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RESPONSE OF BEET TO PHOSPHORUS RATES IN OXISOL WITH HIGH CONTENT OF THE NUTRIENT[1]

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ABSTRACT – An experiment was carried out aiming to evaluate the effect of phosphorus rates on beet, in an Oxisol with high phosphorus (P) content, in Jaboticabal city, São Paulo, Brazil. The treatments were arranged in a factorial scheme, in a randomized block experimental design with four replicates. The factors evaluated were P rates (0, 120, 240, 360 and 480 kg ha^{-1} P_2O_5) and cultivar ('Early Wonder' and 'Kestrel'). At 50 days after transplanting the seedlings, foliar nitrogen (N), P, potassium (K) and boron (B) contents were evaluated, and there was no effect of the interaction between factors on foliar nutrient contents. The accumulation of these four nutrients was evaluated at harvest. All evaluated nutrients accumulated to higher levels in 'Early Wonder' than in 'Kestrel' both in the shoots and tuberous root. N, P and B accumulated more in the tuberous root whilst K accumulated more in the shoots. P dose did not influence the yield. Therefore, phosphate fertilization is not recommended for beet crop when cultivated in an Oxisol with a high content (88 mg dm^{-3}) of available P.

Keywords: *Beta vulgaris*. Phosphate fertilization. Phosphorus excess. Mineral nutrition. Cultivar.

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

RESUMO – Foi realizado um experimento com o objetivo de avaliar o efeito da dose de fósforo na beterraba, em um Latossolo com alto teor de fósforo (P), na cidade de Jaboticabal, Brasil. Os tratamentos foram arranjados em esquema fatorial, em delineamento experimental de blocos casualizados com quatro repetições. Os fatores avaliados foram dose de P (0, 120, 240, 360 e 480 kg ha^{-1} de P_2O_5) e cultivar ('Early Wonder' e 'Kestrel'). Aos 50 dias após o transplante das mudas, foram avaliados os teores foliares de nitrogênio (N), P, potássio (K) e boro (B). Não houve efeito da interação dos fatores sobre os teores foliares de nutrientes. O acúmulo desses quatro nutrientes foi avaliado na colheita. Todos os nutrientes avaliados acumularam-se em níveis mais elevados na 'Early Wonder' do que na 'Kestrel', tanto na parte aérea quanto na raiz tuberosa. N, P e B acumularam-se preferencialmente na raiz tuberosa, enquanto K acumulou-se mais na parte aérea. A dose de P não influenciou no rendimento. Portanto, a fertilização com fosfato não é recomendada para as culturas de beterraba quando cultivadas em um solo Latossolo com alto teor (88 mg dm^{-3}) de P disponível.

Palavras-chave: *Beta vulgaris*. Fertilização fosfatada. Excesso de fósforo. Nutrição mineral. Cultivar.

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INTRODUCTION

In recent years, there has been increased interest in beet due to its benefits for human health. Modern pharmacology shows that red beet extracts exhibit antihypertensive and hypoglycemic activity and it has also been ranked among the most potent antioxidant vegetables (BABARYKIN et al., 2018). There are a large number of red beetroot-based dietary supplements and functional food on the market (HOBBS et al., 2013; WICZKOWSKI et al., 2018) that may promote health benefits.

Beet is among the top ten vegetables grown in Brazil (SEDIYAMA et al., 2011). However, there is a lack of technical information about its cultural management, above all, regarding fertilization.

Although it is one of the two macronutrients accumulated at low levels by beet, P is applied in large quantities through fertilization because tropical soils have a small amount of available P, acidity and have great potential for P adsorption on the positive charges of aluminum and iron oxides, impairing the availability of the nutrient and its absorption by plants (NOVAIS; SMYTH; NUNES, 2007). However, soils that are commonly cultivated with vegetables and are thus under intense management (acidity correction and fertilization) tend to have high fertility and it is not uncommon to have a high P content. There are few recent studies involving mineral nutrition and phosphate fertilization in beet crops (OLIVEIRA et al., 2016; SILVA; SILVA; KLAR, 2017 and SILVA et al., 2019), and all of them were carried out on soils with low levels of P, which is very different from the conditions, in general, found in large beet-producing areas.

