ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.12, p.930-938, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n12p930-938

Accumulation and efficiency of phosphorus use in irrigated cassava cultivars in the Brazilian semiarid region[1]

Acúmulo e eficiência do uso do fósforo em cultivares de mandioca irrigadas no semiárido brasileiro

Francisco A. T. Alves[2], Flávio P. da M. Silveira[3*], Welder de A. R. Lopes[2], Francisco de A. de Oliveira[2], Lindomar M. da Silveira[2] & Aurélio P. Barros Júnior[2]

[1] Research developed at Fazenda Experimental Rafael Fernandes, Alagoinha district, Mossoró, RN, Brazil
[2] Universidade Federal Rural do Semi-Árido/Centro de Ciências Agrárias/Departamento de Ciências Agronômicas e Florestais, Mossoró, RN, Brazil
[3] Universidade Federal do Rio Grande do Norte/Unidade Acadêmica Especializada em Ciências Agrárias/Setor de Produção Agropecuária, Macaíba, RN, Brazil

HIGHLIGHTS:
The largest export of phosphorus in cassava is through the roots.
High doses of phosphorus (240 kg ha^{-1} of P_2O_5) reduce agronomic and recovery efficiencies.
Cassava shows great genetic variability in response to phosphorus fertilization.

ABSTRACT: Phosphorus is of fundamental importance for the energy supply necessary for plant metabolism, but it is still understudied for important agricultural crops such as cassava. The objective of this study was to evaluate the accumulation and efficiency of phosphorus use in different cassava cultivars in the semiarid region. Two experiments were carried out during two agricultural seasons 2018/2019 and 2019/2020 in Mossoró, Rio Grande do Norte state, Brazil. The experimental design was randomized blocks, in split plots, with four replicates. In the plots, five doses of phosphorus (P) (0, 60, 120, 180, and 240 kg ha^{-1} of P_2O_5) were applied in the planting furrow, and four cassava cultivars (Água Morna, BRS Gema de Ovo, Recife, and Venâncio) were cultivated in the subplots. The cultivars Água Morna and Recife export more phosphorus through their roots. The cultivars Venâncio and Água Morna show greater agronomic efficiency when fertilized with 60 kg ha^{-1} of P_2O_5. The apparent P recovery efficiency presented the following order: 'BRS Gema de Ovo' > 'Água Morna' > 'Venâncio' > 'Recife', with higher indices at the dose of 60 kg ha^{-1} of P_2O_5.

Key words: *Manihot esculenta* Crantz, plant nutrition, soil fertility, nutritional efficiency

RESUMO: O fósforo tem importância fundamental para o suprimento energético necessário para o metabolismo vegetal, mas ainda é pouco estudado em culturas importantes, como a mandioca. Objetivou-se avaliar o acúmulo e a eficiência do uso do fósforo em diferentes cultivares de mandioca no semiárido. Foram conduzidos dois experimentos em duas safras agrícolas, 2018/2019 e 2019/2020, em Mossoró-RN. O delineamento experimental foi em blocos ao acaso, em parcelas subdivididas, com quatro repetições. Nas parcelas, foram aplicadas no sulco de cultivo cinco doses de fósforo (P) (0; 60; 120; 180 e 240 kg ha^{-1} de P_2O_5), e, nas subparcelas quatro cultivares de mandioca (Água Morna, BRS Gema de Ovo, Recife e Venâncio). As cultivares Água Morna e Recife exportam mais fósforo através de suas raízes. As cultivares Venâncio e Água Morna apresentam maior eficiência agronômica quando adubadas com 60 kg ha^{-1} de P_2O_5. A eficiência aparente de recuperação do P apresentou a seguinte ordem: 'BRS Gema de Ovo' > 'Água Morna' > 'Venâncio' > 'Recife', com maiores índices na dose de 60 kg ha^{-1} de P_2O_5.

Palavras-chave: *Manihot esculenta* Crantz, nutrição de plantas, fertilidade do solo, eficiência nutricional

• Ref. 260731 – Received 04 Feb, 2022
* Corresponding author - E-mail: flaviopms@hotmail.com
• Accepted 30 Jun, 2022 • Published 20 July, 2022
Editors: Lauriane Almeida dos Anjos Soares & Carlos Alberto Vieira de Azevedo

Introduction

Cassava (*Manihot esculenta* Crantz) is grown as an annual crop in tropical and subtropical regions. Its main product is the starch-rich tubers, which are an important source of carbohydrates and are among the seven most widely grown crops and a staple food for around 800 million people worldwide (FAO, 2019).

Even though it is considered an undemanding crop for fertile soils, most growers cultivate it on soils with low fertility. However, studies have shown that cassava is a crop that responds to fertilization, especially phosphate, which is important for the formation of the root system and increases root growth and productivity (Lima et al., 2018; Omondi et al., 2019; Oliveira et al., 2020; Uchôa et al., 2020; Santos et al., 2021).

Tropical soils are characterized by a high degree of weathering and low levels of phosphorus in a form available to plants as well as low phosphorous mobility (Milić et al., 2019). Several studies have shown that the responses of crops to phosphate fertilization vary according to biotypes and abiotic factors, such as soil nutrient availability (Lima et al., 2018; Katuromunda et al., 2021; Silveira et al., 2021).

Plant adaptation to reduced P availability in the soil can be achieved by making better use of the nutrients present in plant tissue for biomass production or by increasing soil P acquisition capacity (Gautier et al., 2018). In this sense, selecting genotypes with higher nutrient efficiency is regarded as one of the most effective strategies to reduce crop production costs.

Given the above, the objective of this study was to evaluate the accumulation and efficiency of phosphorus use in different cassava cultivars in the semiarid region in Mossoró, Rio Grande do Norte state, Brazil

Material and Methods

The research was carried out in two crop seasons (June 2018 to April 2019 and June 2019 to April 2020), in different areas, at Rafael Fernandes Experimental Farm (5° 03’ 31.00” S, 37° 23’ 47.57” W and 80 m of altitude), at Federal Rural University of the Semi-arid (UFERSA), located in the district of Alagoinha, a rural area of the municipality of Mossoró, Rio Grande do Norte state, Brazil.

According to the Köppen classification, the local climate is BSh type (Alvares et al., 2013), that is, dry and very hot, with a rainy season between February and May, and a dry season from February to May and from June to January. During the research, meteorological variables were collected (Figure 1) in a climatological station located on the central campus of UFERSA, 20 km away from the experimental area.

The experiments were carried out in randomized blocks, in split plots, with four replicates. In the plots, the doses of P were applied in the planting furrow, being 0, 60, 120, 180, and 240 kg ha^{-1} of P_2O_5 (Silva & Gomes, 2008) and the four cultivars (Água Morna, BRS Gema de Ovo, Recife, and Venâncio) were distributed in the subplots.

