e-ISSN 1983-4063 - *www.agro.ufg.br/pat* - Pesq. Agropec. Trop., Goiânia, v. 54, e77737, 2024

Scientific Note

Alternative sources of phosphorus in beet production aiming at the organic system[1]

Lucas Daniel Pimenta[2], Antonio Ismael Inacio Cardoso[3], Jolinda Mércia de Sá[3]

ABSTRACT

The demand for beet produced in the organic system has increased. This study aimed to evaluate the beet production with the use of different proportions of phosphorus sources. A randomized block design was used. The treatments were established in a 6 x 2 + 1 factorial arrangement, corresponding to 6 proportions of the phosphorus fertilizers Yoorin® thermophosphate (YT) and bone meal (BM) (100 % of P_2O_5 with YT; 80 % of P_2O_5 with YT + 20 % of P_2O_5 with BM; 60 % of P_2O_5 with YT + 40 % with BM; 40 % of P_2O_5 with YT + 60 % with BM; 20 % of P_2O_5 with YT + 80 % with BM; and 100 % of P_2O_5 with BM), 2 doses of P_2O_5 (180 - recommended - and 360 kg ha^{-1}) and 1 control without these phosphorus fertilizers. The plant height, number of leaves, root and shoot fresh and dry weight, transverse and longitudinal root diameter and total root yield were evaluated. The recommended fertilizer dose resulted in higher values, when compared to twice the recommendation. The proportion of 0 % of thermophosphate and 100 % of bone meal provided the highest mean values for the evaluated parameters. High phosphorus doses showed to be harmful to beet production.

KEYWORDS: *Beta vulgaris* L., thermophosphate, bone meal, organic fertilization.

RESUMO

Fontes alternativas de fósforo na produção de beterraba visando ao sistema orgânico

A demanda por beterraba produzida em sistema orgânico tem aumentado. Objetivou-se avaliar a produção de beterraba com a utilização de fontes de fósforo em diferentes proporções, utilizando-se delineamento de blocos ao acaso. Os tratamentos foram arranjados em esquema fatorial 6 x 2 + 1, sendo 6 proporções dos adubos fosfatados termofosfato Yoorin® (TY) e farinha de ossos (FO) (100 % de P_2O_5 com TY; 80 % de P_2O_5 com TY + 20 % com FO; 60 % de P_2O_5 com TY + 40 % com FO; 40 % de P_2O_5 com TY + 60 % com FO; 20 % de P_2O_5 com TY + 80 % com FO; e 100 % de P_2O_5 com FO), 2 doses de P_2O_5 (180 - recomendada - e 360 kg ha^{-1}) + 1 controle sem estes adubos fosfatados. A altura de plantas, número de folhas, massa da matéria fresca e seca de folhas e raiz, diâmetro transversal e longitudinal de raízes e produtividade total de raízes foram avaliados. A dose recomendada resultou em valores superiores, em comparação ao dobro da recomendação. A proporção de 0 % de termofosfato e 100 % de farinha de ossos proporcionou maiores valores médios para as características avaliadas. Altas doses de fósforo mostraram-se prejudiciais ao cultivo de beterraba.

PALAVRAS-CHAVE: *Beta vulgaris* L., termofosfato, farinha de ossos, adubação orgânica.

Beet or beetroot (*Beta vulgaris* L.), a species of the Quenopodiaceae family, is one of the main vegetables produced in Brazil. It is rich in iron, sodium, potassium, vitamin A and vitamin B complex, and can be cultivated for sugar production, human consumption or used as animal feed (Tivelli & Trani 2008).

For beet, phosphate fertilizers favor the adequate development of tuberous roots, contributing to the achievement of a better yield and quality of the commercial product, such as a higher content of soluble solids and adequate sugar content (Mahmoud et al. 2014, Bouras et al. 2021). Furthermore, phosphorus is an essential nutrient for the cellular metabolism of plants, as it is directly related to the transfer of energy during important plant growth processes, such as photosynthesis, respiration, carbohydrate metabolism and nitrogen fixation, among others (Ghaly et al. 2019).

