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REGULAR ARTICLE

Parsley production using organic sources of phosphorus

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Autor contribution
GGM: Conceptualization, Experimental data collection, Data custody, Literature review, Writing the manuscript; DCML: Experimental data collection, Literature review; ISSS: Experimental data collection; LDP: Experimental data collection; EPS: Data analysis, Manuscript Review; AIIC: Manuscript Review, Supervision.

Abstract

Parsley is a condiment produced mainly by small producers, often in the organic system. Organic fertilizers make nutrients slowly available to plants when compared to inorganic fertilizers, an important quality for phosphorus (P), which is a nutrient that tends to fixate and adsorption. Thus, the objective of this work was to evaluate the production of parsley with the use of organic sources of phosphorus in different proportions. Fourteen treatments were evaluated, resulting from the factorial 6 x 2 + 2: six proportions of two phosphate fertilizers (thermophosphate Yoorin® (TY) and bone meal (BM)), two doses (recommended (180 kg.ha^{-1} of P_2O_5, and double this) + two controls (without phosphate fertilizer; and with inorganic triple superphosphate fertilizer (recommended dose)). The proportions were: 100% P with TY; 80% P with TY + 20% with BM; 60% P with TY + 40% with BM; 40% P with TY + 60% with BM; 20% P with TY + 80% with BM; 100% P with BM. Shoot height, number of leaves, fresh and dry weight of leaves in two harvests and the total of these two harvests were evaluated. No significant differences were obtained in the two harvests. The lack of effect to phosphate fertilization may be related to the high initial P content in the soil (123 mg.dm^{-3}), which shows that in this case, fertilization with this nutrient is not necessary to produce parsley, despite the official recommendation to fertilize with phosphorus in a soil with a high P content.

Keywords

Bone meal; Organic farming; *Petroselinum crispum*; Thermophosphate.

Introduction

In recent decades, vegetables have become part of the population's eating habits more assiduously, thus, there is a need for the supply of these foods by the producer (Andriolo, 2017). Among the great diversity of cultivated vegetable species, parsley (*Petroselinum crispum*) has been gaining importance as a condiment plant. It also has great social importance, being produced mainly by small producers, often in an organic system.

According to Lima et al. (2020), the average annual growth in retail sales of organic products in the world has been greater than 11% since 2000, which expresses the dynamism and promising future of this sector, especially when this result is compared to data on sales of non-organic horticultural products.

The use of organic fertilizers allows a slower availability of nutrients, compared to inorganic fertilizers, an important characteristic when it comes to phosphorus (P), due to the nutrient tending to fixation and adsorption. In this way, when the release occurs slowly, there is an increase in the chance of absorption by the plant throughout its cycle (Shaji et al., 2021).

Phosphorus is of great importance in plant development, acting in photosynthesis, respiration, energy storage and transfer, cell division, among other processes, and its presence in adequate levels in the soil solution enhances the production of vegetables (Matos et al., 2016; Cardoso et al., 2019).

Considering that most Brazilian soils are acidic, with low fertility and high P retention capacity, fertilization with high doses of phosphate fertilizers is necessary. However, in areas of intensive cultivation of vegetables it is common to find high levels of P (Cecílio Filho et al., 2015) and even so to carry out fertilization with this nutrient. Since phosphorus is a natural and finite resource, excessive use is not sustainable and, therefore, studies on optimizing its use are necessary to achieve sustainable agriculture (Cardoso et al., 2019).

Commonly used as sources of phosphorus in conventional agriculture, superphosphates (simple and triple) are not allowed in the organic cultivation system. In this system only natural sources of phosphorus are allowed, among them thermophosphate Yoorin®. Its production process is based on the fusion of phosphate rocks, enriched with magnesium and silicon, and the presence of silicates protects phosphorus from fixation by iron, aluminum and manganese oxides present in the soil. It also has the characteristic of being soluble in the

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presence of weak acids in the soil and roots, thus making nutrients available according to plant demand (Yoorin, 2023).

Another organic phosphate fertilizer option is bone meal, which is a by-product of slaughtering animals in slaughterhouses. It has low solubility in water and good solubility in weak acids, which results in the release of P into the soil more slowly, reducing its fixation. In addition, the use of this material allows the sustainable use of a product that would be discarded and would become a waste, and bone meal is an alternative to meet phosphorus needs without the need to use natural sources that are finite.