The cultivars had variations in root characteristics, with cream (Água Morna), yellow (BRS Gema de Ovo), and white (Recife and Venâncio) pulp colors. There was pinkish coloration on the root cortex (Água Morna and Venâncio) and white or cream (BRS Gema de Ovo and Recife), in addition to a dark brown outer color of the root for all cultivars. Variation was registered in the branching of the aerial part, in which the cultivar Água Morna had less branching, while the others had intense branching (Fukuda & Guevara, 1998).

The experimental area soil was classified as an Oxisol, of sandy loam texture and flat relief (Rêgo et al., 2016). Soil samples were collected at layers 0-0.20 and 0.20-0.40 m for chemical and physical characterizations (Donagema et al., 2011) (Table 1).

Although the experiments were carried out in two growing periods, adjacent areas were used. The first area (2018/2019 crop season) had higher levels of P, Ca, and Mg, while the second one (2019/2020 crop season) had high sodium concentrations (Table 1).

Before setting up the experiments, soil tillage was carried out with heavy harrowing to incorporate the remaining plant material in the area, in addition to a leveling harrow to homogenize the soil surface. Then, the area was marked, so that each experimental unit consisted of four lines of 6.0 m in length, spaced 1.0 m apart, totaling an area of 24.0 m^2 (6.0 × 4.0 m). The two central lines were considered the useful area of the experimental unit, discarding a plant at each end, totaling 9.6 m^2.

Fertilization was performed following the recommendations of Silva & Gomes (2008) and based on soil analyses. As nitrogen (N), phosphorus (P), and potassium (K) sources, urea (45% N), simple superphosphate (18% P_2O_5), and potassium chloride (60% K_2O) were used, respectively. For each crop, 30 kg ha^{-1} of N and 40 kg ha^{-1} K_2O were applied, while P was applied according to the established treatments. P was applied manually at planting, while N and K were applied via an irrigation system through a diversion tank (“lung”), with half the recommended dose of N supplied at 30 days after emergence (DAE) of the plants, together with the total dose of K. At 60 DAE, the second half of the nitrogen fertilization was applied.

The cuttings were 10 months old and came from the Rafael Fernandes Experimental Farm’s cassava multiplication area. Planting was done by hand, with a stake 0.10-0.15 m long and holding five-seven buds placed in each hole at a depth of 0.10 m, with a spacing of 1.0 m between rows by 0.6 m between holes, yielding a population density of around 16,667 plants ha^{-1}.

The irrigation system used in the experiment was the drip irrigation system, with emitters spaced at 0.30 m and a flow rate of 1.6 L h^{-1}, applying a daily average depth of 4.8 mm. Irrigation was calculated according to the phenological phase (Phase 1: 0-120 days after planting, Kc of 0.56; Phase 2: 120-300 days after planting, Kc of 0.98; Phase 3: 300-360 days after planting, Kc of 0.50), according to Coelho Filho (2020). Eight months after planting, irrigation was suspended.

Weed control was executed by manual weeding, and due to the occurrence of mite attack, the application of a commercial product with the active ingredient spiromesifen was carried out.

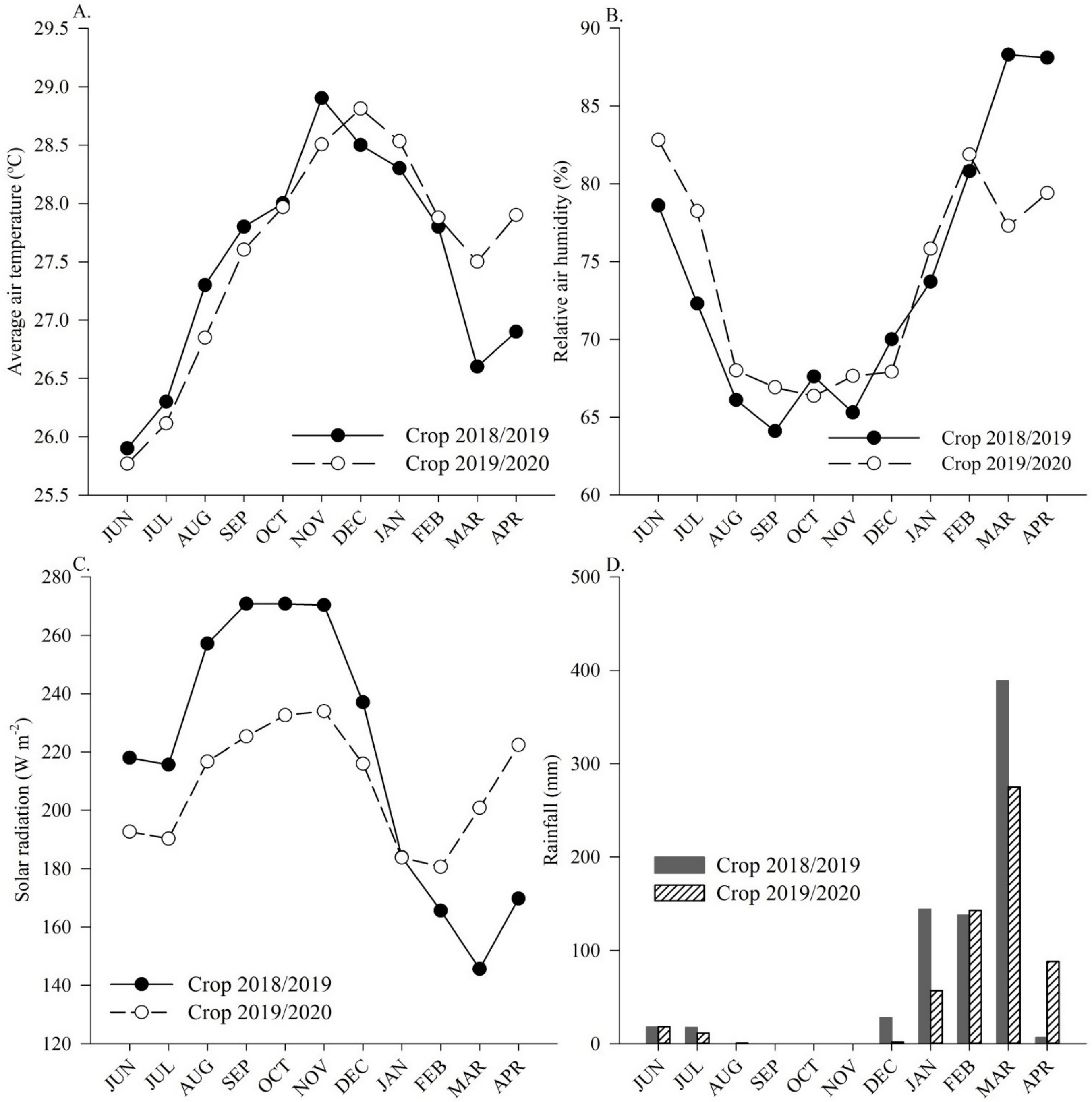

Figure 1. Values of mean air temperature (A), relative air humidity (B), solar radiation (C), and accumulated rainfall (D) in the two growing periods (2018/2019 and 2019/2020)