In recent years, the demand for beet produced in the organic system has increased. Despite this market growth, little information is currently found in the literature on the influence of organic fertilization on the beet production (Magro et al.

[1] Received: Nov. 10, 2023. Accepted: Feb. 15, 2024. Published: Mar. 25, 2024. DOI: 10.1590/1983-40632024v5477737.
[2] Universidade Estadual Paulista, Department of Rural Engineering, Botucatu, SP, Brazil.
E-mail/ORCID: lucas.pimenta@unesp.br/0009-0001-1952-8484.
[3] Universidade Estadual Paulista, Department of Horticulture, Botucatu, SP, Brazil.
E-mail/ORCID: antonio-ismael.cardoso@unesp.br/0000-0003-3251-9491; jolinda.sa@unesp.br/0000-0003-4953-2641.

2015). This information is necessary to optimize the use of nutrients, mainly phosphate fertilizers, since phosphorus is a scarce and limited natural resource.

The use of natural phosphates has increased because they are products cheaper than inorganic ones and have agronomic efficiency, providing the nutrient along the cycle, promoting a high yield, and, depending on the source, can be used both in conventional and organic systems (Cardoso et al. 2019).

Despite not being often the nutrient most accumulated by plants, including beet (Cardoso et al. 2017), phosphorus is applied in large quantities, since, in general, most of the soils in Brazil have acid reaction, low fertility and high phosphorus retention capacity, leading to the need to apply high doses of this macronutrient, causing negative impacts on production costs (Cecílio Filho et al. 2015, Nowaki et al. 2017, Cardoso et al. 2019). In addition, because it is applied in large quantities at each cultivation season, it is common for soils with intensive vegetable production to have high levels of this nutrient, and yet producers continue to apply phosphorus in each new production cycle (Cecílio Filho et al. 2015).

The phosphate fertilizers most used in vegetable production are simple and triple superphosphates (Cardoso et al. 2019), or formulated in which they are used with sources of nitrogen and potassium. However, these sources are not allowed in the fertilization of organic vegetables. In this scenario, one of the fertilizers most frequently used in organic production systems as a source of phosphorus is thermophosphate, due to its low aggressiveness to the soil. Accordingly, the use of Yoorin® thermophosphate as a phosphorus source has increased, given its mineral origin and the authorization for its use in organic cultivation (Riveros et al. 2021).

There are also other sources of phosphorus used in organic agriculture, such as bone meal, which has low solubility in water and good solubility in weak acids, resulting in the slow release of P to the soil, decreasing its adsorption (Cavallaro Júnior 2006, Ferreira & Balbino 2014). Bone meal is an alternative to supply phosphorus needs without using natural sources which are finite. In addition, the use of this material allows the reuse of a product that would otherwise be discarded in the environment and would become waste (Jupp et al. 2021).

However, although these P sources have been used in organic cultivation systems, there is scarce information available in the scientific literature about their use in vegetable production, and no information at all regarding beet. In addition, because they show different rates of P release into plants, using a mixture of phosphorus sources could be more advantageous than relying on a single source.

From this perspective, this study aimed to evaluate the production of beet using sources and proportions of phosphate fertilizers.

The research was conducted at the São Manuel experimental farm, owned by the Universidade Estadual Paulista, in Botucatu, São Paulo state, Brazil (22º46’28’’S, 48º34’37’’W and altitude of 750 m). According to the Köppen classification, the local climate is *Cfa*, corresponding to a warm, temperate (mesothermal) and humid climate. The average monthly rainfall during the experiment (06/21/2021 to 09/19/2021) was 113.4 mm, whereas the average maximum and minimum temperatures were 25.8 and 13.3 ºC, respectively (Ciiagro 2021).

