ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.6, p.487-495, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n6p487-495

Sweet potato yield and quality as a function of phosphorus fertilization in different soils[1]

Produtividade e qualidade da batata-doce em função da adubação fosfatada em diferentes solos

Carlos F. dos S. Cordeiro[2*], Fábio R. Echer[3], Guilherme D. Batista[3] & Adalton M. Fernandes[4]

[1] Research developed at Presidente Prudente, São Paulo, Brazil, and Anhumas, São Paulo, Brazil
[2] Universidade Estadual Paulista/Departamento de Produção e Melhoramento Vegetal, Botucatu, SP, Brazil
[3] Universidade do Oeste Paulista/Departamento de Agronomia, Presidente Prudente, SP, Brazil
[4] Universidade Estadual Paulista "Júlio de Mesquita Filho"/Centro de Raízes e Amidos Tropicais, Botucatu, SP, Brazil

HIGHLIGHTS:

High sweet potato quality and yield can be obtained in soils with P concentration > 20 mg dm^{-3} without P fertilization.
Soils with P concentration < 5.0 mg dm^{-3} require 68 kg ha^{-1} of P for maximum yield.
Replacing of exported P requires 370 g of P per Mg of sweet potato.

ABSTRACT: Phosphorus (P) is an essential nutrient for growth and yield of sweet potatoes; in sandy soils, sweet potato yield and quality may be limited by application of low P doses, mainly in degraded areas. The objective of this work was to evaluate the effect of P doses on yield and quality of sweet potato root tubers grown in tropical sandy soils with different initial P availabilities: 23.2 mg dm^{-3} (high P - crop rotation) and 3.7 mg dm^{-3} (low P - post degraded pasture). Two experiments were carried out in a randomized block design, with four replicates. The treatments consisted of P doses (0, 22, 44, 88, and 176 kg ha^{-1}) applied to the planting bed. Tuber yield, number and mean weight of tubers, P concentration in leaves and tubers, exported P, as well as the percentage of starch, reducing sugars, total sugars, and sucrose in the tubers were evaluated. P concentration in the soil was evaluated at the end of the experiment. In the area with high P availability (> 20 mg dm^{-3} - resin), increasing P doses did not increase root tuber yield and decreased root starch concentrations. In the area with low P availability (< 3.7 mg dm^{-3} - resin), root tuber yield and starch concentration peaked when applying 68 and 33 kg ha^{-1} of P, respectively. In areas after degraded pasture, with low initial soil P concentration, P fertilization for sweet potato crops should be carried out with a P dose of 68 kg ha^{-1}. In areas with crop rotation and adequate soil P concentration, P fertilization should be carried out to replace the amount of P exported by the harvested root tubers to avoid decreases in soil fertility.

Key words: *Ipomoea batatas* (L.) Lam, sandy soil, degraded pasture, starch, reducing sugars

RESUMO: O fósforo (P) é um nutriente essencial para o crescimento e produtividade da batata-doce, e em solos arenosos, a produtividade e a qualidade da batata-doce podem ser limitadas pela baixa dose de P aplicada, principalmente em áreas degradadas. O objetivo deste trabalho foi avaliar o efeito de doses de fósforo na produtividade e qualidade das raízes tuberosas de batata-doce cultivadas em solos arenosos tropicais com diferentes disponibilidades iniciais de P; 23,2 mg dm^{-3} (P alto – rotação de culturas) e 3,7 mg dm^{-3} (P baixo – pós pastagem degradada). Dois experimentos foram conduzidos em blocos casualizados, com quatro repetições. Os tratamentos consistiram de doses de P (0, 22, 44, 88 e 176 kg ha^{-1}) aplicadas no sulco de plantio. Foram avaliadas a produtividade, número e peso médio de tubérculos, teor de P nas folhas e nos tubérculos, exportação de P, além da porcentagem de amido, açúcar redutor, açúcar total e sacarose nos tubérculos. No final do estudo foi avaliado o teor de P no solo. Em área com alta disponibilidade de P (> 20 mg dm^{-3} - resina), o aumento das doses de P não aumenta a produtividade de tubérculos e diminui as concentrações de amido nas raízes. Em área com baixa disponibilidade de P (< 3,7 mg dm^{-3} - resina), a produtividade de tubérculos e a concentração de amido atingiram o máximo ao aplicar 68 e 33 kg ha^{-1} de P, respectivamente. Cultivo de batata-doce em área após pastagem degradada com baixo teor inicial de P no solo, a adubação fosfatada deve ser realizada na dose de 68 kg ha^{-1} de P. Em área com rotação de culturas e teor adequado de P no solo, a adubação fosfatada deve ser realizada para repor a quantidade de P exportada pelas raízes tuberosas colhidas para evitar a perda da fertilidade do solo.

Palavras-chave: *Ipomoea batatas* (L.) Lam, solo arenoso, pastagem degradada, amido, açúcar redutor

• Ref. 264173 – Received 19 May, 2022
* Corresponding author - E-mail: cordeirocfs@gmail.com
• Accepted 30 Jan, 2023 • Published 11 Feb, 2023
Editors: Geovani Soares de Lima & Walter Esfrain Pereira

Introduction

Sweet potato [*Ipomoea batatas* (L.) Lam.] crops have been often grown in marginal areas of tropical and subtropical climate regions, in which the soils are poor in essential nutrients (Minemba et al., 2019; Munda et al., 2019; Navarro et al., 2020; Wang et al., 2022) and have low addition of nutrients, especially phosphorus (P) (Corrêa et al., 2018; Munda et al., 2019; Fernandes & Ribeiro, 2020; Kareem et al., 2020; Nyarko et al., 2022). It results in poor vegetative growth and yield (Munda et al., 2019), since P is one of the main nutrients for most plant species, including sweet potato (El-Sayed et al., 2011; Ichikawa et al., 2019). P deficiency reduces ATP synthesis, canopy photosynthetic rate, root growth, and yield and quality of sweet potatoes (Oliveira et al., 2005a; Minemba et al., 2019; Li et al., 2020).