Table 1. Soil chemical and physical characterization, at layers 0-0.20 and 0.20-0.40 m, of the experimental areas during two growing crop seasons (2018/2019 and 2019/2020)

Soil layer (m)	pH	P*	K^+	Na^+	Ca^{2+}	Mg^{2+}	Sand	Silt	Clay
		($mg\ dm^{-3}$)			($cmol_c\ dm^{-3}$)		($kg\ kg^{-1}$)		
1st Crop season (2018/2019)									
0-0.20	5.90	8.30	38.90	1.20	0.80	0.50	0.91	0.02	0.07
0.20-0.40	5.50	2.00	50.80	1.20	0.70	0.20	0.88	0.03	0.09
2nd Crop season (2019/2020)									
0-0.20	5.90	3.70	41.10	9.30	0.60	0.20	0.91	0.02	0.07
0.20-0.40	4.90	0.90	24.30	8.30	0.50	0.10	0.88	0.03	0.09

*P, K, Na - Extractor Mehlich 1; Ca^{2+}, Mg^{2+} - Extractor KCl 1 Mol L^{-1}

For laboratory analysis, two whole plants from each subplot were collected, separated into leaves, stems, and roots, and weighed. Then, triple washing was carried out with distilled water and neutral detergent, waiting for the excess water to escape from the material, which was subjected to drying in a forced circulation oven at 65 °C until the weight was stabilized.

Afterward, the leaves, stem, and commercial roots dry matter (g per plant) was obtained. The samples were ground in a Wiley-type mill (2-mm sieve) and placed in closed containers.

Nitric-perchloric digestion was used to obtain extracts from different parts of the plants (Malavolta et al., 1997). From the P contents and the quantification of the dry matter of leaves, stems, and roots, the P accumulation ratio (g per plant) was calculated for each plant organ (leaves, stems, and roots) by multiplying the content of each nutrient by the mass of sample dry matter.

The agronomic efficiency (AE) and apparent efficiency of recovery (AER) were calculated by Fageria (2009):

$$AE = \frac{(RYwf - RYwoutf)}{APa} \quad (1)$$

where:

AE - agronomic efficiency (kg kg^{-1});

RYwf - root yield with phosphate fertilizer (kg ha^{-1});

RYwoutf - root yield without phosphate fertilizer (kg ha^{-1}); and,

APa - amount of P applied (kg ha^{-1}).

$$ARE = \frac{(APwf - APwoutf)}{APa} \quad (2)$$

where:

ARE - apparent recovery efficiency (kg kg^{-1});

APwf - accumulation of P in shoots and roots with P fertilizer (kg);

APwoutf - accumulation of P in shoots and roots without fertilizer P (kg); and,

APa - amount of P applied (kg).

Statistical analysis for the two harvests was performed separately for each harvest, using the SISVAR 5.6 program (Ferreira, 2014), whose results were subjected to analysis of variance using the F test ($p \leq 0.05$). For P doses, regression analyses were performed (linear and quadratic) and the equations were chosen based on the coefficient of determination and the significance of the coefficients. The cultivars were compared by the Tukey mean comparison test ($p \leq 0.05$).

Results and Discussion

In the two cultivation growing periods, there were different responses for P accumulation in the roots of the cultivars as a function of the increase in the applied P doses (Table 2). In the first cultivation, the cultivar Recife showed the highest accumulation of P in the roots for the highest of the P_2O_5 doses applied, not significantly differing from the cultivar Gema de Ovo at doses 0 and 240 kg ha^{-1} of P_2O_5, and from the cultivar Água Morna at doses of 60 and 120 kg ha^{-1} of P_2O_5. On the other hand, the cultivar Venâncio showed lower P accumulation for most doses. Even at the highest doses, the accumulation of P by this cultivar was low, which is justified due to its lesser root development compared to the others.

According to Kumar et al. (2019), plants with greater root volume have better phosphorus uptake, because P is an integral component of important compounds in plant cells, including phosphate-sugars, respiration, and photosynthesis intermediates, as well as the phospholipids that make up plant membranes. It is also a component of nucleotides used in plant energy metabolism (such as ATP) and in DNA and RNA (Taiz et al., 2017).

As the movement of P from the soil by diffusion to the roots is restricted, diffusion is generally considered to be the most limiting factor in the uptake of P by plants. The ability of plants to absorb phosphorus from the soil depends on the concentration of those ions in the soil solution at the root surface, in addition to the area of the root surface in contact with the solution (Fink et al., 2016).

On the other hand, for the cultivar BRS Gema de Ovo, the data obtained did not fit the proposed models, obtaining mean accumulations of 0.911 g per plant (Table 2). For the cultivars Água Morna, Recife, and Venâncio, the data showed a better fit to the quadratic model, with higher values occurring at doses of 110.17, 110.25, and 141.38 kg ha^{-1} of P_2O_5, with maximum accumulations of 1.564, 1.613, and 0.704 g per plant being obtained, in cultivars Água Morna, Recife, and Venâncio, respectively (Table 2).

In the second year of cultivation, it can be seen that, as observed in the first year of cultivation, the cultivar Venâncio showed less P accumulation at most P_2O_5 doses, except for the dose of 160 kg ha^{-1}. It was possible to adjust the regression model for all cultivars, with maximum accumulations

Table 2. Phosphorus accumulation (g per plant) in cassava cultivar roots as a function of P_2O_5 doses in two crop seasons