Crops on P-deficient soils will generally respond well to P application; however, if the P content in the soil is above 61 mg dm^{-3} (P-resin), there is often little response of the plant to phosphate fertilization and only maintenance fertilization is recommended to keep the nutrient within the high range (TRANI et al., 2018), although positive responses have been found in broccoli (*Brassica oleracea* var. italica) and cauliflower (*Brassica oleracea* var. botrytis) (CECÍLIO FILHO et al., 2015), lettuce (*Lactuca sativa*) (CECÍLIO FILHO et al., 2018) and tomato (*Solanum lycopersicum*) (CECÍLIO FILHO; TREVIZANELI; RUGELES-REYES, 2020).

In the case of beet, when the P content in the soil is considered high there is wide variation in the recommendation for P-fertilization. Casali (1999) recommended 180 kg ha^{-1} P_2O_5, CQFS-RS/SC (2004) recommended 140 to 180 kg ha^{-1} P_2O_5 and Trani et al. (2018) recommended 180 kg ha^{-1} P_2O_5. Furthermore, the recommendations do not provide information on the possible differentiated responses of cultivars.

Excess P can cause biomass reduction by the interaction with other nutrients and deregulate protein synthesis (BINDRABAN; DIMKPA; PANDEY, 2020). From an environmental point of view, P starts to be considered a pollutant when it is in excess in water resources, because it causes eutrophication and a reduction in the amount of dissolved oxygen in the surface waters, which will probably cause the death of fish and other aquatic organisms (KLEIN; AGNE, 2012).

Soils with a high P content are potential contaminants in water sources due to the erosion process in regions with high rainfall. Therefore, excessive fertilization can contribute negatively to the environment.

In this context, the objective was to evaluate the response of beet cultivars to supply of phosphorus fertilizer when the P level in the Oxisol is high.

MATERIAL AND METHODS

The experiment was carried out in the field from May 26 to September 25, 2017, at São Paulo State University, in Jaboticabal city (21° 14’ 05” S, 48° 17’ 09” W and 615 m.a.s.l.), São Paulo, Brazil. The values of minimum and maximum temperature and rainfall during the experimental period (Table 1) were obtained from the Agroclimatological Station of the university.

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
Augost	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.

Ten treatments were evaluated in randomized blocks with a 5 x 2 factorial scheme and four replications. The treatments resulted from two factors: P doses (0, 120, 240, 360 and 480 kg ha^{-1} P_2O_5) and beet cultivars 'Kestrel' (Sakata) and 'Early Wonder Super Tall Top' (Top Seed/Agristar). The rates were proposed based on the recommendation of Trani and Raij (1997), according to which 180 kg ha^{-1} P_2O_5 should be applied when the P content in the soil is high (> 60 mg dm^{-3}). Each experimental unit had 1.5 m of length and 1.0 m of width. It was composed of six rows, each row with ten pits with two plants, which resulted in 496,000 plants per hectare. The border of each experimental unit corresponded to the plants located in the first and last rows and by the first and last plant of each row.

The soil of the experimental area was classified as an Oxisol. The clay, sand and silt contents corresponded to 615, 253 and 132 g kg^{-1}, respectively, classifying the soil as having very clayey texture. Before planting the soil (layer of 0–20 cm) was analyzed according to Raij et al. (2001) and showed the following attributes: pH 6.0 ($CaCl_2$); 25 g dm^{-3} of organic matter, 88 and 10 mg dm^{-3} of available P and S, respectively; 3.3, 26.0, 16.0, 1.0, 21 and 66.7 mmol$_c$ dm^{-3} of K, Ca, Mg, Al, H+Al and cation exchange capacity, respectively. The P content in the soil was considered high according to the classification of Trani and Raij (1997).

Liming was performed three months before planting of beet aiming to increase the base saturation to 80% as recommended by Trani and Raij (1997). Organic fertilization was not performed. Beds were prepared to receive seedlings of the cultivars. Seedling thinning was performed, leaving two plants per tray cell 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 fertilization was performed as recommended by Trani and Raij (1997). Nitrogen (20 kg ha^{-1} N, urea - 45% N), potassium (60 kg ha^{-1} K_2O, potassium chloride - 60% K_2O), boron (2 kg ha^{-1} B, boric acid - 17% B) and zinc (3 kg ha^{-1} Zn, zinc sulphate - 22% Zn) were applied in the bed.