The soil of the experimental area is classified as a Typical Dystrophic Red Ferralsol with sandy texture (Embrapa 2013) or Ferralsol (FAO 2022). The main soil chemical characteristics (0-20 cm) were determined by collecting a sample in the area before the implementation of the experiment, with the following results: pH($CaCl_2$) = 6.0; organic matter = 11.0 g dm^{-3}; P_{resin} = 123.0 g dm^{-3}; base saturation (V) = 73.0 %; Al^{3+} = 0.0 $mmol_c$ dm^{-3}; H + Al = 13.0 $mmol_c$ dm^{-3}; K = 2.4 $mmol_c$ dm^{-3}; Ca = 29.0 $mmol_c$ dm^{-3}; Mg = 5.0 $mmol_c$ dm^{-3}; SB = 37.0 $mmol_c$ dm^{-3}; CEC = 50.0 $mmol_c$ dm^{-3}. The phosphorus content (123 g dm^{-3}) is considered high, according to Trani et al. (1997).

The experimental design was randomized blocks, with five replications and plots measuring 1 m². Thirteen treatments were evaluated, resulting from a 6 x 2 + 1 factorial arrangement, corresponding to six proportions of two phosphate fertilizers allowed in the organic system [Yoorin® thermophosphate and bone meal x two doses of phosphorus - the recommended dose of 180 kg ha^{-1} (Trani et al. 1997) and twice this value]. The studied proportions were: 100 % of P_2O_5 with Yoorin® thermophosphate; 80 % of P_2O_5 with Yoorin® thermophosphate + 20 % of P_2O_5 with bone meal; 60 % of P_2O_5 with Yoorin® thermophosphate + 40 % with bone meal; 40 % of P_2O_5 with Yoorin® thermophosphate + 60 % with bone meal; 20 % of P_2O_5 with Yoorin® thermophosphate + 80 % with bone meal; and 100 % of P_2O_5 with bone meal. The phosphate fertilizers were analyzed for their chemical characteristics (Table 1).

Soil correction was not necessary, as the base saturation (V = 73 %) was adequate for the beet crop. The plant beds were raised (1.0 x 70.0 x 0.25 m) after the application of chicken manure (12 t ha^{-1}) and castor bean cake (460 kg ha^{-1}) over the entire area. Then, in each plot, the phosphate fertilizers were applied (according to each treatment) and incorporated into the soil with a hoe. The phosphate fertilization was carried out one week before transplanting the seedlings.

The seedlings were produced in conventional seed germination trays, using the beet hybrid Cabernet. Transplanting was carried out on 06/21/2021, observing a spacing of 25 cm between rows and 10 cm between plants, with 40 plants $plot^{-1}$ (4 rows with 10 plants row^{-1}).

At 30 days after transplanting, topdressing fertilization was carried out with castor bean cake (480 kg ha^{-1}). Weed control was performed using a hoe. It was not necessary to control pests or diseases, and a micro sprinkler irrigation system was adopted, operating with approximately 4 mm of water per day in the absence of rain.

The harvest was carried out on 09/19/2021, and the following characteristics were evaluated in five plants of the central rows per plot: number of leaves, determined by counting the expanded and fully formed leaves, with results expressed in number of leaves per plant; plant height, measured in centimeters with a ruler from the base to the top of the plant stem; shoot and root fresh weight, obtained after the plants were separated into shoots and roots and weighed in a semi-analytical precision scale (0.1 g); root length and diameter, measured with a caliper, with the length being measured from the upper to the lower end of the roots; shoot and root dry weight, for which each plant part was placed in kraft paper bags and later oven-dried to constant weight at 65 ºC (for approximately 72 h). Then, the dried plant material was weighed in a precision analytical scale (0.001 g).

The data were subjected to analysis of variance, and a regression was adjusted for the proportions factor. The doses were compared by the Tukey test (5 %), using the Sisvar software (Ferreira 2011).

The number of leaves per plant and plant height did not differ for the phosphorus proportions or doses (Table 2). The average number of leaves per plant (11.3 leaves) and the average plant height (25.6 cm) were similar to those reported by other authors (Corrêa et al. 2014, Candian et al. 2016, Silva et al. 2018, Aguilar et al. 2021), demonstrating that the plants were not restricted, regarding shoot development.