Cultivars	Doses of P_2O_5 (kg ha^{-1})					Regression equation	R^2
	0	60	120	180	240		
1st Crop season (2018/2019)							
(P: $p \leq 0.01$; C: $p \leq 0.01$; P x C: $p \leq 0.01$; CV: 17.17%)							
Água Morna	0.703 b	1.712 a	1.604 a	1.396 ab	0.742 b	$y = 0.848 + 0.013^{*}x - 0.000059^{**}x^2$	0.75
BRS Gema de Ovo	1.101 a	1.143 b	0.726 b	0.955 b	0.841 ab	y = ns = 0.911	
Recife	1.110 a	1.512 a	1.812 a	1,551 a	1.076 a	$y = 1.139 + 0.0086^{*}x - 0.000039^{**}x^2$	0.72
Venâncio	0.158 c	0.421 c	0.769 b	1.089 ab	0.428 c	$y = 0.125 + 0.0082^{**}x - 0.000029^{**}x^2$	0.93
2nd Crop season (2019/2020)							
(P: $p \leq 0.01$; C: $p \leq 0.01$; P x C: $p \leq 0.05$; CV: 21.25%)							
Água Morna	0.535 ab	1.154 a	1.663 a	1.396 ab	1.291 a	$y = 0.539 + 0.013^{**}x - 0,000044^{*}x^2$	0.837
BRS Gema de Ovo	0.506 ab	1.079 a	1,187 b	0.955 c	0.983 ab	$y = 0.572 + 0.0082^{**}x - 0.000028^{**}x^2$	0.794
Recife	0.783 a	1.151 a	1.315 ab	1,551 a	1.308 a	$y = 0.767 + 0.0079^{**}x - 0.000023^{**}x^2$	0.946
Venâncio	0.354 b	0.623 b	1.112 b	1.089 bc	0.872 b	$y = 0.297 + 0.0096^{*}x - 0.000029^{**}x^2$	0.921

Different letters in the column indicate significant differences between cultivars at $p \leq 0.05$ according to the Tukey test; **, *, ns - Significant at $p \leq 0.01$ and $p \leq 0.05$, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation estimated at 1.499, 1.172, 1.445, and 1.091 g per plant, at doses of 147.73, 146.43, 171.74, and 165.52 kg ha^{-1} of P_2O_5 for the cultivars 'Água Morna', 'BRS Gema de Ovo', 'Recife', and 'Venâncio', respectively.

In general, it appears that the response of the cultivars to phosphate fertilization was more evident in the second year of cultivation. This fact can be attributed to the lower P content in the soil of the area used in this cycle.

Thus, it is observed that there was a great difference between the two crops in their response to phosphate fertilization (Figure 1). This difference may have been because the soil in the experimental area during the 2019/2020 crop season had, before fertilization, practically half the P content of the soil in the first 2018/2019 crop season (Table 1).

The amount extracted by the roots is similar to the results presented by Magolbo (2019), who obtained P accumulations ranging from 13.1 to 14.7 kg ha^{-1}. In addition to the cultivars' internal characteristics, the increase in nutrient availability and the source used are factors that can alter the uptake of phosphorus by plants (Pelá et al., 2017). For Pellet & El-Sharkawy (1993), the differences in absorption between cassava cultivars can be explained by the fact that each cultivar presents a special mechanism for P uptake, such as diffusion and, to a lesser extent the mass flow.

According to Kumar et al. (2019), plants with greater root volume have better phosphorus uptake. The ability of plants to absorb phosphorus from the soil depends on the concentration of phosphorus ions in the soil solution at the root surface, in addition to the area of the root surface in contact with the solution (Fink et al., 2016).

For P accumulation in the stem (in the 2018/2019 growing period crop), there were significant differences between cultivars for all P_2O_5 doses, in which the Recife cultivar presented higher values for most doses. On the other hand, the cultivar BRS Gema de Ovo presented, in general, the lowest values (Table 3).

There was adjustment to the regression model for the cultivars Água Morna, BRS Gema de Ovo, Recife, and Venâncio, which had maximum accumulations of 0.900, 1.618, 1.752, and 1.154 g per plant, respectively, for doses 132.82, 105.26, 122.81, and 133.33 kg ha^{-1} of P_2O_5 (Table 3).

In the second year of cultivation (2019/2020), there was no significant difference between cultivars in the absence of phosphate fertilization. In the other doses, the cultivars BRS Gema de Ovo and Venâncio were superior to the others, while the lowest values occurred in the cultivars Água Morna and Recife (Table 3).

The cultivars Água Morna, Recife, and Venâncio were affected in a quadratic way by the phosphorus doses, with the maximum values of 0.406, 0.454, and 0.397 g per plant obtained at doses 139.28, 177.27, and 159.52 kg ha^{-1} of P_2O_5, for the cultivars Água Morna, Recife, and Venâncio, respectively. For the cultivar BRS Gema de Ovo, there was a linear and increasing response, with the highest accumulation of P (0.854 g per plant) occurring at the dose 240 kg ha^{-1} of P_2O_5 (Table 3).

In general, it appears that the plants showed lower P absorption in the second season. Another factor that may have influenced the lower P absorption in the second year of cultivation is related to the lower P content in the soil used (Table 1).

Magolbo (2019) verified accumulations varying from 4 to 4.5 kg ha^{-1} of P values close to those obtained in the present study. Pellet & El-Sharkawy (1993) stated that the distinct behavior of cassava genotypes is due to the difference in dry matter partition patterns, the balance between shoot production, and the behavior of starch storage into the roots.

Analyzing the accumulation of P in the leaves, there was no difference between the cultivars at the rate of 60 kg ha^{-1} of P_2O_5. In the absence of phosphate fertilization, the highest values occurred in cultivars BRS Gema de Ovo and Recife. At the dose of 120 kg ha^{-1} of P_2O_5, there was a significant difference only between the cultivars Água Morna and Venâncio. In the other doses, the cultivar Venâncio presented greater accumulation of P in the leaves (Table 4)

It was verified that in the first crop season there was no adjustment for the model proposed for the cultivar Recife, which obtained an average accumulation of 0.445 g per plant. For the other cultivars, the data were adjusted to the quadratic model in the BRS Gema de Ovo and Venâncio cultivars, in which the highest values for each cultivar occurred at doses of 108.33 and 176.31 kg ha^{-1} of P_2O_5, with accumulations of 0.546 and 0.772 g per plant of P, for cultivars BRS Gema de Ovo and Venâncio, respectively. For the cultivar Água Morna, there was an increasing linear response, in which the highest accumulation of P (0.460 g per plant) occurred at the rate 240 kg ha^{-1} of P_2O_5 (Table 4).