Although these products are used by producers in the organic system, there is little scientific information about their use. In addition, because they present different rates of P release to the plants, the use of a mixture of these sources may be more advantageous than the use of only one source. However, research is needed with these fertilizers to be able to recommend their use, mainly in cultures with a relatively short cycle such as parsley and in areas of intensive cultivation, where, many times, the levels of P in the soil are high and even thus, there is the application of fertilizers in large quantities. Given the above, the objective of this work was to evaluate the production of parsley using different sources and proportions of phosphate fertilizers in the organic cultivation system.

Materials and Methods

The experiment was conducted at the Experimental Farm of UNESP, located in São Manuel/SP (latitude: 22° 44' 52" South; longitude: 48° 35' 1"; altitude: 740m). The soil where the experiment was installed is a Typical Dystrophic Red Latosol, sandy texture. A chemical analysis of the soil (0-20 cm) was carried out and the results are shown in Table 1.

Experimental design and treatments

Fourteen treatments were evaluated, resulting from the factorial 6 x 2 + 2, with 6 proportions of 2 phosphate fertilizers allowed in the organic system (thermophosphate Yoorin® (TY) and bone meal (BM)), 2 doses (recommended and double this) + 2 controls (without phosphate fertilization; and with inorganic fertilization with triple superphosphate (TS) at the recommended dose). Treatments are described in Table 2. According to the soil analysis, the recommended dose was 180 $kg.ha^{-1}$ of P_2O_5 (Raij et al., 1997). In the treatment with TS, urea (20 $kg.ha^{-1}$ of N) and potassium chloride (120 $kg.ha^{-1}$ of K_2O) were also used. The experimental design was in randomized blocks, with five replications and plots of 1 m^2.

To calculate the amount of each phosphate fertilizer, chemical analyzes were carried out. The results of the chemical analysis of thermophosphate Yoorin® and bone meal are described in Table 3.

Table 1. Results of chemical analysis of the soil (0-20 cm).

pH $CaCl_2$	O.M. $g.dm^{-3}$	P_{resin} $mg.dm^{-3}$	V %	Al^{3+}	H+Al	K	Ca	Mg	SB	CEC
				----------	----------	----------	$mmol_c.dm^{-3}$	----------	----------	
6.0	11	123	73	0	13	2.4	29	5	37	50

O.M. = organic matter; V = base saturation; SB = sum of bases; CEC = cation exchange capacity

Table 2. Treatments tested.

Treatments	Proportions	Doses
1	100% TY	180 kg P_2O_5 ha^{-1}
2	80% TY + 20% BM	180 kg P_2O_5 ha^{-1}
3	60% TY + 40% BM	180 kg P_2O_5 ha^{-1}
4	40% TY + 60% BM	180 kg P_2O_5 ha^{-1}
5	20% TY + 80% BM	180 kg P_2O_5 ha^{-1}
6	100% BM	180 kg P_2O_5 ha^{-1}
7	100% TY	360 kg P_2O_5 ha^{-1}
8	80% TY + 20% BM	360 kg P_2O_5 ha^{-1}
9	60% TY + 40% BM	360 kg P_2O_5 ha^{-1}
10	40% TY + 60% BM	360 kg P_2O_5 ha^{-1}
11	20% TY + 80% BM	360 kg P_2O_5 ha^{-1}
12	100% BM	360 kg P_2O_5 ha^{-1}
Control 1	without phosphate fertilization	0 kg P_2O_5 ha^{-1}
Control 2	inorganic fertilization	180 kg P_2O_5 ha^{-1}

TY = thermophosphate Yoorin®; BM = bone meal.

Table 3. Results of chemical analysis of termophosphate Yoorin® and bone meal.

	pH	H	O.C.	O.M.	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn	Fe	C/N
		--------	--------	--------	--------	%	--------	--------	--------	--------		--------	$mg.kg^{-1}$	--------		
TY	6.2	14	7	11	0.96	13.7	0.7	8.8	0.65	4	0	82	414	279	19082	6.1
BM	-	-	-	-	0	17	0	19	8	0	0	0	0	0	0	-

TY = thermophosphate Yoorin®; BM = bone meal; H = humidity; O.C. = organic carbon; O.M. = organic matter.

Preparation and conduction of the experiment

After preparing the beds (1.0 m wide and 0.2 m high) (Figure 1), the fertilizers were spread over the surface of each plot (1 m^2), in the amounts defined for each treatment, in addition to poultry manure (1250 $g.m^{-2}$, throughout the experimental area). Then, the incorporation of fertilizers was carried out with a hoe.