The P doses established for the treatments were totally applied before transplanting the seedling, using triple superphosphate (41% P_2O_5). As side-dressing, fertilization was divided into two applications, at 20 and 40 days after transplantation, with N (80 kg ha^{-1} N, urea) and K (60 kg ha^{-1} K_2O, potassium chloride).

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

Foliar N, P, K and B contents (g kg^{-1} and mg kg^{-1}) were obtained at 50 days after transplanting. One leaf from each plant of 10 plants per experimental plot was collected to evaluate the nutritional status according to Trani and Raij (1997). The leaves were washed, dried and minced, and the extract was prepared in a laboratory to determine the nutrient contents according to the methodology of Miyazawa et al. (2009).

The accumulations of N, P, K and B in the shoot and tuberous root (mg plant^{-1}) were calculated at harvest. For this, 10 plants per experimental unit were separated into shoot and tuberous root to determine the nutrient contents of each plant part. The nutrient accumulation was calculated by multiplying the dry biomass 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 found in the shoot and tuberous root. As nutrient exportation, it was considered the amount present in the tuberous root.

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

Aiming to estimate yield, firstly, the fresh mass of tuberous root of all plants in the useful area of the experimental unit was measured. Next, the yield (kg ha^{-1}) was estimated considering that 6,200 m^2 of area was really cultivated in one hectare.

Depletion of P content (mg dm^{-3}) in the soil after beet harvest was calculated. For this, the amount of P removed from the soil was calculated considering the accumulated amount of P in the tuberous root, which corresponds to the exported nutrient. This amount was expressed in mg dm^{-3} and it was verified how much soil P depletion was compared to the initial value.

Analysis of variance by F test ($\alpha \leq 5\%$) for both evaluated factors and their interaction was performed according to the experimental design. Additionally, the regression study for P rates was performed. The significant equations of higher order and coefficient of determination were chosen. The AgroEstat statistical program (BARBOSA; MALDONATO JÚNIOR, 2015) was used to perform the statistical analysis.

RESULTS AND DISCUSSION

There was no significant interaction between the factors cultivar and P rate on the leaf contents of the nutrients at 50 days after transplanting, but there was a simple effect of the cultivar (Table 2).

The foliar N contents observed (Table 2) were below the range recommended for beet, which is from 30 to 50 g kg^{-1} (TRANI et al., 2018). Although the values were below this range, there were no visual symptoms of N deficiency in any of the treatments. The observed contents were close to the maximum N content of 32.9 g kg^{-1} observed by Avalhães et al. (2009) when they evaluated the growth of ‘Early Wonder’ beet as a function of P dose.

The foliar P contents observed (Table 2) were higher than the contents considered adequate by Trani et al. (2018), who recommended a range of 2 to 4 g kg^{-1}. The average content of P was high (7.0 g kg^{-1}), even in the control treatment, which contained 6.7 g kg^{-1}. These high values reflect the result of the chemical analysis of the soil for the P content, 88 mg dm^{-3}, which is considered high. However, no symptoms of P toxicity (chlorosis at the edges of old leaves and light roots) were observed, even at the maximum rate of P under which the foliar content was 7.2 g kg^{-1}. The results obtained in this study were similar to those found by Oliveira et al. (2016), who reported a maximum leaf P content of 7.8 g kg^{-1} in an experiment with ‘Early Wonder’ at the fertilization of 333 kg ha^{-1} of P_2O_5.

Table 2. Foliar content of N, P, K and B and yield as a function of cultivar and P rates.

Sources of variation	F values				
	N	P	K	B	Yield
Cultivar (C)	13.7**[1]	36.9**	0.1^{ns}	4.8*	1.90^{ns}
P dose (P)	1.6^{ns}	0.7^{ns}	1.3^{ns}	2.3^{ns}	0.23^{ns}
C x P	0.9^{ns}	0.3^{ns}	2.3^{ns}	1.7^{ns}	0.23^{ns}
CV (%)	9.9	9.8	16.8	29.9	16.52
Cultivar	Means				
	g kg^{-1}			mg kg^{-1}	kg ha^{-1}
‘Early Wonder’	25.2 a	7.7 a	60. 6 a	44.8 a	33011 a
‘Kestrel’	22.5 b	6.4 b	61. 6 a	36.4 b	30717 a
MSD	1.5	0.5	6.6	7.9	3416
P-P_2O_5 dose (kg ha^{-1})	Means				
	g kg^{-1}			mg kg^{-1}	kg ha^{-1}
0	23.9	6.7	57.1	40.3	30298.6
120	22.1	6.9	67.0	36.8	32034.6
240	24.1	7.2	60.7	38.2	32123.7
360	24.3	7.1	57.7	51.8	32488.0
480	24.9	7.2	63.1	35.9	32378.2
MSD	3.4	1.0	15.0	17.7	7689.1