Table 3. Phosphorus (P) accumulation in cassava cultivar stems as a function of P_2O_5 doses in two crops

Cultivars	Doses of P_2O_5 (kg ha^{-1})					Regression equation	R^2
	0	60	120	180	240		
1st Crop season (2018/2019)							
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 22.82%)							
Água Morna	0.260 b	0.885 b	0.682 c	0.680 b	0.593 b	$y = 0.336 + 0.0085^{*}x - 0.000032^{**}x^2$	0.79
BRS Gema de Ovo	0.819 a	1.855 a	1,454 b	1.015 ab	0.639 b	$y = 0.987 + 0.012^{**}x - 0.000057^{**}x^2$	0.74
Recife	0.829 a	1.251 ab	1.959 a	1.332 a	0.985 ab	$y = 0.782 + 0.014^{*}x - 0.000057^{**}x^2$	0.80
Venâncio	0.486 b	1.183 b	1.774 a	1.304 a	1.017 a	$y = 0.483 + 0.016^{**}x - 0.000060^{**}x^2$	0.91
2nd Crop season (2019/2020)							
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 22.46%)							
Água Morna	0.147 a	0.268 b	0.477 b	0.321 b	0.267 c	$y = 0.135 + 0.0039^{*}x - 0.00014^{**}x^2$	0.79
BRS Gema de Ovo	0.186 a	0.418 a	0.672 a	0.713 a	0.794 a	$y = 0.254 + 0.0025^{**}x$	0.91
Recife	0.143 a	0.225 b	0.445 b	0.490 b	0.371 b	$y = 0.108 + 0.0039^{**}x - 0.000011^{*}x^2$	0.88
Venâncio	0.211 a	0.397 a	0.677 a	0.798 a	0.536 a	$y = 0.163 + 0.0067^{*}x - 0.00021^{**}x^2$	0.89

Different letters in the column indicate significant differences between cultivars at p ≤ 0.05 according to the Tukey test; **, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Table 4. Phosphorus (P) accumulation in cassava cultivar leaves as a function of P_2O_5 doses in two crop seasons

Cultivars	Doses of P_2O_5 (kg ha^{-1})					Regression equation	R^2
	0	60	120	180	240		
1st Crop season (2018/2019)							
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 28.34%)							
Água Morna	0.198 b	0.301 a	0.412 b	0.378 b	0.446 b	y = 0.232 + 0.00095**x	0.84
BRS Gema de Ovo	0.414 ab	0.497 a	0.558 ab	0.488 b	0.326 b	y = 0.405 + 0.0026*x – 0.000012**x²	0.97
Recife	0.513 a	0.397 a	0.510 ab	0.329 b	0.526 ab	y = ns = 0.455	
Venâncio	0.182 b	0.510 a	0.725 a	0.758 a	0.702 a	y = 0.182 + 0.0067**x – 0.000019**x²	0.99
2nd Crop season (2019/2020)							
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 17.93%)							
Água Morna	0.178 a	0.317 ab	0.335 a	0.273 c	0.222 c	y = 0.190 + 0.0023*x – 0,000009**x²	0.89
BRS Gema de Ovo	0.273 a	0.432 a	0.437 a	0.601 a	0.549 a	y = 0.314 + 0.0012**x	0.91
Recife	0.192 a	0.298 b	0.497 a	0.476 b	0.421 b	y = 0.172 + 0.0036**x – 0.000011**x²	0.88
Venâncio	0.193 a	0.312 ab	0.368 a	0.513 ab	0.473 ab	y = 0.219 + 0.0013**x	0.88

Different letters in the column indicate significant differences between cultivars at p ≤ 0.05 according to the Tukey test; **, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

In the second season, there was no significant difference between cultivars in terms of P accumulation in cassava leaves for doses 0 and 120 kg ha^{-1} of P_2O_5. At the dose of 60 kg ha^{-1}, there was a difference only between the cultivars BRS Gema de Ovo and Recife. At doses of 160 and 240 kg ha^{-1} of P_2O_5, the highest values occurred in cultivars BRS Gema de Ovo and Venâncio, while cultivar Água Morna showed lower P accumulation in leaf tissue (Table 4).

The accumulation of P in the leaf tissue was affected in a quadratic way in the cultivars Água Morna and Recife, with the highest values occurring at doses of 127.78 and 163.63 kg ha^{-1} of P_2O_5, with maximum values of 0.339 and 0.466 g per plant, respectively. For the BRS Gema de Ovo and Venâncio cultivars, there were linear responses, with greater P accumulation occurring at the highest P_2O_5 dose (240 kg ha^{-1}), with 0.602 and 0.531 g per plant, in the BRS Gema de Ovo and Venâncio cultivars, respectively (Table 4).

This reduction in P accumulation at higher doses may be due to the antagonistic interaction of this nutrient with other elements, as excess P in the soil causes a decrease in Zn and Fe availability.

Regarding the total accumulation of P in the plants (roots, stem, and leaves), it was found that in the first crop season, total P accumulation differed among cultivars at all P_2O_5 doses. In the absence of phosphate fertilization, the highest values occurred in cultivars BRS Gema de Ovo and Recife. The cultivar BRS Gema de Ovo was superior to the other cultivars at the dose of 60 kg ha^{-1} of P_2O_5, while the cultivar Recife was superior at the dose of 120 kg ha^{-1} of P_2O_5. In the other doses, the cultivars Recife and Venâncio presented higher values (Table 5).

The total accumulations of P were affected in a quadratic way in response to the increase in the doses of P_2O_5, with the highest value estimated for the doses of 122.22, 92.39, 120.88, and 140.91 kg ha^{-1} of P_2O_5, with maximum values in 2.731, 3.418, 3.787, and 2.979 g per plant, respectively, in the cultivars Água Morna, BRS Gema de Ovo, Recife, and Venâncio (Table 5).

In the second crop season (2019/2020), there was a significant difference between the cultivars only at the dose of 60 kg ha^{-1} of P_2O_5, in which the BRS Gema de Ovo cultivar was superior to the Venâncio cultivar, and these did not differ from the others (Table 5).

As observed in the first crop season, all cultivars were affected in a quadratic way by the P_2O_5 doses. The highest accumulations of P in plants were obtained at doses of 143.94, 170.45, 182.92, and 163.63 kg ha^{-1}, in which 2.222, 2.307, 2.422, and 2.134 g per plant were obtained, in cultivars Água Morna, BRS Gema de Ovo, Recife, and Venâncio, respectively (Table 5).

In both crop seasons, excessive doses of P_2O_5 reduced the accumulation of P. This must have occurred because the high P content in the soil negatively affects symbiosis with mycorrhizal fungi (Lin et al., 2020), and as these fungi have a beneficial effect on plant nutrition, especially in cassava, P absorption was impaired at the highest doses.