Sweet potato plants are very efficient in P uptake (Oliveira et al., 2005a, 2005b), which, however, becomes highly dependent on symbiosis with arbuscular mycorrhizae under low P availability conditions (Tong et al., 2013). Therefore, a balanced phosphate nutrition for this crop is essential to achieve high yields and maintain soil fertility, as high amounts of P are exported by the harvested root tubers (Fernandes et al., 2020).

P fertilize doses between 35 and 52 kg ha^{-1} were recommended for sweet potato by Oliveira et al. (2005a) and Nascimento et al. (2019), but these studies did not consider the initial soil fertility levels. Sweet potato crops have been grown in pasture areas under recovery conditions, which have low soil P concentrations, but also in areas with crop rotation, which have higher initial P concentrations. Thus, some cases present P deficiency and others present excess fertilization. Thus, adjusting P doses for sweet potato crops is needed for different production environments. The objective of this work was to assess the effect of P doses on yield and quality of sweet potato root tubers grown in sandy soils with low and high initial P availabilities, under tropical conditions.

Material and Methods

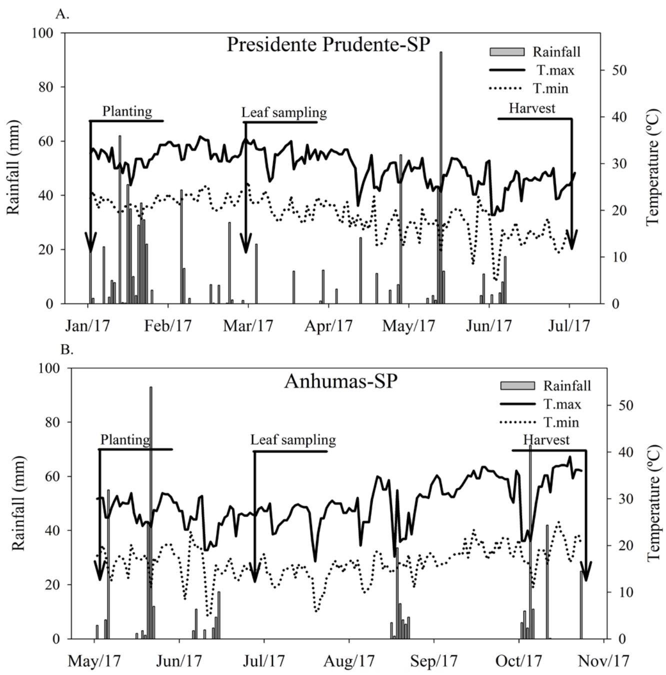
Two field experiments were carried out in commercial sweet potato areas in western São Paulo state, Brazil. The first was carried out from January to July 2017 in an area grown with sweet potato for four years that presented high soil phosphorus (P) availability (Table 1). The second was carried out from May to October 2017 in a degraded pasture area (*Urochloa decumbens* cv. Basilisk) with low soil P availability (Table 1). The distance between the two areas was less than 50 km. The region has an Aw, tropical savannah climate with a dry winter, according to the Köppen classification. The soils of the areas were classified as Oxisols of sandy texture (Table 1). The soil characterization shown in Table 1 are from soil samples collected on the day of sweet potato planting, i.e., after liming. Liming was carried out using 1.0 and 1.3 Mg ha^{-1} of dolomitic limestone (31% CaO and 21% MgO) for the areas of Presidente Prudente, SP (high soil P – crop rotation area) and Anhumas, SP (low soil P – degraded pasture area), respectively, 30 days before soil tillage. Soil tillage (conventional tillage) was carried out using a moldboard plow, a disc plow, and a levelling disc harrow.

Table 1. Geographic coordinates, altitude, and chemical attributes of the 0.0-0.20 m soil layer of the experimental areas before sweet potato planting

Location and soil characteristics	Site (soil P concentration)	
	Presidente Prudente, SP (High P)	Anhumas, SP (Low P)
Geographic coordinates	21°59'33"S; 51°21'21"W	22°17'43"S; 51°23'10"W
Altitude (m asl)	430	470
pH (1:2.5 soil/$CaCl_2$ suspension 0.01 mol L^{-1})	4.8	5.6
Soil organic matter (g dm^{-3})	9.1	8.9
$P_{resin-extractable}$ (mg dm^{-3})	23.2	3.7
K^+ (mmol$_c$ dm^{-3})	3.6	1.2
Ca^{++} (mmol$_c$ dm^{-3})	8.2	9.6
Mg^{++} (mmol$_c$ dm^{-3})	2.1	3.4
Cation exchange capacity (mmol$_c$ dm^{-3})	33.0	27.8
Base saturation (%)	42.1	51.1
Clay (g kg^{-1})	122	138
Silt (g kg^{-1})	64	65
Sandy (g kg^{-1})	814	800

The total rainfall depths during the crop cycle were 805 mm for the area with adequate soil P, and 511 mm for the area with low soil P. Rainfall depths and maximum and minimum temperatures during the experiments are shown in Figure 1. Water balance during the sweet potato cycle in the two areas are shown in Figure 2.