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

The foliar potassium contents observed ranged from 57.1 to 67.0 g kg^{-1} and were higher than those considered adequate by Trani et al. (2018), that is 20 to 40 g kg^{-1}. However, the vast majority of studies in our literature report K contents for beet above the range considered to be adequate (CARDOSO et al., 2017; PASSOS et al., 2020).

The foliar B content ranged from 35.9 to 51.8 mg kg^{-1}; the range recommended by Trani et al. (2018) is 40 to 80 mg kg^{-1}. The doses of 0 and 360 kg ha^{-1} of P_2O_5 led to B contents above 40 mg kg^{-1}. The results found in this study are similar to the levels of B (33 to 49 mg kg^{-1}) found by Gondim et al. (2011), for the ‘Early Wonder’ beet.

There was no interaction between the factors and no simple effect of cultivar and P rate on yield (Table 2). There was no fit of the polynomial equation for the mean yield as a function of the P rate. The average yield corresponded to 31.864 kg ha^{-1}, which is within the appropriate range for the crop, from 30.000 to 50.000 kg ha^{-1} (TRANI et al., 2018).

The difference between the yields without P fertilization and with the maximum P dose was only 2.079,60 kg ha^{-1} of beetroot. The lack of the plant's response to phosphate fertilization, even at high doses, is related to the high available P content (88 mg dm^{-3}) shown by the chemical analysis of the soil. According to Trani et al. (2018), the content found in this soil is considered high and, for this condition, the recommended rate of fertilization is 180 kg ha^{-1} of P_2O_5. A positive response of beet to P rates was observed by Silva et al. (2019), who found maximum yields of 21.71 t ha^{-1} and 22.59 t ha^{-1} for ‘Early Wonder’ and ‘Kestrel’, respectively, in Red-Yellow Argisol with a low P content in the soil (2.0 mg dm^{-3} of P). Oliveira et al. (2016) evaluated the response of beet to rates of P in two growing seasons, in Cambissolo Háplico (250 g kg^{-1} of clay and 2.5 mg dm^{-3} of P), and also obtained a maximum yield with 379 to 400 kg ha^{-1} of P_2O_5.

The nutrient accumulations in the beet shoot and root at harvest were not influenced by the interaction between the factors cultivar and P dose; however, there were simple effects of these two factors. The accumulated amounts of all nutrients evaluated in both the shoot and the tuberous root were significantly higher in 'Early Wonder' than in 'Kestrel' (Table 3).

Table 3. Accumulation of N, P, K and B in the shoot (S) and tuberous root (TR) of beet as a function of cultivar and K

Sources of variaton	F values							
	N-S	P-S	K-S	B-S	N-TR	P-TR	K-TR	B-TR
Cultivar (C)	16.9**[1]	64.2**	44.7**	27.2**	5.7*	20.7**	5.1*	5.5*
P dose (P)	0.54^{ns}	0.7^{ns}	1.6^{ns}	0.8^{ns}	0.2^{ns}	1.4^{ns}	0.6^{ns}	3.2*
C x P	1.5^{ns}	1.3^{ns}	1.0^{ns}	0.7^{ns}	2.1^{ns}	0.5^{ns}	2.4^{ns}	$1.^{ns}$
CV (%)	35.1	18.7	23.8	33.4	16.3	18.8	27.3	15.4
Cultivar	Means (mg plant^{-1})							
‘Early Wonder’	150.3 a	40.9 a	590.1 a	0.17 a	223.3 a	45.0 a	230.7 a	1.06 a
‘Kestrel’	94.5 b	25.2 b	353.4 b	0.10 b	197.5 b	34.3 b	189.9 b	0.94 b
MSD	27.9	4.0	73.0	0.03	22.3	4.9	37.2	0.10
P-P_2O_5 dose (kg ha^{-1})	Means (mg plant^{-1})							
0	108.8	30.3	394.2	0.15	210.6	35.1	184.0	0.89
120	116.3	32.4	509.9	0.15	210.8	39.0	216.3	0.93
240	119.3	34.7	503.3	0.14	212.5	42.4	210.7	1.05
360	130.4	34.1	506.7	0.13	217.3	42.7	218.8	1.03
480	136.6	33.8	446.8	0.12	200.8	39.2	221.5	1.13
MSD	62.7	9.1	164.2	0.07	50.2	10.9	83.7	0.23