Seedlings of the cultivar Lisa were produced in trays with 200 cells, with five seeds per cell, and transplanted on 7/2/2021 at 25 cm spacing between rows and 10 cm between holes, totaling 40 holes per plot.

Top dressing was applied with castor bean cake (1250 $g.m^{-2}$, in plots with organic sources) and urea (4.4 $g.m^{-2}$, in plots with triple superphosphate). Irrigation with micro sprinklers was used, applying an average of 3 mm of water per day. The control of spontaneous plants was done manually throughout the cycle, and it was not necessary to control pests and pathogens.

Figure 1. Area preparation.

Evaluated characteristics and statistical analysis

Only the ten central holes of each plot were analyzed. At 59 days after transplanting (DAT) the harvest was performed, cutting all the leaves of the useful plants close to the ground, with a knife. After this first harvest, the plants sprouted, and another harvest was carried out 21 days later. As soon as they were harvested, the leaves of the plants were taken to the Department of Vegetal Production, Horticulture sector, of FCA-UNESP, Botucatu Campus, where the evaluations were made in each harvest: aerial part height: it was obtained in the field, before harvesting, with a ruler, from ground level to the tip of the highest leaf; number of leaves: all the leaves of the useful plot were counted and the average per m^2 was estimated; fresh matter weight: all the plants in the useful plot were weighed on a digital scale, with a precision of 0.1g, and the average per m^2 was estimated; dry matter weight: the plants were placed in a forced ventilation oven (65°C), for three days, then they were weighed on a digital scale, with a precision of 0.1 g, and the average per m^2 and total fresh and dry matter weight was estimated: after obtaining the weight in each harvest, the sum of the two harvests was calculated to obtain the total weight production of fresh and dry matter, with estimated data per m^2.

Data were subjected to analysis of variance, F test to compare doses and polynomial regression analysis for the proportions of the two sources of organic phosphorus. To compare the control treatments (without phosphorus and with inorganic fertilizer) with the treatments with organic sources, Dunnett's test (5%) was used.

Results and discussion

There was no difference between treatments for all evaluated characteristics, either by the F test or by the regression analysis (Table 4 and 5). The lack of effect of phosphate fertilization between the sources and proportions both in the first (Table 4) and in the second harvest and for the total of the two harvests (Table 5) and in comparison to the control without phosphate fertilization, both with organic sources (TY and BM) as the inorganic (ST) (Table 6), for all evaluated characteristics may be related to the high initial P content in the soil (123 $mg.dm^{-3}$). According to Grangeiro et al. (2011), this value is sufficient to meet the demand of the plants and, according to Quaggio et al. (2022), values above 120 $mg.dm^{-3}$ are considered too high, even for growing vegetables. Plants grown in P deficient soils respond well to P fertilization, however the response is less evident in soils with high nutrient content (Malhotra et al., 2018).

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 doses of P applied in each season. In the area where the research was installed, despite having remained fallow for about 3 months, it has been used to produce vegetables for several years, always with phosphorus fertilization before the installation of each crop. Cecílio Filho et al. (2013) found no difference in cabbage production in a soil with a P content of 93 $mg.dm^{-3}$, as well as Cecílio Filho et al. (2017) also did not obtain differences in radish production with the application of phosphorus (0 to 400 $kg.ha^{-1}$ of P_2O_5) in a soil not so rich in P (60 $mg.dm^{-3}$).

On the other hand, Cecílio Filho et al. (2015) in a soil rich in P (103 $mg.dm^{-3}$), obtained an increase in size and head weight in cauliflower and broccoli. Despite the differences, in the best treatment (244 $kg.ha^{-1}$ of P_2O_5) the increase was only 12.5% compared to the control without application of phosphorus (dose 0) and at high doses (above 244 $kg.ha^{-1}$ of P_2O_5) there was a reduction in cauliflower production. In research with three lettuce cultivars of different varietal types, Cecílio Filho et al. (2018) reported an increase in production up to the highest dose studied (300 $kg.ha^{-1}$ of P_2O_5), even though the soil was initially rich in P (136 $mg.dm^{-3}$). Also in industrial type tomatoes, Cecílio Filho et al. (2020) reported an increase in fruit productivity with up to 400 $kg.ha^{-1}$ of P_2O_5 in a soil rich in P (145 $mg.dm^{-3}$). However, with higher doses there was a great loss of production, and with 1000 $kg.ha^{-1}$ of P_2O_5 the productivity was lower than the treatment without application of P.