When phosphorus is supplied to cassava, it presents positive responses, which vary mainly according to the genotype

Table 5. Phosphorus (P) accumulation in the plants of cassava cultivars as a function of P_2O_5 doses in two crop seasons

Cultivars	Doses of P_2O_5 (kg ha^{-1})					Regression equation	R^2
	0	60	120	180	240		
1st Crop season (2018/2019)							
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 19.75%)							
Água Morna	1.161 b	2.898 b	2.697 b	2.152 b	1.782 b	y = 1.387 + 0.022*x – 0.000090**x²	0.76
BRS Gema de Ovo	2.335 a	4.026 a	3.215 b	2.245 b	1.806 b	y = 2.633 + 0.017*x – 0.000092**x²	0.74
Recife	2.452 a	3.226 b	4.282 a	2.858 a	2.587 a	y = 2.458 + 0.022*x – 0.000091**x²	0.70
Venâncio	0.827 b	2.115 c	3.267 b	2.720 a	2.147 ab	y = 0.792 + 0.031**x – 0.00011**x²	0.95
2nd Crop season (2019/2020)							
(P: p ≤ 0.01; C: p ≤ 0.05; P x C: p ≤ 0.05; CV: 20.80%)							
Água Morna	0.862 a	1.693 ab	2.475 a	1.991 a	1.790 a	y = 0.855 + 0.019**x – 0,000066**x²	0.91
BRS Gema de Ovo	0.965 a	1.929 a	2.297 a	2.268 a	2.326 a	y = 1.029 + 0.015**x – 0.000044*x²	0.96
Recife	1.118 a	1.655 ab	2.167 a	2.518 a	2.101 a	y = 1.050 + 0.015**x – 0.000041**x²	0.95
Venâncio	0.757 a	1.332 b	2.158 a	2.402 a	1.879 a	y = 0.645 + 0.018**x – 0.000055**x²	0.94

Different letters in the column indicate significant differences between cultivars at p ≤ 0.05 according to the Tukey test; **, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

and availability of the nutrient in the soil (Lima et al., 2018; Katuromunda et al., 2021).

Agronomic efficiency (AE) refers to the capacity of the plant to produce roots that are more commercially viable. In the case of cassava, for each unit of P applied, it estimates the capacity and efficiency of the plant to use the P available in the soil; that is, it corresponds to the economic production obtained per unit of applied nutrient.

For this characteristic, in the two harvests periods, different responses were observed among the cultivars according to the phosphorus doses. In the first and second crop seasons, the cultivars Venâncio and BRS Gema de Ovo stood out from the others because they presented higher and lower AE values, respectively, in all doses of P_2O_5 (Table 6).

The cultivars Água Morna and Venâncio showed higher AE values in the lowest dose of phosphorus, being 180.915 and 237.360 kg kg^{-1}, respectively. The increase in P_2O_5 doses caused a linear reduction in the AE of these cultivars, so that the lowest values occurred at the highest dose, obtaining -32.925 kg kg^{-1} for the cultivar Água Morna, and 58.80 kg kg^{-1} for the cultivar Venâncio. For cultivars BRS Gema de Ova and Recife there were quadratic responses, with higher AE values at doses 220.833 and 91.153 kg ha^{-1}, with maximum values of -27.75 and 50.47 kg kg^{-1}, respectively (Table 6).

Roots with smaller specific surfaces, that is, smaller area per unit of weight, have greater contact and reactivity with the soil solution and clay minerals, allowing greater uptake of the element, which contributes to increased phosphorus use efficiency (Reis et al., 2017).

In the second harvest, the highest AE of all cultivars was observed in the lowest dose of phosphorus, being 244.752, 170.348, 166.103, and 299.863 kg kg^{-1}, in the cultivars Água Morna, BRS Gema de Ovo, Recife, and Venâncio, respectively (Table 6). The increase in P_2O_5 doses linearly reduced the AE of all cultivars, so that the lowest values occur at the dose of 240 kg ha^{-1} of P_2O_5, being 86.832 kg kg^{-1} (Água Morna), 40.612 kg kg^{-1} (BRS Gema de Ovo), 53.063 kg kg^{-1} (Recife), and 79.303 kg kg^{-1} (Venâncio) (Table 6).

These results show, for soil with medium P content, the cultivars Água Morna, Venâncio, and BRS Gema de Ovo are more responsive to phosphate fertilization. In addition, the BRS Gema de Ovo cultivar was more demanding on P. According to Santos et al. (2017), the genotypes with a high response rate are interesting, as they respond to the increase in P in the soil when cultivated in suitable environments. For Zanella et al. (2019), genotypes that are more efficient are recommended for crops that adapt from low to high technological levels.

Regarding the apparent recovery efficiency (ARE), in the first crop season, the cultivar BRS Gema de Ovo had the highest ARE at the lowest dose of P_2O_5, while the cultivar Recife had the lowest ARE. However, with the increase of the P_2O_5 doses, the cultivar Venâncio presented ARE superior to the other cultivars. In addition, it appears that, contrary to what was observed with the Venâncio cultivar, the BRS Gema de Ovo cultivar had reduced ARE (Table 7).

In this crop season (2018/2019), it appears that in the first crop there was a statistical adjustment of the quadratic models for the cultivars Água Morna, BRS Gema de Ovo, and Venâncio, and linear for the cultivar Venâncio. For the cultivars Água Morna and BRS Gema de Ovo, the highest values of ARE occurred at the rate of 60 kg ha^{-1} of P_2O_5, being 0.856 and 1.254 kg kg^{-1}, respectively. With the increase in the P_2O_5 doses, the ARE reduced until the doses 228.12 kg ha^{-1} (0.023 kg kg^{-1}) and 194.44 kg ha^{-1} (-0.107 kg kg^{-1}), respectively in the cultivars Água Morna and BRS Gema de Ovo, respectively, with a tendency to increase from these doses. For the cultivar Recife, the highest ARE (0.221 kg kg^{-1}) occurred at the rate of 90 kg ha^{-1}, decreasing from this rate onwards. In the Venâncio cultivar, the increase in P_2O_5 doses caused a linear decrease in ARE, with a variation from 0.479 to 0.095 kg kg^{-1}, for doses of 60 and 240 kg ha^{-1} of P_2O_5, respectively (Table 7).

In the second crop season, there was a significant difference between the cultivars at doses of 60 and 120 kg ha^{-1} of P_2O_5. At the dose of 60 kg ha^{-1} of P_2O_5, the highest ARE were observed in the cultivars Água Morna and BRS Gema de Ovo. For the dose of 120 kg ha^{-1} of P_2O_5, there was a difference only between the cultivars Água Morna and Recife (Table 7).

In this crop season (2019/2020), the increase in P_2O_5 doses caused a linear reduction in ARE in the cultivars Água Morna, BRS Gema de Ovo, and Recife, so that, between the doses of 60 and 240 kg ha^{-1}, the ARE varied from 0.318 to 0.066 kg kg^{-1} (Água Morna), 0.321 to 0.081 kg kg^{-1} (BRS Gema de Ovo), and 0.219 to 0.079 kg kg^{-1} (Recife). For the cultivar Venâncio, the data were adjusted to the quadratic model, with the highest ARE (0.197 kg kg^{-1}) estimated for the dose of 96.49 kg ha^{-1} of P_2O_5 (Table 7).