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

In the shoot, there was fit of quadratic equation only for K accumulation ($Y = 403.06 + 0.8969x – 0.001691x^2$, $R^2 = 0.90$, $F = 5.26$**), with a maximum (522 mg per plant) at 265 kg ha^{-1} of P_2O_5. In the tuberous root, there was fit of linear equation only for B ($Y = 0.89 + 0.000488x$, $R^2 = 0.89$, $F = 11.5$**) with a maximum of 1.12 mg per plant when 480 kg ha^{-1} of P_2O_5 was supplied.

The amount of N accumulated in the shoot was similar to that found by Oliveira et al. (2017), 106.5 mg per plant. The N absorbed by the tuberous roots is assimilated during the formation of nitrogenous compounds in the plant, with a link between the absorption of N and the increase in yield (OLIVEIRA et al., 2017).

P accumulation in the tuberous root was greater than in the shoot, as also observed by Grangeiro et al. (2007), but unlike that found by Silva, Silva and Klar (2017). The main factors that led to this discrepancy between the results are the type of soil and the amount of P available in the soil. The levels of P in the studies mentioned above were 157 and 2.5 mg dm^{-3}, respectively.

Potassium was the most accumulated nutrient and the contents in the shoot and tuberous root were distributed as 70% and 30% of the total accumulated, respectively. Similar proportions were found by Grangeiro et al. (2007), Silva et al. (2011), Silva, Silva and Klar (2017) and Passos et al. (2020), who also found that K was the most accumulated nutrient.

Regarding B accumulation, it was about seven times higher in the tuberous root (0.8 to 1.1 mg per plant) than in the shoot (0.12 to 0.16 mg per plant). Table 3 shows the difference between the P rates for B content in the tuberous root and this result was not discussed in the results.

Of the total accumulated nutrients (Table 3), the tuberous root of 'Early Wonder' and 'Kestrel' accumulated 59.8 and 67.6 of N, 52.4 and 57.6% of P, 28.1 and 35.0 of K and 86.0 and 90.4% of B, respectively. Therefore, N, P and B accumulated preferentially in the tuberous root, while K accumulated preferentially in the shoot.

Given that phosphate fertilization did not promote an increase in beet yield due to the high P content in the soil, an alternative approach would be to fertilize in order to maintain the P content in the soil. To calculate the amount required, the amount of nutrient exported in the tuberous root needs to be calculated. Thus, for the average yield of the cultivars (31,860 kg ha^{-1}), the exported amounts of P were 45.0 and 34.3 mg per plant of 'Early Wonder' and 'Kestrel', respectively (Table 3) or 22.32 and 17.12 kg ha^{-1} of P (496,000 plants per hectare).

These quantities cause reductions of 11.2 and 8.6 mg dm^{-3} of P in the soil, considering the top 20 cm layer of the soil. However, as the soil P content prior to the experiment installation was 88 mg dm^{-3}, these reductions do not alter the high content of the nutrient in the medium, which according to Trani et al. (2018) exceeds 60 mg dm^{-3}.

In view of the results, neither phosphate fertilization for beet nor fertilization for maintaining the P content in the soil is recommended when the Oxisol has a high P content.

CONCLUSION

In Oxisol with a high phosphorus content (88 mg dm^{-3}), beet does not require fertilization with phosphorus, as there is no increase in productivity.

In Oxisol with a high phosphorus content, the yield of both ‘Early Wonder’ and ‘Kestrel’ is indifferent to phosphorus fertilization, with similar yield for both cultivars.

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