The experiments were conducted in a randomized block design, with four replicates. The treatments consisted of P doses (0, 22, 44, 88, and 176 kg ha^{-1}) and were carried out by applying triple superphosphate 41% P_2O_5 to the planting bed. The fertilizer was applied before planting, to the planting furrows at a depth of approximately 6 cm and covered with soil. Sweet potato seedlings of the cultivar Canadense were



T.max - Maximum air temperature; and, T.min - Minimum air temperature

Figure 1. Rainfall depths and maximum and minimum air temperatures during the sweet potato cycle in the two experimental areas

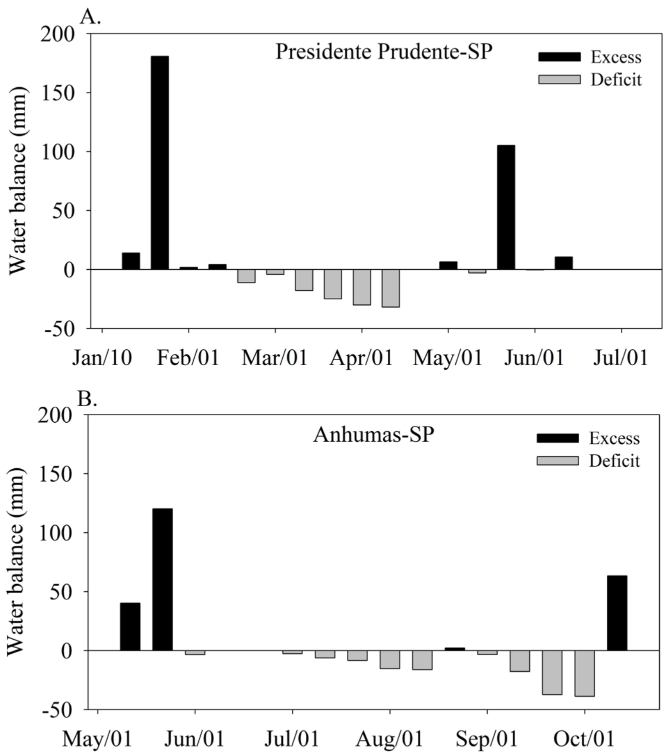


Figure 2. Water balance during the sweet potato cycle in the two experimental areas, calculated according to Thornthwaite & Mather (1955)

used, with 15 cm length and four to six nodes above and four to six nodes below the ground level. Each plot had four 5-m rows with spacing of 0.80 m between rows and 0.40 m between plants, totaling 16 m^2 per plot.

After soil tillage, beds of approximately 0.30 m height were raised; furrows were then opened on the beds, and the planting fertilization was carried out by applying the P doses to the furrows, according to the treatments, together with 20 kg ha^{-1} of N (urea, 45% N), and 50 kg ha^{-1} of K (potassium chloride, 60% K_2O) (Peressin et al., 2022) The crop was grown without irrigation (both areas); crop protection managements (weeds, pests, and diseases) were carried out as needed, according to practices adopted for commercial crops.

Fully expanded leaves were sampled at 60 days after planting (DAP) (Peressin et al., 2022). They were washed with distilled water, dried in an oven at 65 °C for 48 hours, and then ground. P concentrations in leaves were determined according to the methodology described by Malavolta et al. (1997).

Sweet potato root tubers from the two central rows of each plot were manually harvested at 182 DAP (area with high soil P availability) and 172 DAP (area with low soil P availability). The root tubers were washed and subsequently weighed on a precision scale (0.01 g). Total number of root tubers m^{-2}, mean weight of root tubers, and root tuber yield (total) were determined. Subsequently, 10 root tubers were randomly selected, washed with distilled water, sliced (1 cm), and dried in an oven at 65 °C for 48 hours. The samples were ground to determine P concentration, total sugars, reducing sugars, sucrose, and starch in the root tubers.

P concentrations in the sweet potato root tubers were determined using the methodology described by Malavolta et al. (1997). The P exported by root tubers was estimated considering the yield, dry matter, and P concentrations in root tubers. Total concentrations of sugars, reducing sugars, and sucrose were determined using a spectrophotometer, according to the Somogyi method, as adapted by Nelson (1944). Starch concentrations were determined by enzymatic hydrolysis, according to the method described in ISO (1987), followed by sugar concentration analysis (Nelson, 1944). The obtained sugar concentrations were converted to starch concentrations by multiplying the values by the factor 0.9.

Samples of the 0.0-0.20 m soil layer were collected (five sub-samples per plot) after harvesting to determine soil P concentrations, as described by van Raij et al. (2001).

The soil P efficiency was calculated using the P concentrations found after the sweet potato harvesting, using Eq. 1, as suggested by Gava et al. (1997).

$$\text{P efficiency} = \text{P dose} - \text{P control} \quad (1)$$

where:

P dose - soil P in the treatment; and,

P control - P in the control treatment.

The P use efficiency was calculated using Eq. 2, as suggested by Fageria et al. (2010).

$$\text{P use efficiency} = \text{P doses} - \frac{\text{yield control}}{\text{P dose}} \quad (2)$$

where:

P doses - root tuber yield in the treatment;

