^{-1}) identified by Gondim et al. (2015), for 'Early Wonder' beet.

There was no interaction between the factors studied and an isolated effect of K dose on beet yield. Only an isolated effect of the cultivar factor was observed (Table 2). Even with a linear increase in the leaf K content, yield did not increase with the increase in the supply of K to the crop. Probably, the beet's lack of response to increased K doses may be associated with its high content in the soil. This was sufficient to meet the needs of the crop even without supplying K. The lack of response to the application of K in soils with high K content was also found for cabbage (CORREA; CARDOSO; CLAUDIO, 2013)

and lettuce (CECÍLIO FILHO et al., 2015). The lack of relationship between the increase in K leaf content and yield characterises the consumption of the nutrient by beet above its necessity, since the K leaf content was above the range considered appropriate (20-40 g kg^{-1}) by Trani et al. (2018). Therefore, the amount of K present in the soil was sufficient to maximise the productivity of the two cultivars under these growing conditions.

Regarding cultivars, 'Early Wonder' performed better (29710.9 kg ha^{-1}) than 'Kestrel' (26230.5 kg ha^{-1}). Normally, the hybrid cultivar has greater productive potential, which was not found in this study, probably due to the greater adaptation of the non-hybrid cultivar to the climatic conditions of the experimental location.

Regarding beet harvest, the accumulation of nutrients in the shoot and tuberous root parts did not have a significant interaction between the cultivar and K dose factors; however, there was an isolated effect of the factors (Table 3).

Table 3. Summary of the variance analysis for accumulation of N, P, K and B in the shoot (S) and tuberous root (TR) of beet as a function of cultivar and K dose.

Sources of variation	F values							
	N-S	P-S	K-S	B-S	N-TR	P-TR	K-TR	B-TR
Cultivar (C)	34.0**[1]	39.3**	0.2^{ns}	21.7**	9.2**	14.1**	5.8*	4.4*
K dose (K)	0.4^{ns}	0.6^{ns}	0.07^{ns}	1.6^{ns}	2.2^{ns}	5.4**	2.0^{ns}	1.2^{ns}
C x K	0.3^{ns}	0.06^{ns}	0.4^{ns}	0.2^{ns}	0.2^{ns}	2.0^{ns}	2.5^{ns}	0.5^{ns}
CV (%)	25.2	25.7	53.6	41.3	14.9	14.9	29.4	28.7
Cultivar	Means (mg plant^{-1})							
'Early Wonder'	151.2 a	38.3 a	389.7 a	0.2 a	251.0 a	37.3 a	271.3 a	0.43 a
'Kestrel'	88.8 b	21.3 b	357.9 a	0.1 b	213.9 b	30.6 b	210.8 b	0.35 b
Average	-	-	373.8	-	-	-	-	-
MSD	22.3	5.7	147.4	0.05	25.4	3.7	52.2	0.08
Dose of K$_2$O (kg ha^{-1})	Means (mg plant^{-1})							
0	124.2	29.8	383.1	0.18	219.1	31.4	194.9	0.44
60	127.3	32.4	368.9	0.19	231.2	37.7	271.6	0.39
120	112.4	29.6	393.4	0.13	258.2	37.3	266.1	0.34
180	116.2	27.4	349.7	0.15	221.3	29.5	231.5	0.39
Average	120.0	29.8	373.8	0.15	232.5	34.0	241.0	0.39
Regression eq.	ns	ns	ns	ns	ns	Quadr.	Quadr.	ns

1 F test, **: $p \leq 0.01$; *: $p \leq 0.05$; ns: no significant; Quadr.: quadratic equation; CV: coefficient of variation; MSD: minimum significant difference.