The adequate supply of nutrients is essential to obtain high productivity, with phosphorus (P) being a limiting factor in Brazilian soils (Silva et al., 2018). As it is one of the nutrients that most limit crop production, as it is part of several metabolic processes, such as energy transfer, protein synthesis, photosynthesis, and respiration (Cecílio Filho et al. 2020), even in soils with high content there is a recommendation for the application of phosphorus and, maybe this recommendation is not necessary.

The high demand for nutrients, combined with the low use of phosphate fertilizer by plants due to fixation in the soil, often leads vegetable growers to apply large amounts of fertilizers regardless of the level of nutrients present in the soil, without monitoring soil fertility before planting (Cecílio Filho et al., 2017) and with the rapid cycle of most vegetables, this operation can be performed several times a year. According to Pavinato et al. (2020), if the efficiency of phosphorus use is less than 100%, accumulation of the nutrient in the soil is observed, and this frequently occurs in Brazilian production systems. Thus, when applied in doses greater than recommended or applied consecutively without analyzing their levels, the applications become inefficient and may even impair production, as reported by Nascimento et al. (2020) who obtained a reduction in arugula productivity the higher the P dose (0 to 300 $kg.ha^{-1}$ of P_2O_5) in a soil rich in this nutrient (115 $mg.dm^{-3}$).

In case of high levels of available P, in a not too long period, the phosphate fertilizers can be eliminated without losses in production (Mardamootoo et al., 2021) as observed in this research with parsley.

In addition to not causing damage to production, the elimination of fertilization allows the producer to avoid unnecessary expenses with phosphate fertilizer and labor for its application. If thermophosphate is used, the value is quoted at US$ 787.00 per ton (IEA, 2023), resulting in significant savings for the producer, regardless of his production scale.

Therefore, despite the official recommendation to fertilize with phosphorus in a soil with a high content of this nutrient, phosphorus fertilization should not be recommended for parsley production. The application of phosphorus beyond what is required by the crop does not positively affect its development, but negatively affects it in economic terms.

Table 4. F test values in the analysis of variance for the dose and proportion factors and their interaction in the first harvest.

	HAP1	**NL1**	**FW1**	**DW1**
Doses (D)	0.307^{ns}	0.033^{ns}	0.026^{ns}	0.002^{ns}
Proportion (P)	0.211^{ns}	0.620^{ns}	0.189^{ns}	0.202^{ns}
Interation D x P	0.125^{ns}	0.025^{ns}	0.160^{ns}	0.091^{ns}
CV (%)	11.2	21.2	26.1	22.7

^{ns} = non-significant at 5% probability; CV= Coefficient of variation; HAP1= Height of the aerial part; NL1= Number of leaves; FW1= fresh matter weight; DW1= dry matter weight.

Table 5. F test values in the analysis of variance for the dose and proportion factors and their interaction in the second harvest and in the total of two harvests.

	HAP2	**NL2**	**FW2**	**DW2**	**TFW**	**TDW**
Doses (D)	0.083^{ns}	0.037^{ns}	0.093^{ns}	0.033^{ns}	0.086^{ns}	0.006^{ns}
Proportions (P)	0.472^{ns}	0.259^{ns}	0.282^{ns}	0.424^{ns}	0.075^{ns}	0.073^{ns}
Interation D x P	0.376^{ns}	0.360^{ns}	0.933^{ns}	0.150^{ns}	0.601^{ns}	0.554^{ns}
CV (%)	14.2	23.8	29.9	23.2	21.5	16.6

^{ns} = non-significant at 5% probability; CV= Coefficient of variation; HAP2= Height of the aerial part; NL2= Number of leaves; FW2= fresh matter weight; DW2= dry matter weight; TFW = total fresh weight; TDW = total dry weight.

Table 6. Comparison of the recommended doses (1= 180 kg.ha^{-1} of P_2O_5) and twice this dose (2= 360 kg.ha^{-1} of P_2O_5) and the proportions between thermophosphate Yoorin and bone meal (BM) with control (without P fertilizers) and inorganic treatment (triple superphosphate) for fresh matter weight in the first (FW1), second (FW2) harvest, and total fresh weight (TFW), dry matter weight in the first (DW1), second (DW2) harvest and total dry weight (TDW), number of leaves in the first (NL1), and second (NL2) harvest, height of the aerial part in the first (HAP1), and second (HAP2) harvest.