Yield control - yield in the control treatment; and,

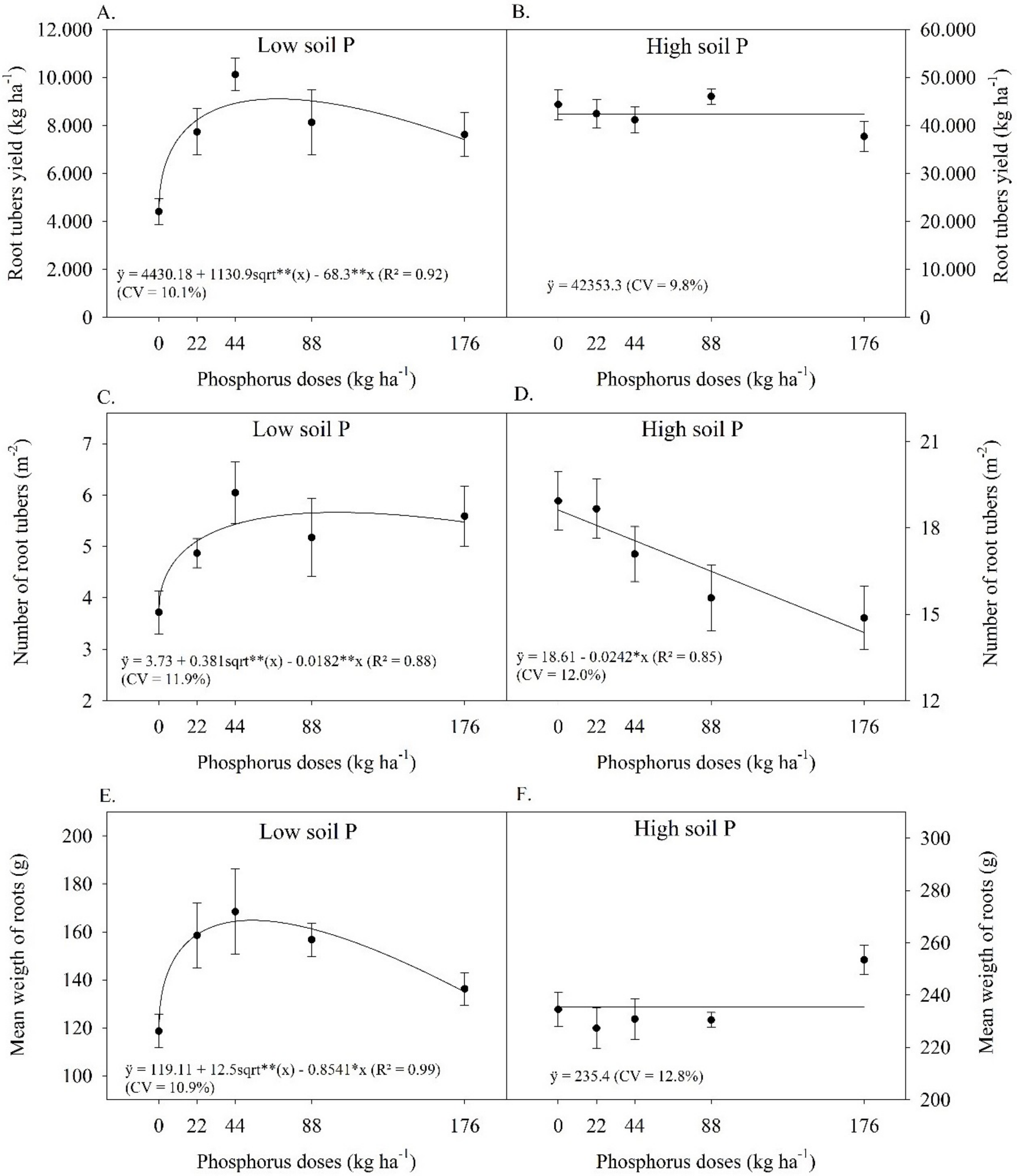
P dose - P dose applied.

The data were subjected to the Shapiro-Wilk normality and homogeneity tests. Data of both experiments were subjected to analysis of variance (ANOVA), separately. Transformation of data was not necessary, as the data were normal and homogeneous. Regression analysis was used to analyze the effect of P doses. The program Sisvar 5.6 was used, and graphs were developed using the SigmaPlot® 10.0.

Results and Discussion

The phosphorus (P) doses had no effect on root tuber yield of sweet potato plants grown in the area with high soil P; the soil P stocks were enough to result in root tuber yields higher than 42 Mg ha^{-1} (Figure 3B). The number of root tubers m^{-2} decreased linearly as the P doses were increased (Figure 3D), with no effect on mean root weights (Figure 3F). A high-water deficit (Figure 2B) limited the yield responses (Figure 3A). Soils with low P concentrations limit the growth of roots and shoots of sweet potato (Li et al., 2020).

The P doses increased the root tuber yield by 120% up to the P dose of 68 kg ha^{-1} in the area with low soil P, compared to the control (Figure 3A). The number of roots m^{-2} increased by 67% and the mean root weight increased by 44% when using the P doses of 101 and 53 kg ha^{-1}, respectively (Figures 3C and E). The soil P concentration decreased to 12 mg dm^{-3} after harvesting



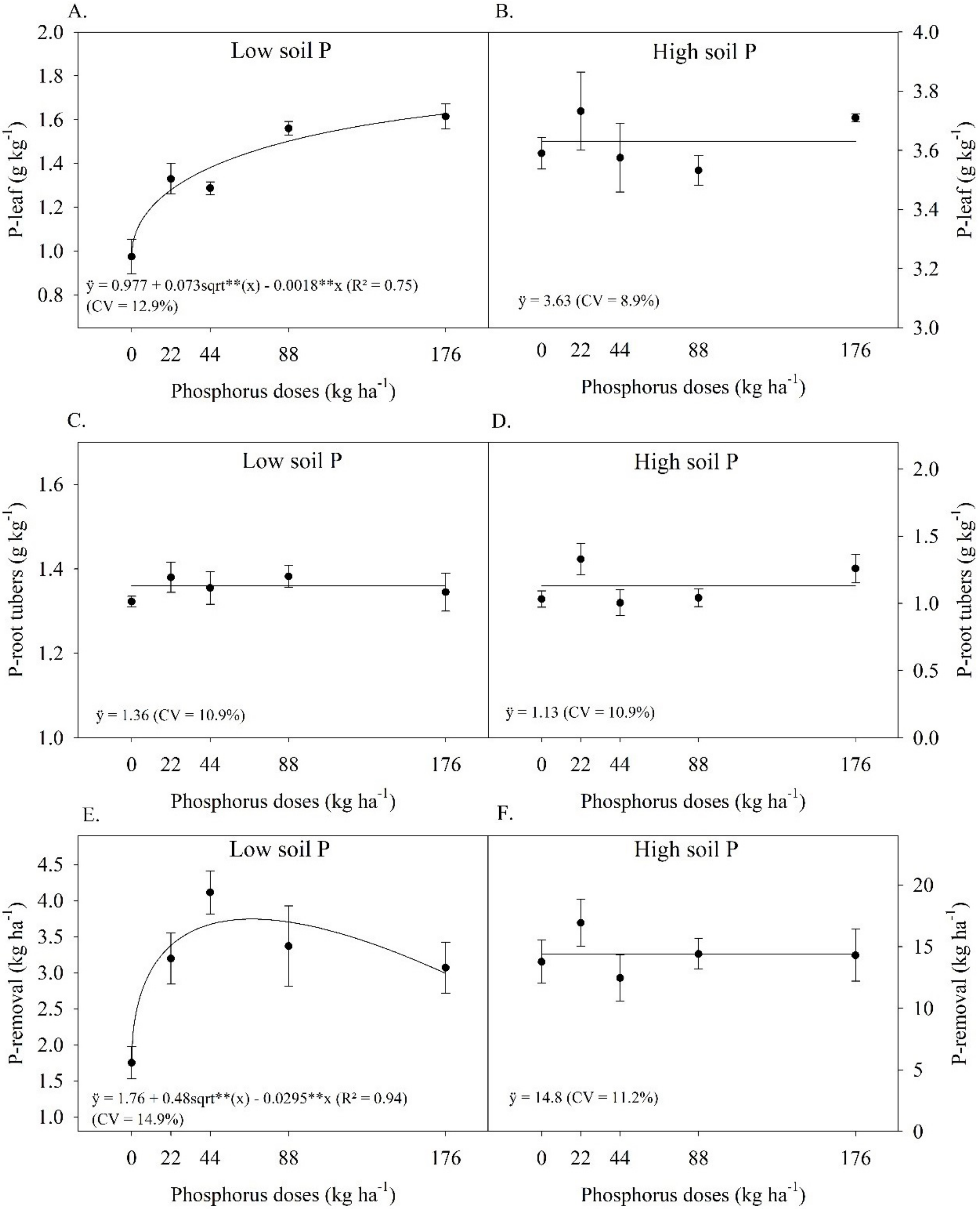
** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard error of the mean