There was no adjustment of the polynomial equation for accumulations of N, P, K and B in the beet shoot. The means of N, P, K and B accumulated in the shoot were 120.0, 29.8, 373.8 and 0.15 mg per plant (Table 3), respectively. For tuberous root, a quadratic equation was adjusted for the P and K

accumulations. The maximum accumulations of P and K were 38.4 and 276.8 mg per plant, obtained with 85 and 101 kg ha^{-1} of K$_2$O, respectively (Figure 2). The means of N and B accumulated in the tuberous root were 232.54 and 0.39 mg per plant, respectively (Table 3).
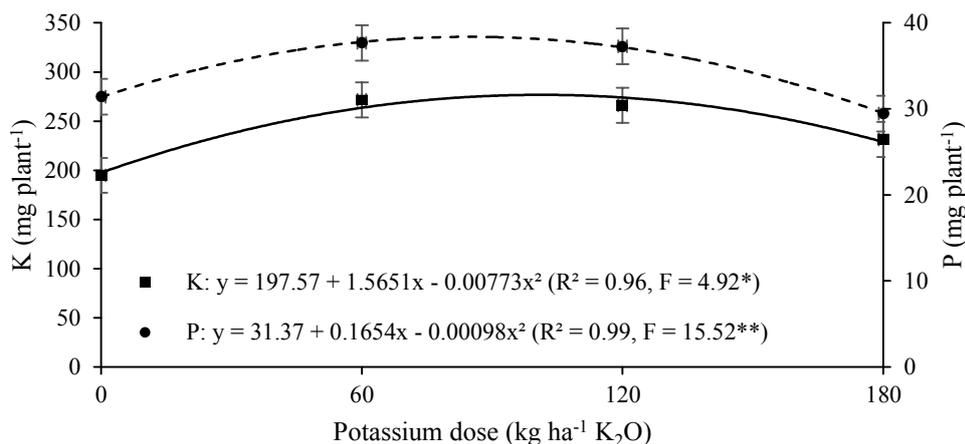
Figure 2. Phosphorus and potassium accumulations in the tuberous root of beet, at harvest, as a function of potassium dose.

In an experiment with the hybrid beet 'Boro', Cardoso et al. (2017) observed, at harvest, N total accumulation of 177.3 mg in the shoot and 481.8 mg in the tuberous root. P was accumulated in a smaller amount among macronutrients, in agreement with that observed by Silva, Silva and Klar (2017). K was the nutrient accumulated in greater quantity by the shoot and tuberous root of beet (Table 3), corresponding to a total of 305 kg ha^{-1} of K and equivalent to 367.5 kg ha^{-1} of K$_2$O. The accumulated amount of B by beet was similar to that obtained by Gondim et al. (2015), when growing beet on substrate.

The observed results determined the order of accumulation by beet, with K > N > P > B, in agreement with the findings other authors (SEDIYAMA et al., 2011; CARDOSO et al., 2017; SILVA; SILVA; KLAR, 2017). Of the total accumulated nutrients, the tuberous root participated with 66% of N, 53% of P, 39% of K and 72% of B. Trani et al. (2013) found that the quantities of macronutrients extracted by beet in kg ha^{-1} (tuberous roots + leaves) were 78-275 N, 18-40 P, 83-476 K.

Although there was no increase in yield of beet cultivars in response to a supply of K up to 180 kg ha^{-1} of K$_2$O, which at first does not justify carrying out potassium fertilisation for the crop when it is cultivated in an Oxisol with a high K content, exports of K by the 'Early Wonder' and 'Kestrel' beet (Table 3) reduced the soil K content by 2.8 and 2.2 mmol$_c$ dm^{-3}, respectively. These reductions caused reclassification of K levels in the soil to a low level for both cultivars, which according to Trani et al. (2018) has a limit of 1.5 mmol$_c$ dm^{-3}. Thus, in order to keep the K content in the soil at a high level, after the beet harvest, it is possible to choose potassium fertilisation with a dose related to the amounts accumulated in the 'Early Wonder' and 'Kestrel' beet roots, that is, 162 and 126 kg ha^{-1} of K$_2$O, respectively.

CONCLUSION

In Oxisol with a high potassium content, it is not recommended to fertilise the cultivation of beet with potassium, as there is no increase in productivity.

In Oxisol with a high potassium content, the yield of both 'Early Wonder' and 'Kestrel' is indifferent to potassium fertilisation, with similar productivity between them.

To maintain soil fertility at a high potassium level, fertilisation with 162 and 126 kg ha^{-1} of K$_2$O is recommended for 'Early Wonder' and 'Kestrel', respectively, doses equivalent to the quantities exported by the beet root.

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