There was no difference among the proportions of phosphate fertilizers at the highest dose for root dry mass (360 kg ha^{-1} of P_2O_5), with average of

Table 1. Chemical analysis of Yoorin® thermophosphate (YT), bone meal (BM), castor bean cake (CB) and chicken manure (CM).

Fertilizers	pH	OM	C/N	N	P	K	Mg	Ca	S	B	Cu	Mn	Zn	Fe
		%		%						mg kg^{-1}				
YT	-	-	-	-	17.00	-	8.00	19.00	-	-	-	-	-	-
BM	6.2	11.0	6/1	0.36	13.62	0.70	0.65	8.81	4.00	0.0	82.0	414.0	279.0	19,082
CB	5.7	35.3	4/3	4.80	1.87	1.22	0.71	2.59	0.22	14.5	330.0	230.0	33.0	4,194
CM	7.5	11.0	8/1	0.75	3.92	0.30	0.58	10.94	0.08	0.0	64.0	471.0	353.0	7,172

Table 2. Mean values for number of leaves per plant (NL), shoot height (SH), shoot (SFM) and root (RFM) fresh mass, root longitudinal (LD) and transversal (TD) diameter, shoot (SDM) and root (RDM) dry mass, and total yield (TY) of roots of sugar beet, as a function of the doses of phosphate fertilizers.

Dose kg ha^{-1}	NL	SH cm	SFM	RFM	LD	TD	SDM	RDM	TY t ha^{-1}
			g		mm		g		
180	11.2 a*	25.6 a	54.7 a	151.0 a	62.7 a	62.3 a	13.3 a	43.6 a	6.6 a
360	11.4 a	25.5 a	50.0 a	128.8 b	60.7 a	62.3 a	10.4 b	37.6 b	5.6 b
CV (%)	13.1	10.1	21.8	23.2	10.9	8.7	8.0	7.4	23.2

* Means followed by the same lowercase letter, in the column, do not differ statistically by the Tukey test (p ≤ 0.05).

37.5 g plant^{-1}. On the other hand, for the lowest dose (180 kg ha^{-1} of P_2O_5), the highest dry mass was obtained with the use of 100 % of phosphorus with bone meal, while the lowest root dry mass was obtained with 100 % of phosphorus and thermophosphate (Figure 1), representing a difference of 28 %.

For root fresh mass (Figure 2), shoot dry mass (Figure 3) and yield (Figure 3), the data fit the

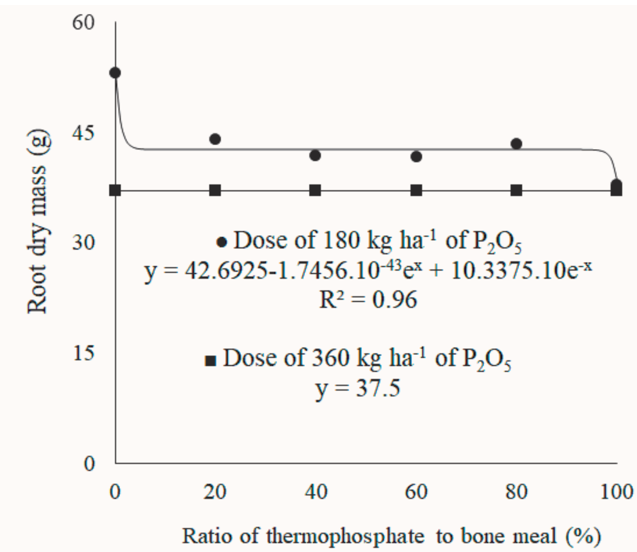

Figure 1. Root dry mass of sugar beet, as a function of phosphorous doses and proportions of Yoorin® thermophosphate, in relation to bone meal.