Figure 3. Root tuber yield (A and B), number of root tubers per area (m^2) (C and D), and mean weight of sweet potato roots (E and F) as a function of phosphorus (P) doses in areas with low and high soil P concentrations

sweet potato from plants grown under absence of P fertilization (Table 1 and Figure 6B), which was due to a high extraction and export of P by plants in high yield areas (Fernandes et al., 2020). However, the soil collection was carried out soon after harvesting, thus, there was not enough time for the P from shoots and roots not harvested to return to the soil system.

The P doses had no effect on leaf P, root P, and exported P (roots) in the soil with high soil P concentration, presenting mean values of 3.63, 1.13 g kg^{-1}, and 14.4 kg ha^{-1}, respectively (Figures 4B, 4D, and 4F). Leaf P concentrations increased exponentially as the P dose was increased up to 1.6 g kg^{-1} (Figure 4A) in the area with low soil P. The P fertilization had no effect on root P concentrations, but the exported P increased up to the estimated P dose of 68 kg ha^{-1}, with an estimated exported P of 3.8 kg ha^{-1} (Figures 4C and 4E).

The area with high soil P availability maintained the P leaf concentrations within the sufficiency range for the crop (2.3-5.0 g kg^{-1}) (Peressin et al., 2022), presenting no response to the P