Table 6. Agronomic efficiency of cassava cultivars as a function of P_2O_5 doses in two crop seasons

Cultivars	Doses of P_2O_5 (kg ha^{-1})				Regression equation	R^2
	60	120	180	240		
	1st Crop season (2018/2019)					
	(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 30.63%)					
Água Morna	136.75 b	72.61 b	-4.75 b	-15.72 b	$y = 180.915 - 0.891^{**}x$	0.93
BRS Gema de Ovo	-153.75 d	-70.77 c	-40.81 d	-26.65 b	$y = -261.84 + 2.12^{**}x - 0.0048^{*}x^2$	0.99
Recife	38.22 c	67.05 b	-12.83 c	-59.31 c	$y = 7.262 + 0.948^{**}x - 0.0052^{*}x^2$	0.89
Venâncio	179.25 a	163.00 a	113.82 a	46.78 a	$y = 237.36 - 0.744^{**}x$	0.94
	2nd Crop season (2019/2020)					
	(P: p ≤ 0.01; C: p ≤ 0.05; P x C: p ≤ 0.01; CV: 20.80%)					
Água Morna	203.657 b	166.772 a	129.237 a	84.582 a	$y = 244.752 - 0.658^{**}$	0.99
BRS Gema de Ovo	107.682 c	94.207 b	-17.000c	-31.125 c	$y = 170.348 - 0.879^{**}$	0.88
Recife	127.610 c	118.472 b	93.945 b	41.485 b	$y = 166.103 - 0.471^{**}x$	0.89
Venâncio	256.152 a	166.942 a	145.517 a	79.520 a	$y = 299.863 - 0.919^{**}x$	0.95

Different letters in the column indicate significant differences between cultivars at p ≤ 0.05 according to the Tukey test; **, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

Table 7. Apparent recovery efficiency of cassava cultivars as a function of P_2O_5 doses in two crop seasons

Cultivars	Doses of P_2O_5 (kg ha^{-1})				Regression equation	R^2
	60	120	180	240		
1st Crop season (2018/2019)						
(P: p ≤ 0.01; C: p ≤ 0.01; P x C: p ≤ 0.01; CV: 26.83%)						
Água Morna	0.475 b	0.217 b	0.067 b	0.045 ab	$y = 0.856 - 0.0073^{**}x + 0.000016^{*}x^2$	0.99
BRS Gema de Ovo	0.552 a	0.057 c	-0.065 d	-0.035 c	$y = 1.254 - 0.014^{*}x + 0.000036^{*}x^2$	0.99
Recife	0.195 d	0.257 b	0.095 c	0.017 bc	$y = 0.140 + 0.0018^{**}x - 0.000010^{*}x^2$	0.86
Venâncio	0.357 c	0.337 a	0.175 a	0.092 a	$y = 0.479 - 0.0016^{**}x$	0.93
2nd Crop season (2019/2020)						
(P: p ≤ 0.01; C: p ≤ 0.05; P x C: p ≤ 0.01; CV: 19.73%)						
Água Morna	0.235 a	0.232 a	0.112 a	0.065 a	$y = 0.318 - 0{,}00105^{**}x$	0.89
BRS Gema de Ovo	0.270 a	0.197 ab	0.120 a	0.095 a	$y = 0.321 - 0.0010^{**}x$	0.96
Recife	0.175 b	0.155 b	0.132 a	0.067 a	$y = 0.219 - 0.00058^{**}x$	0.91
Venâncio	0.187 b	0.196 ab	0.150 a	0.077 a	$y = 0.144 + 0.0011^{**}x - 0.0000057^{**}x^2$	0.99

Different letters in the column indicate significant differences between cultivars at p ≤ 0.05 according to the Tukey test; **, *, ns - Significant at p ≤ 0.01 and p ≤ 0.05, and not significant by F test; R^2 - Coefficient of determination; CV - Coefficient of variation

In general, it appears that the soil with the highest P content presented higher ARE at the lowest P_2O_5 doses. However, high doses drastically reduced the ARE. On the other hand, plants grown in soil with lower P content showed an increase in ARE with phosphate fertilization, demonstrating the need for higher doses of P_2O_5. The nutrient ARE is the rate of nutrients absorbed by the plant from the applied fertilizer. Thus, high doses of P_2O_5 resulted in lower ARE indices, possibly indicating that the lowest doses of P_2O_5 applied were sufficient to meet the nutritional requirements of the plants.

The low P recovery may be related to the high Fe and Al contents in the soil that fix or immobilize the P, which make it unavailable to plants (Fageria, 2009). Furthermore, when a plant is in a low availability P environment, it tends to use it more efficiently, contrary to what is observed when the plant is subjected to a condition of high availability of this nutrient, in this sense, at high doses the plant tends to be less efficient at absorption.

Conclusions

1. Cultivars Água Morna, and Recife export more phosphorus through their roots.
2. The cultivars Venâncio and Água Morna show greater agronomic efficiency when fertilized with 60 kg ha^{-1} of P_2O_5.
3. The apparent P recovery efficiency presented the following order: 'BRS Gema de Ovo' > 'Água Morna' > 'Venâncio' > 'Recife', with higher indices at the dose of 60 kg ha^{-1} of P_2O_5.

Literature Cited

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org:10.1127/0941-2948/2013/0507

Coelho Filho, M. A. Irrigação da cultura da mandioca. Cruz das Almas: EMBRAPA, 2020. 12p. Comunicado Técnico 172

Donagema, G. K.; Campos, D. V. B.; Calderano, S. B.; Teixeira, W. G.; Viana, J. H. M. Manual de métodos de análises de solos. 2.ed. Rio de Janeiro: Embrapa Solos, 2011.

Fageria, N. K. The use of nutrients in crop plants. Boca Raton: CRC Press, 2009. 430p.

FAO - Organização das Nações Unidas para a Alimentação e Agricultura. Proteção da mandioca, uma cultura negligenciada, de pragas e doenças. 2019. Available on: <http://www.fao.org/3/ca7117en/CA7117EN.pdf >. Accessed on: Nov. 2021.

Ferreira, D. F. Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia, v.38, p.109-112, 2014. https://doi.org/10.1590/S1413-70542014000200001

Fink, J. R.; Inda, A. V.; Tischer, T.; Barrón, V. Iron oxides and organic matter on soil phosphorus availability. Ciência Agrotecnologia, v.10, p.369-379, 2016. https://doi.org/10.1590/1413-70542016404023016

Fukuda, W. M. G.; Guevara, C. L. Descritores morfológicos e agronômicos para a caracterização de mandioca (*Manihot esculenta* Crantz). Cruz das Almas: EMBRAPA CNPMF, 1998. 38p.