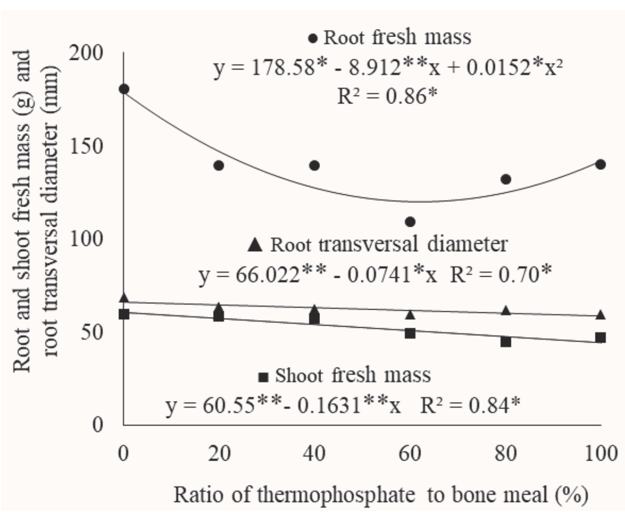

Figure 2. Root and shoot fresh mass and transversal diameter of beet, as a function of Yoorin® thermophosphate proportions, in relation to bone meal. * and **: significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F test.

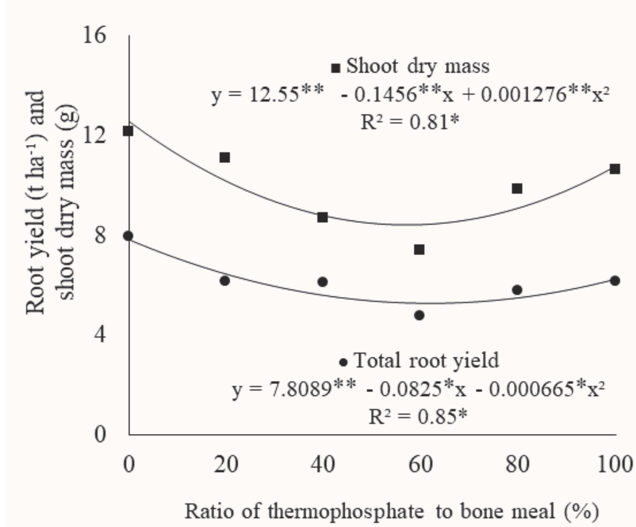

Figure 3. Shoot dry mass and root yield of beet, as a function of Yoorin® thermophosphate proportions, in relation to bone meal. * and **: significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F test.

quadratic model, with higher values being achieved when using 100 % of phosphorus applied with bone meal. For root diameter (Figure 2), the decrease in the values was linear, with higher values obtained when using 100 % of phosphorus applied with bone meal.

There was no difference between the doses for shoot fresh mass. However, a 26 % reduction was observed at the highest thermophosphate proportion (Figure 2), changing from 60.6 to 44.3 g, when using 100 % of bone meal and 100 % of thermophosphate, respectively. Despite the differences in fresh matter values, the observed values (average of 52.4 g plant^{-1}, ranging from 44.3 to 60.6 g) were also similar to those reported by Corrêa et al. (2014), Candian et al. (2016), Silva et al. (2018) and Aguilar et al. (2021), showing that, even in the treatment where the lowest values were observed (100 % of phosphate fertilization with thermophosphate), these are within the normal range reported by these authors.

When comparing the doses (Table 2), in addition to the vegetative parameters of the shoot part, there was also no difference for root length and diameter. On the other hand, for root fresh and dry mass, shoot dry mass and yield, higher values were obtained at the lowest dose of phosphorus (180 kg ha^{-1} of P_2O_5).

The fact that when there was a significant difference between the phosphorus doses the superiority was for the lowest dose shows that there is really no need for greater amounts of this nutrient. It was expected that, because these are organic sources with a slow nutrient release, when compared to inorganic fertilizers (e.g., single and triple superphosphate), higher doses could possibly yield better results. But, as the initial phosphorus content (123 g dm^{-3}) was high, doses higher than the recommended ones would not lead to better results.