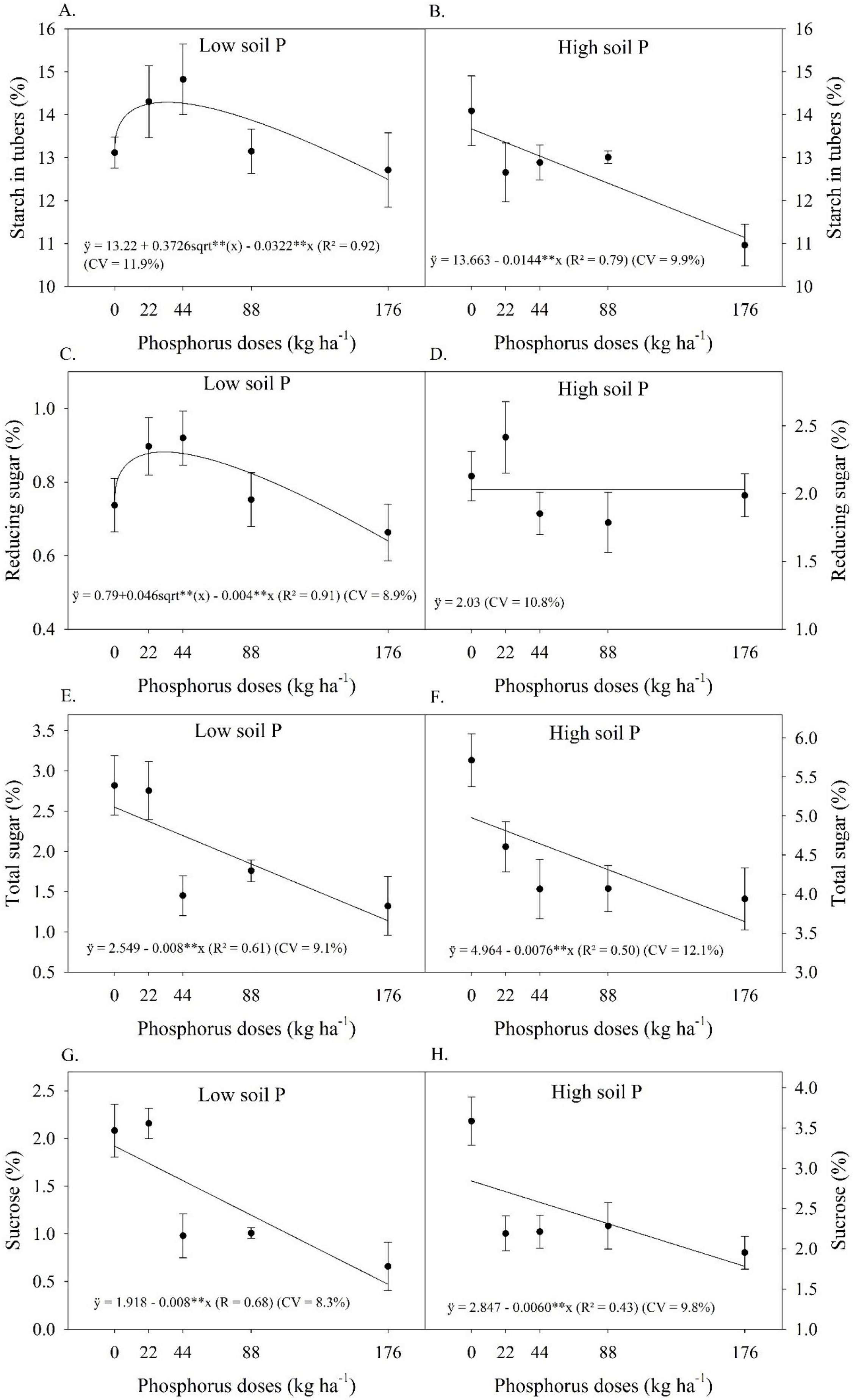


** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard error of the mean

Figure 4. Phosphorus (P) concentrations in leaves (A and B) and root tubers (C and D) and P exported by sweet potato (E and F) plants as a function of phosphorus (P) doses in areas with low and high soil P concentrations

doses applied (Figure 4B). Fernandes et al. (2020) reported leaf P concentrations between 3.6 and 4.0 g kg^{-1} (recent fully developed leaves) for the cultivar Canadense grown in high yield areas (40 Mg ha^{-1} root tubers), as in the present study for the area with high soil P (Figure 4B). However, leaf P concentrations in plants in the area with low soil P presented responses to P doses of up to 176 kg ha^{-1}, increasing up to 1.62 g kg^{-1}, which is still lower than the sufficiency range for the crop (Figure 4A).

Nevertheless, increases in root tuber yield were found when using P doses up to 68 kg ha^{-1}, denoting no correlation between



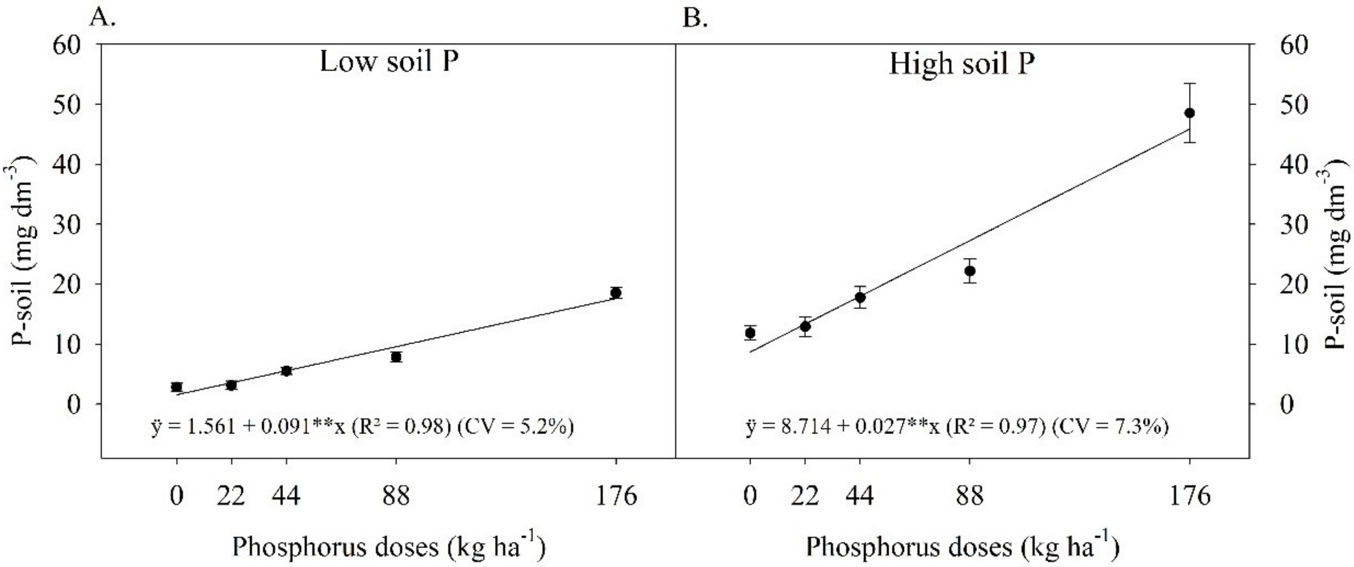
** - Significant at $p \leq 0.01$ by the F test. Vertical bars represent the standard error of the mean

Figure 5. Concentrations of starch (A and B), reducing sugars (C and D), total sugars (E and F), and sucrose (G and H) in root tubers (% of fresh weight) of sweet potato plants as a function of phosphorus (P) doses in areas with low and high soil P concentrations

leaf P concentration and root tuber yield, even for the highest P doses applied to the area with low soil P availability. According to Minemba et al. (2019), sweet potato plants maintain constant, low P concentrations in their tissues (< 1.0 g kg^{-1}), resulting in a high P use efficiency in areas with low soil P. This may explain the absence of correlation between low leaf P concentrations and soil P deficiency on root tuber yield. Thumé et al. (2013) evaluated leaves from the middle third of sweet potato plants at 90 DAP and established a critical leaf P concentration of 1.8 g kg^{-1} for the cultivar Carolina Vitória, which is lower than that established by Peressin et al. (2022) for fully developed leaves (60 DAP). In addition, the present study showed that leaf P concentrations in sweet potato plants grown in the area with low soil P were lower than those established by those studies (Figure 4A).

Root starch concentrations increased up to the P dose of 33 kg ha^{-1} and decreased when using the highest P doses (Figure 5A) in the area with low soil P. However, in the area with high soil P, root starch concentrations decreased linearly up to 18.4% (Figure 5B) as the P doses were increased. P is an essential nutrient for synthesis and accumulation of starch in roots (Oliveira et al., 2005b) and for increasing total sugar concentration (El-Sayed et al., 2011). However, the root starch concentrations increased with P fertilization only when the initial soil P content was low (Figure 5A).