Dose	BM Ratio	FW1	FW2	TFW	DW1	DW2	TDW	NL1	NL2	HAP1	HAP2
1	100	382.0^{ab}	308.0^{ab}	690.0^{ab}	10.4^{ab}	8.5^{ab}	18.9^{ab}	209.4^{ab}	169.2^{ab}	34.0^{ab}	31.9^{ab}
1	80	420.4^{ab}	339.2^{ab}	759.6^{ab}	10.9^{ab}	9.4^{ab}	20.3^{ab}	189.0^{ab}	186.6^{ab}	35.4^{ab}	35.3^{ab}
1	60	434.0^{ab}	298.4^{ab}	732.4^{ab}	10.2^{ab}	8.6^{ab}	18.8^{ab}	207.0^{ab}	222.0^{ab}	36.1^{ab}	35.9^{ab}
1	40	414.4^{ab}	267.6^{ab}	682.0^{ab}	11.0^{ab}	7.2^{ab}	18.1^{ab}	207.0^{ab}	210.0^{ab}	38.4^{ab}	30.8^{ab}
1	20	402.0^{ab}	296.0^{ab}	698.0^{ab}	11.0^{ab}	8.4^{ab}	19.4^{ab}	260.4^{ab}	205.2^{ab}	34.5^{ab}	30.5^{ab}
1	0	438.8^{ab}	304.8^{ab}	743.6^{ab}	11.7^{ab}	8.8^{ab}	20.5^{ab}	186.6^{ab}	176.4^{ab}	36.0^{ab}	33.0^{ab}
2	100	405.6^{ab}	354.4^{ab}	760.0^{ab}	10.8^{ab}	9.7^{ab}	20.5^{ab}	224.4^{ab}	196.2^{ab}	34.5^{ab}	32.8^{ab}
2	80	395.2^{ab}	257.6^{ab}	652.8^{ab}	10.6^{ab}	7.2^{ab}	17.8^{ab}	193.8^{ab}	167.4^{ab}	36.7^{ab}	30.4^{ab}
2	60	427.6^{ab}	322.0^{ab}	749.6^{ab}	11.0^{ab}	8.9^{ab}	19.8^{ab}	209.4^{ab}	216.0^{ab}	37.5^{ab}	33.6^{ab}
2	40	414.8^{ab}	333.2^{ab}	748.0^{ab}	10.9^{ab}	9.0^{ab}	19.9^{ab}	240.6^{ab}	206.4^{ab}	38.9^{ab}	33.8^{ab}
2	20	451.6^{ab}	324.0^{ab}	775.6^{ab}	10.7^{ab}	8.3^{ab}	19.1^{ab}	171.6^{ab}	186.0^{ab}	35.6^{ab}	33.3^{ab}
2	0	424.0^{ab}	266.0^{ab}	690.0^{ab}	11.3^{ab}	7.4^{ab}	18.7^{ab}	232.2^{ab}	183.6^{ab}	34.9^{ab}	31.6^{ab}
Without P	-	364.0^{a}	295.6^{a}	659.6^{a}	9.8^{a}	8.0^{a}	17.8^{a}	232.2^{a}	194.4^{a}	33.0^{a}	33.2^{a}
Inorganic	-	463.6^{b}	305.6^{b}	769.2^{b}	10.8^{b}	9.6^{b}	20.4^{b}	180.0^{b}	209.4^{b}	36.0^{b}	30.7^{b}

Conclusions

Phosphate fertilization is not recommended in soil with high levels of the nutrient for parsley production.

The use of organic sources of phosphorus in soils with more than 120 mg.dm^{-3} is economically unsustainable.

References

Andriolo, J. L. (2017). General Horticulture. (3rd ed.). Santa Maria: UFSM.

Cardoso, A. I. I., Silva, P. N. D. L., Colombari, L. F., Lanna, N. B., Fernandes, D. M. (2019). Phosphorus sources associated with organic compound in broccoli production and soil chemical attributes. Hortic Bras., 37, 228-233. https://doi.org/10.1590/S0102-053620190215

Cecílio Filho, A. B., Bonela, G. D., Cruz, M. C. P., Rugeles-Reyes, S. M., Menezello, A. C. F. (2018). Phosphate fertilization for lettuce in an Oxisol with high available phosphorus content. Científica. 46(1), 57-65. https://doi.org/10.15361/1984-5529.2018v46n1p57-65

Cecílio Filho, A. B., Dutra, A. F., Silva, G. S. (2017). Phosphate and potassium fertilization for radish grown in a latosol with a high content of these nutrients. Rev. Caatinga. 30(2), 412-419. http://dx.doi.org/10.1590/1983-21252017v30n216rc

Cecílio Filho, A. B., Silva, G. S., Cortez, J. W. M. (2013). Phosphorus fertilization of 'Fuyutoyo' cabbages in phosphorus-rich Eutrustox soil. Chil. J. Agric. Res. 73(3), 288-292. http://dx.doi.org/10.4067/S0718-58392013000300012

Cecílio Filho, A. B., Silva, A. L. P., Mendoza-Cortez, J. W., Barbosa, J. C. (2015). Cauliflower and broccoli productivity as influenced by phosphorus fertilizer doses in a P-rich soil. Aust J Crop Sci., 9(8), 709-712.