According to Marschner (1995) and Cecílio Filho et al. (2015), phosphorus in excess can cause nutritional unbalance in the plant and micronutrient deficiency, especially for zinc, resulting in a lower yield, mainly in soil rich in P, as observed for beet in this research and for cauliflower (Cecilio Filho et al. 2015), tomato (Cecílio Filho et al. 2020) and arugula (Nascimento et al. 2020). Besides a possible yield reduction, the excess of P fertilization can promote environmental pollution and increased production costs (Zhang et al. 2019, Nascimento et al. 2020). According to Nascimento et al. (2020), besides zinc, the excess of phosphorus fertilization can affect the absorption of other nutrients such as copper, iron and manganese, resulting in a lower yield. So, the eventual phosphorus toxicity is not common (Malhotra et al. 2018), being more common the nutritional unbalance in the plant.

Phosphorus is an important nutrient for agriculture, due to its role as an essential macronutrient for plants (Malavolta 2006). The presence of phosphorus in the plant becomes indispensable, with its absence resulting in plant growth reductions, in addition to the risk of chlorosis on leaves and interveinal necrosis, mainly observed in older leaves. In adequate proportions, phosphorus favors root development and increases the uptake of water and other nutrients available in the soil, thus favoring the yield of harvested products (Fageria et al. 2017).

In a research with industrial-type tomatoes, Cecílio Filho et al. (2020) reported an increase in fruit yield when using up to 400 kg ha^{-1} of P_2O_5 in a soil rich in phosphorus (145 mg dm^{-3}). However, there were great production losses at higher levels, with the dose of 1,000 kg ha^{-1} of P_2O_5 resulting in a lower yield than in the treatment without phosphorus application, what shows that the excess of phosphorus can be harmful. In another study, Coutinho et al. (2014) reported an increase in the production of commercial tomato in a soil with average phosphorus contents (23 mg dm^3), with the application of up to 290 kg ha^{-1} of P_2O_5, decreasing at higher doses. Zhang et al. (2007) and Nowaki et al. (2017) did not observe a significant effect of phosphorus doses on the commercial yield of mustard and tomato, respectively, in soils with high levels of phosphorus.

According to Cecílio Filho et al. (2015), it is common to find soils with high levels of phosphorus in areas where vegetables are grown, mostly with a short cycle and with high phosphorus doses applied in each season. Thus, when applied in doses greater than the recommended one or consecutively without analyzing its levels, the applications become inefficient and may even impair the production, as reported by Nascimento et al. (2020), who observed a reduction in arugula yield at higher phosphorus doses (0-300 kg ha^{-1} of P_2O_5), in a soil rich in this nutrient (115 mg dm^{-3}). In the area where their research was carried out, despite having remained fallow for about three months, the soil had been used to produce vegetables for several years, always with phosphorus fertilization before the planting of each crop.

From the results obtained, it is observed that, in a soil with high phosphorus contents, it may not be necessary to apply phosphate fertilizers for each new crop, what can further increase the nutrient's level in the soil and eventually become a problem, with reduced yield and increased production costs.

For soils with high initial phosphorus contents, phosphate fertilization can be discarded and, if applied at a high dose, this nutrient can even negatively affect the production.

REFERENCES

AGUILAR, A. S.; VASQUE, H.; CARDOSO, A. I. I.; BARDIVIESSO, E. M.; PELVINE, R. A.; BEZERRA, S. R. B.; NASSER, M. D.; PUTTI, F. F.; LEMES, E. M. Beet production using vermiculite incorporated with Dystrophic Red Latosol (Oxisol). *Research, Society and Development*, v. 10, n. 1, e26810111157, 2021.

BOURAS, H.; BOUAZIZ, A.; BOUAZZAMA, B.; HIRICH, A.; CHOUKR-ALLAH, R. How phosphorus fertilization alleviates the effect of salinity on sugar beet (*Beta vulgaris* L.) productivity and quality. *Agronomy*, v. 11, n. 8, e1491, 2021.