Furthermore, the concentrations of total sugars and sucrose decreased as the P dose was increased, regardless of the initial soil P availability (Figures 5E and H). Oliveira et al. (2005b) reported increases in root tuber starch concentrations when applying up to 56 kg ha^{-1} of P to a soil with low P availability. However, in the present study, the application of P doses higher than 33 kg ha^{-1} did not increase starch concentrations in sweet potato root tubers grown in the area with low soil P. The high initial soil P availability, combined with P fertilization, decreased the starch concentrations in the root tubers, regardless of the P dose applied. It can be attributed to the cultivar used, as the cultivars may present different responses to soil P fertilization (Li et al., 2020) and yield. In the present study, the yield of the area with low soil P was low (Figure 3) due to drought (Figure 2). The increases in P doses increased the soil P after sweet potato harvesting (Figure 6).



** - Significant at $p \leq 0.01$by the F test. Vertical bars represent the standard error of the mean

Figure 6. Soil phosphorus (P) concentration (0.0-0.20 m layer) as a function of P doses (A and B) after sweet potato harvesting in areas with low and high soil P concentrations

Table 2. Soil phosphorus efficiency and use efficiency as a function of the applied P doses

P rate (kg ha^{-1})	Low soil P	High soil P
	Soil P efficiency (mg dm^{-3} of P kg^{-1} of P applied)	
0	--	--
22	0.1	0.5
44	1.2	2.6
88	2.2	4.5
176	6.9	16.0
ŷ=	-1.7025-0.0401**x (R^2=0.96)	-1.3475+0.0919**x (R^2=0.98)
CV	10.3	12.9
	P use efficiency (root tuber yield (kg) per kg of P applied)	
0	--	--
22	150.8	-87.2
44	129.7	-72.1
88	42.2	19.1
176	18.2	-37.7
ŷ=	13.9415+33.0617sqrt**(x)-2.5817**x (R^2=0.85)	-44.5
CV	11.2	13.5

** - Significant at $p \leq 0.01$ by the F test

In the area with low soil P, the P dose of 176 kg ha^{-1} increased the soil P concentration to 16 mg dm^{-3}, i.e., 11 kg ha^{-1} of P were necessary to increase 1.0 mg dm^{-3} in soil P (Table 2). In the area with high soil P, the P dose of 44 kg ha^{-1} maintained the soil P concentrations higher than 16 mg dm^{-3}, and 4.8 kg ha^{-1} of P were necessary to increase 1.0 mg dm^{-3} in soil P (Table 2).

The highest P use efficiency in the area with low soil P was found for the P doses of 22 and 44 kg ha^{-1} (Table 2). However, the highest P use efficiency in the area with high soil P was found when using the P dose of 88 kg ha^{-1} (Table 2). Soils with high P availability to plants decrease the demand for mineral P fertilization, as reported by Dumbuya et al. (2016), requiring only 1.3 of P per Mg of sweet potato produced. This information is relevant because the largest areas of sweet potato crops have soils with low P contents, usually in degraded pasture areas under recovery conditions.

Conclusions

1. Sweet potato plants grown in soils with high phosphorus concentrations (> 20 mg dm^{-3} P-resin) require soil P fertilization only to replace the P exported by root tubers at harvest, since P doses higher than these concentrations do not increase root tuber yield, and decrease root starch concentrations.

2. The area with low soil P concentrations (< 3.7 mg dm^{-3} - resin) required 68 kg ha^{-1} of P to reach the highest root tuber yield, whereas the highest root starch concentration was reached when using the P dose of 33 kg ha^{-1}.

3. Phosphorus fertilization decreases concentrations of total sugars and sucrose in sweet potato root tubers, regardless of the initial soil P availability, does not change the concentration of reducing sugars in soils with high P availability, and increases sugar concentration in areas with low soil P.

Literature Cited

Corrêa, C. V.; Gouveia, A. M. de S.; Lanna, N. de B. L.; Tavares, A. E. B.; Mendonça, V. Z.; Campos, F. G.; Silva, J. O.; Cardoso, A. I. I.; Evangelista, R. M. The split application of potassium influence the production, nutrients extraction, and quality of sweet potatoes. Journal of Plant Nutrition, v.41, p.2048-2056, 2018. https://doi.org/10.1080/01904167.2018.1485162

Dumbuya, G.; Sarkodie-Addo, J.; Daramy, M. A.; Jalloh, M. Growth and yield response of sweet potato to diffent tillage methods and phosphorus fertilizer doses in Ghana. Journal of Experimental Biology and Agricultural Sciences, v.4, p.476-483, 2016. http://dx.doi.org/10.18006/2016.4(5).475.483

El-Sayed, H. E. A.; Saif-el-Dean, A.; Ezzat, S.; El-Morsy, A. H. A. Responses of productivity and quality of sweet potato to phosphorus fertilizer doses and application methods of the humic acid. International Research Journal of Agricultural Science and Soil Science, v.1, p.383-393, 2011.

Fageria, N. K.; Santos, A. B. dos; Moraes, M. F. de. Yield, potassium uptake, and use efficiency in upland rice genotypes. Communications in Soil Science Plant Analysis, v.41, p.2676-2684, 2010. https://doi.org/10.1080/00103624.2010.517882

Fernandes, A. M.; Assunção, N. S.; Ribeiro, N. P.; Gazola, B.; Silva, R. M. da. Nutrient uptake and removal by sweet potato fertilized with green manure and nitrogen on sandy soil. Revista Brasileira de Ciência do Solo, v.44, p.1-25, 2020. https://doi.org/10.36783/18069657rbcs20190127

Fernandes, A. M.; Ribeiro, N. P. Mineral nutrition and fertilization of sweet potato. Científica, v.48, p.325-338, 2020. https://doi.org/10.15361/1984-5529.2020v48n4p325-338

Gava, J. L.; Gonçalves, J. L. M.; Shibata, F. Y.; Corradini L. Eficiência relativa de fertilizantes fosfatados no crescimento inicial de eucalipto cultivado em solos do cerrado. Revista Brasileira de Ciência do Solo, v.21, p.497-504, 1997. http://dx.doi.org/10.1590/S0100-06831997000300020

Ichikawa, E.; Fernandes, A. M.; Mota, L. H. da S. de O. Rooting of sweet potato seedlings submitted to supplemental calcium and phosphorus nutrition on substrate. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.860-868, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n11p860-868

ISO - International Organization for Standarization. Norme ISO 6647 (F). Riz – Determination de La teneur em amylose. Switzerland, 1987. 3p.