Gautier, A.; Cookson, S. J.; Hevin, C.; Vivin, P.; Lauvergeat, V.; Mollier, A. Phosphorus acquisition efficiency and phosphorus remobilization mediate genotype-specific differences in shoot phosphorus content in grapevine. Tree Physiology, v.38, p.1742-1751, 2018. https://doi.org/10.1093/treephys/tpy074

Katuromunda, S.; Ekwaro, B.; Wanaku, B. Yield performance of newly developed cassava varieties in response to inorganic fertilizers. Modern Applied Science, v.15, p.60-68, 2021. http://dx.doi.org/10.5539/mas.v15n4p60

Kumar, A.; Shahbaz, M.; Koirala, M.; Blagodatskaya, E.; Seidel, S. J.; Kuzyakov, Y.; Pausch, J. Root trait plasticity and plant nutrient acquisition in phosphorus limited soil. Journal of Plant Nutrition and Soil Science, v.182, p.945-952, 2019. https://doi.org/10.1002/jpln.201900322

Lima, A. G. de; Carvalho, L. R. de; Mota, M. C.; Lima Júnior, A. F. de; Moreira, J. M.; Silva, A. P. da; Barbuio, R.; Rosa, J. Q. S. Produtividade de mandioca avaliada sobre adubação fosfatada e adubação de cobertura. PUBVET, v.12, p.1-4, 2018.

Lin, C.; Wang, Y.; Liu, M.; Li, Q.; Xiao, W.; Song, X. Effects of nitrogen deposition and phosphorus addition on arbuscular mycorrhizal fungi of Chinese fr (*Cunninghamia lanceolata*). Scientific Reports, v.10, p.1-8, 2020. https://doi.org/10.1038/s41598-020-69213-6

Magolbo, L. A. S. Efeito da adubação fosfatada no crescimento, produtividade e acúmulo de fósforo e amido em mandioca para indústria. Botucatu: UNESP, 2019. 63p. Dissertação Mestrado

Malavolta, E.; Vitti, G. C.; Oliveira, S. A. Avaliação do estado nutricional das plantas: princípios e aplicações. 2.ed. Piracicaba: Associação Brasileira de Potassa e do Fósforo, 1997. 319p.

Milić, S.; Ninkov, J.; Zeremski, T.; Latković, D.; Šeremešić, S.; Radovanović, V.; Žarković, B. Soil fertility and phosphorus fractions in a calcareous chernozem after a longterm field experiment. Geoderma, v.339, p.9-19, 2019. https://doi.org/10.1016/J.GEODERMA.2018.12.017

Oliveira, L. B. de; Oliveira Júnior, A. do R.; Machado, E. B. N.; Silva, B. M. A.; Carvalho, G. P. de; Silva, B. C. R.; Avaliação da produtividade de mandioca em função de diferentes doses de fósforo. Brazilian Journal of Development, v.6, p.72441-72452, 2020. https://doi.org/10.34117/bjdv6n9-624

Omondi, J. O.; Lazarovitch, N.; Rachmilevitch, S.; Yermiyahu, U. Phosphorus affects storage root yield of cassava through root numbers. Journal of Plant Nutrition, v.42, p.2070-2079, 2019. https://doi.org/10.1080/01904167.2019.1655033

Pelá, A.; Gonçalves, R. N.; Pereira, F. de S.; Rodrigues, F.; Cruz, S. J. S. Phosphorus use efficiency in maize as a function of different sources. Australian Journal of Crop Science, v.11, p.71-75. 2017. https://doi.org/10.21475/ajcs.2017.11.01.236

Pellet, D.; El-Sharkawy, M. A. Cassava varietal response to phosphorus fertilization. II. Phosphorus uptake and use efficiency. Field Crops Research, v.35, p.13-20, 1993.

Rêgo, L. G. da S.; Martins, C. M.; Silva, E. F. da; Silva, J. J. da; Lima, R. N. da S. Pedogenesis and soil classification of an experimental farm in Mossoró, state of Rio Grande do Norte, Brazil. Revista Caatinga, v.29, p.1036-1042, 2016. https://doi.org/10.1590/1983-21252016v29n430rc

Reis, G. G. dos; Pereira, F. B.; Granato, I. S. C.; Dovale, J. C.; Fritsche-Neto, R. Tropical maize selection indexes genotypes for efficiency in use of nutrients: phosphorus. Revista Ceres, v.64, p.266-273, 2017. https://doi.org/10.1590/0034-737X201764030007

Santos, M. M. dos; Santos, M. G. dos; Souza, A. C.; Montelo, A. B.; Silva, D. L. da; Araújo, L. C.; Ribeiro, R. R.; Santos, L. L. dos. Produtividade de genótipos de mandioca em função de dose de fósforo no município de Gurupi-TO. Brazilian Journal of Development, v.7, p.1-12, 2021. https://doi.org/10.34117/bjdv7n10-365

Santos, W. F. dos; Silva, R. M.; Sodré, L. F.; Maciel, L. C.; Aguiar, R. W. S.; Cangussu, A. S. R.; Santos, M. M. Resposta e eficiência ao uso do nitrogênio em genótipos de milho tropicais. Revista Tecnologia & Ciência Agropecuária, v.11, p.7-12, 2017.

Silva, A. D. A. da; Gomes, R. V. A. Macaxeira. In: Cavalcanti, F. J. de A. (ed.). Recomendações de adubação para o Estado de Pernambuco: 2ª aproximação. 3.ed. Revisada. Recife: Instituto Agronômico de Pernambuco, 2008. 164p.

Silveira, F. P. da M.; Lopes, W. A. R.; Oliveira, P. R. H. de; Lima, F. L. dos S.; Silveira, L. M. da; Barros Júnior, A. P. Quality of table cassava roots fertilized with phosphorus. Revista Caatinga, v.34, p.965-975, 2021. http://dx.doi.org/10.1590/1983-21252021v34n424rc

Taiz, L.; Zeiger, E.; Moller, I. M.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: ArtMed, 2017. 858p.

Uchôa, S. C. P.; Nascimento, F. R. do; Alves, J. M. A.; Melo, V. F.; Silva, D. C. O. da; Silva, A. J. da; Batista, K. D.; Matos, K. da S.; Albuquerque, J. A. A. de. Phosphorus fertilizer in the yield and quality of tuberous roots of cassava cultivars in the Amazonian savanna, Brazil. Revista de Ciências Agrárias, v.43, p.381-389, 2020. https://doi.org/10.19084/rca.20746

Zanella, R.; Meira, D.; Zdziarski, A. D.; Brusamarello, A. P.; Oliveira, P. H. de; Benin, G. Performance of common bean genotypes as a function of growing seasons and technological input levels. Pesquisa Agropecuária Tropical, v.49, p.1-10, 2019. http://dx.doi.org/10.1590/1983-40632019v4954989