CANDIAN, J. S.; SPADONI, T. B.; CARDOSO, A. I. I.; WATANABE, C. Y.; PINTO, L. A. T. C. Influência do sulfato de magnésio na produção da beterraba. *Revista de Biologia e Ciências da Terra*, v. 16, n. 2, p. 58-65, 2016.

CARDOSO, A. I. I.; MAGRO, F. O.; OLIVEIRA JUNIOR, M. X.; ABRAAO, C.; TAVARES, A. E. B.; FERNANDES,

D. M. Accumulation of macronutrients in beetroot plant. *Horticultura Brasileira*, v. 35, n. 3, p. 328-334, 2017.

CARDOSO, A. I. I.; SILVA, P. N. L.; COLOMBARI, L. F.; LANNA, N. B. L.; FERNANDES, D. M. Phosphorus sources associated with organic compound in broccoli production and soil chemical attributes. *Horticultura Brasileira*, v. 37, n. 2, p. 228-233, 2019.

CAVALLARO JÚNIOR, M. L. *Fertilizantes orgânicos e minerais como fontes de N e de P para produção de rúcula e tomate*. 2006. Dissertação (Mestrado em Tecnologia da Produção Agrícola) - Instituto Agronômico de Campinas, Campinas, 2006.

CECÍLIO FILHO, A. B.; SILVA, L. P. A.; MENDOZA-CORTEZ, J. W.; BARBOSA, J. C. Cauliflower and broccoli productivity as influenced by phosphorus fertilizer doses in a P-rich soil. *Australian Journal of Crop Science*, v. 9, n. 8, p. 709-712, 2015.

CECÍLIO FILHO, A. B.; TREVIZANELI, B.; RUGELES-REYES, S. M. Phosphorus (P) improves industrial tomato quality and yield in soil with high phosphorus content. *Australian Journal of Crop Science*, v. 14, n. 8, p. 1335-1341, 2020.

CENTRO INTEGRADO DE INFORMAÇÕES AGROMETEOROLÓGICAS (Ciiagro). *Cartas climáticas básicas*. 2021. Available at: http://www.ciiagro.org.br/ema/index.php?id=263. Access in: Mar. 2024.

CORRÊA, C. V.; CARDOSO, A. I. I.; SOUZA, L. G.; ANTUNES, W. L. P.; MAGOLBO, L. A. Produção de beterraba em função do espaçamento. *Horticultura Brasileira*, v. 32, n. 1, p. 111-114, 2014.

COUTINHO, E. L. M.; ORIOLI JÚNIOR, V.; SILVA, E. J. da; COUTINHO NETO, A. M.; CARDOSO, S. S. Nutrición, producción y calidad de frutos de tomate para procesamiento en función de la fertilización con fósforo y potasio. *Agrociencia*, v. 18, n. 2, p. 40-46, 2014.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (Embrapa). Centro Nacional de Pesquisa de Solos. *Sistema brasileiro de classificação de solos*. 3. ed. Brasília, DF: Embrapa, 2013.

FAGERIA, K. N.; VIRUPAX, Z. H.; BALIGAR, C. *Phosphorus management in crop production*. Boca Raton: CRC Press, 2017.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, v. 35, n. 6, p. 1039-1042, 2011.

FERREIRA, E.; BALBINO, T. *Carta de cores para a avaliação qualitativa da farinha de ossos calcinada*. Titular: Instituto Nacional de Propriedade Industrial. BR2020140083923. Depósito: 07 abr. 2014.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). *World reference base for soil resources*: international soil classification system for naming soils and creating legends for soil maps. 4. ed. Vienna: IUSS, 2022.

GHALY, F.; ABD-HADY, M.; ABD-ELHAMIED, M. Effect of varieties, phosphorus and boron fertilization on sugar beet yield and its quality. *Journal of Soil Science and Agricultural Engineering*, v. 10, n. 2, p. 115-122, 2019.