Kareem, I.; Akinrinde, E. A.; Oladosu, Y; Eifediyi, E. K.; Abdulmaliq, S. Y.; Alasinrin, S. Y.; Kareem, S.; Adekola, O. F. Enhancement of phosphorus uptake, growth and yield of sweet potato (*Ipomoea batatas*) with phosphorus fertilizers. Journal of Applied Sciences and Environmental Management, v.24, p.79-83. 2020. https://dx.doi.org/10.4314/jasem.v24i1.11

Li, C.; Wang, J.; Zhang, Y. C. Root growth and phosphorus efficiency among sweet potato genotypes under low phosphorus. Journal of Plant Nutrition, v.43, p.1320-1330, 2020. https://doi.10.1080/01904167.2020.1729803

Malavolta, E. A.; Vitti, G. C.; Oliveira, A. S. de. Avaliação do estado nutricional das plantas: princípios e aplicações. Piracicaba: Potafós, 1997. 201p.

Minemba, D.; Gleeson, D. B.; Veneklaas, E.; Ryana, M. H. Variation in morphological and physiological root traits and organic acid exudation of three sweet potato (*Ipomoea batatas*) cultivars under seven phosphorus levels. Scientia Horticulturae, v.256, p.1-11, 2019. https://doi.org/10.1016/j.scienta.2019.108572

Munda, E.; Pieterse, P. J.; Andrade, M. I.; Makunde, G. S.; Pereira, E. I. Improving productivity of orange-fleshed sweet potato (*Ipomoea batatas*) through intercropping with legumes and moderate phosphorus application. South African Journal of Plant and Soil, v.36, p.1-8, 2019. https://doi.org/10.1080/02571862.2018.1548659

Nascimento, S. M. C.; Cecilio-Filho, A. B.; Silva, A. S. N. da; Vargas, P. F. Carotene yield in sweet potato after potassium and phosphorus fertiliser application. Revista Caatinga, v.32, p.851-857, 2019 https://doi.org/10.1590/1983-21252019v32n330rc

Navarro, J.; Salazar, J.; Kang, J. J.; Parsons, J.; Cheng, C. L.; Castillo, A.; Pujol Pereira, E. I. P. Compost and biochar to promote soil biological activities under sweet potatoes cultivation in a subtropical semiarid region. Applied and Environmental Soil Science, v.2020, p.1-11, 2020. https://doi.org/10.1155/2020/7230595

Nelson, N. A photometric adaptation of the Somogyi method for the determination of glucose. Journal of Biological Chemistry, v.153, p.375-380, 1944.

Nyarko, A.; Sarkodie-Addo, J.; Adofo, K.; Addae-Duah, O.; Quaye, M. O. Nutritional quality responses of sweet potato to different doses of organic and inorganic fertilizers. International Journal of Plant & Soil Science, v.34, p.1-9, 2022. https://doi.org/10-15.10.9734/IJPSS/2022/v34i830894

Oliveira, A. P. de; Silva, J. E. L. da; Pereira, W. E.; Barbosa, L. J. das N. Produção de batata-doce em função de doses de P_2O_5 em dois sistemas de cultivo. Horticultura Brasileira, v.23, p.768-772, 2005a. https://doi.org/10.1590/S0102-05362005000300016

Oliveira, A. P. de; Silva, J. E. L. da; Pereira, W. E.; Barbosa, L. J. das N. Produção de batata-doce e teor de amido nas raízes em função de doses de P_2O_5. Acta Scientiarum Agronomy, v.27, p.747-751, 2005b. https://doi.org/10.4025/actasciagron.v27i4.1342

Peressin, V. A.; Feltran, J. C.; Ros, A.B.; Fernandes, A. M. I. J.Batata-Doce. In: Raij, B. (Eds). Recomendações de adubação e calagem para o estado de São Paulo. 2.ed. Campinas: Instituto Agronômico de Campinas, 2022. 329p. Boletim Técnico 100

Thornthwaite, C. W.; Mather, J. R. The water balance Centerton, NJ: Drexel Institute of Technology - Laboratory of Climatology, 1955. 104p.

Thumé, M. A.; Dias, L. E.; Silveira, M. A. da; Assis, I. R. de. Níveis críticos foliares de nutrientes de três cultivares de batata-doce, selecionados para a produção de etanol. Revista Ceres, v.60, p.863-875, 2013. http://dx.doi.org/10.1590/S0034-737X2013000600015

Tong, Y.; Gabriel-Neumann, E.; Ngwene, B.; Krumbein, A.; Baldermann, S.; Schreiner, M.; George E. Effects of single and mixed inoculation with two arbuscular mycorrhizal fungi in two different levels of phosphorus supply on β-carotene concentrations in sweet potato (*Ipomoea batatas* L.) tubers. Plant and Soil, v.372, p.361-374, 2013. http://dx.doi.org/10.1007/s11104-013-1708-y

van Raij, B.; Andrade, J. C.; Cantarella, H.; Quaggio, J. A. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico de Campinas, 2001. 300p.

Wang, D.; Chen, X.; Tang, Z.; Liu, M.; Jin, R.; Zhang, A.; Zhao, P. Application of humic acid compound fertilizer for increasing sweet potato yield and improving the soil fertility. Journal of Plant Nutrition, v.45, p.1933-1941, 2022. https://doi.org/10.1080/01904167.2022.2046064