Cecílio Filho, A. B., Trevizaneli, B., Rugeles-Reyes, S. M. (2020). Phosphorus (P) improves industrial tomato quality and yield in soil with high phosphorus content. Austr. J. Crop Sci. 14(8), 1335-1341. http://dx.doi.org/10.21475/ajcs.20.14.08.p2629

Grangeiro, L. C., Freitas, F. C. L., Negreiros, M. Z., Marrocos, S. T. P., Lucena, R. R. M., Oliveira, R. A. (2011). Nutrients growth and accumulation in coriander and rocket. Rev. Bras. Cienc. Agrar. 6, 11-16. http://dx.doi.org/10.5039/agraria.v6i1a634

Instituto de Economia Agrícola (2023, Jul 5). São Paulo: Banco de dados. http://www.iea.agricultura.sp.gov.br.

Lima, S. K., Galiza, M., Valadares, A. A., Alves, F. (2020). Production and consumption of organic products in the world and in Brazil. Text No. 2538. Instituto de Pesquisa Econômica Aplicada (IPEA), Brasília.

Malhotra, H., Vandana, Sharma, S., Pandey, R. (2018). Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In: Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., Hawrylak-Nowak, B. (eds) Plant Nutrients and Abiotic Stress Tolerance. Springer, Singapore. https://doi.org/10.1007/978-981-10-9044-8_7

Mardamootoo, T., du Preez, C. C., & Barnard, J. H. (2021). Phosphorus management issues for crop production: A review. African Journal of Agricultural Research, 17(7), 939-952. https://doi.org/10.5897/AJAR2020.15205

Matos, L. S., Santos, N. S., Anjos, G. L., Souza, D. S., Santos, A. R. (2016). Arugula cv. Apreciatta Folha Larga submitted to doses of phosphorus. Rev. Encic. Bios. 2016: 13(23), 1815-1823.

Nascimento, C. S., Nascimento, C. S., Cecílio Filho, A. B. (2020). Agronomic Performance of Rocket as a function of phosphorus fertilization in a P-Rich Soil. Rev. Caatinga. 33(3), 860-864. https://doi.org/10.1590/1983-21252020v33n330rc

Pavinato, P.S., Cherubin, M.R., Soltangheisi, A. et al. Revealing soil legacy phosphorus to promote sustainable agriculture in Brazil. Sci Rep 10, 15615 (2020). https://doi.org/10.1038/s41598-020-72302-1

Quaggio, J. A., Mattos Jr., D., Raij, B. V. (2022). Phosphorus. In: Cantarella, H., Quaggio, J. A., Mattos Jr., D., Boaretto, R. M., Raij, B. V. Boletim 100: Fertilization and liming recommendations for the State of São Paulo. Campinas: Instituto Agronômico.

Raij, B. V., Cantarella, H., Quaggio, J. A., Furlani, A. M. (1997). Fertilization and liming recommendations for the State of São Paulo. Campinas: Instituto Agronômico and Fundação IAC.175 p.

Shaji, H., Chandran, V., Mathew, L. (2021). Organic fertilizers as a route to controlled release of nutrients. In: Lewu, F. B., Volova, T., Thomas, S., Rakhimol, K. R. (eds) Controlled Release Fertilizers for Sustainable Agriculture. https://doi.org/10.1016/B978-0-12-819555-0.00013-3

Silva, J. V. S., Cruz, S. C. S., Alovisi, A. M. T., Kurihara, C. H., Xavier, W. D., Martinez, M. A. (2018). Phosphate fertilizer in common beans grown with a Brachiaria brizantha cv. Marandú mulch. Rev. Ceres. 65(2), 181-188. https://doi.org/10.1590/0034-737X201865020010

Yoorin. (2023, jun 26). Poços de Caldas: Fertilizantes Mitsui SA. Produtos Yoorin. https://www.yoorin.com.br/pt/produtos/yoorin.