JUPP, A. R.; BEIJER, S.; NARAIN, G. C.; SCHIPPER, W.; SLOOTWEG, J. C. Phosphorus recovery and recycling: closing the loop. *Chemical Society Reviews*, v. 50, n. 1, p. 87-101, 2021.

MAGRO, F. O.; GASPARETTO, E.; TAKATA, W. H.; CARDOSO, A. I. I.; FERNANDES, D. M.; EVANGELISTA, R. M. Organic compost and potassium top dressing fertilization on production and quality of beetroot. *Australian Journal of Crop Science*, v. 9, n. 10, p. 962-967, 2015.

MAHMOUD, E. A.; RAMADAN, B. S. H.; EL-GEDDAWY, I. H.; KORANY SAMAH, F. Effect of mineral and bio-fertilization on productivity of sugar beet. *Journal of Plant Production*, v. 5, n. 4, p. 699-710, 2014.

MALAVOLTA, E. *Manual de nutrição de plantas*. São Paulo: Agronômica Ceres, 2006.

MALHOTRA, H.; SHARMA, S.; PANDEY, R. Phosphorus nutrition: plant growth in response to deficiency and excess. *In*: HASANUZZAMAN, M.; FUJITA, M.; OKU, H.; NAHAR, K.; HAWRYLAK-NOWAK, B. (ed.). *Plant nutrients and abiotic stress tolerance*. Singapore: Springer, 2018. p. 171-190.

MARSCHNER, H. *Mineral nutrition of higher plants*. London: Academic Press, 1995.

NASCIMENTO, C. S.; NASCIMENTO, C. S.; CECÍLIO FILHO, A. B. Agronomic performance of rocket as a function of phosphorus fertilisation in a P-rich soil. *Revista Caatinga*, v. 33, n. 3, p. 860-864, 2020.

NOWAKI, R. H.; PARENT, S. E.; CECÍLIO FILHO, A. B.; ROZANE, N. B. M.; SILVA, J. A.; NATALE, W.; PARENT, L. Phosphorus overfertilization and nutrient misbalance of irrigated tomato crops in Brazil. *Frontiers in Plant Science*, v. 8, e825, 2017.

RIVEROS, J. T.; JUNQUEIRA, A. M. R. ; SOARES, J. P. G.; SAMPAIO, E. Insumos para a produção orgânica: um estudo entre Paranoá, Distrito Federal, Brasil e Granada, Meta, Colômbia. *Nature and Conservation*, v. 3, n. 4, p. 120-136, 2021.

SILVA, P. N. L.; LANNA, N. B. L.; CARDOSO, A. I. I. Doses de bokashi em cobertura na produção de beterraba. *Revista de Agricultura Neotropical*, v. 5, n. 1, p. 28-34, 2018.

TIVELLI, S. W.; TRANI, P. E. *Hortaliças*: beterraba (*Beta vulgaris* L.). 2008. Available at: www.infobibos.com/artigos/2008_3/beterraba/index.htm. Access on: July 07, 2020.

TRANI, P. E.; PASSOS, F. A.; TAVARES, M.; AZEVEDO FILHO, J. A. Beterraba, nabo, rabanete e salsa. *In*: RAIJ, B.; CANTARELLA, H.; QUAGGIO, J. A.; FURLANI, A. M. C. (ed.). *Recomendações de adubação e calagem para o estado de São Paulo*. 2. ed. Campinas: IAC, 1997. p. 174. (Boletim técnico, 100).

ZHANG, X. S.; LIAO, H.; CHEN, Q.; CHRISTIE, P.; LI, X. L.; ZHANG, F. S. Response of tomato on calcareous soils to different seedbed phosphorus application rates. *Pedosphere*, v. 17, n. 1, p. 70-76, 2007.

ZHANG, Y.; XIE, D.; NI, J.; ZENG, X. Optimizing phosphate fertilizer application to reduce nutrient loss in a mustard (*Brassica juncea* var. tumida)-maize (*Zea mays* L.) rotation system in Three Gorges Reservoir area. *Soil and Tillage Research*, v. 190, n. 1, p. 78-85, 2019.