BIOSCIENCE JOURNAL

AGRONOMIC PERFORMANCE OF CASSAVA FERTILIZED WITH PHOSPHORUS DOSES

Flávio Pereira da Mota SILVEIRA[1], Welder de Araújo Rangel LOPES[2], Pedro Ramon Holanda DE OLIVEIRA[3], Manoel Galdino DOS SANTOS[2], Alex Lima MONTEIRO[2], Gisele Lopes DOS SANTOS[2], Silvana Fraga DA SILVA[2], Ênio Gomes Flôr SOUZA[4], Lindomar Maria DA SILVEIRA[5], Aurélio Paes BARROS JÚNIOR[5]

[1] Academic Unit Specialized in Agricultural Sciences, Universidade Federal do Rio Grande do Norte, Macaíba, Rio Grande do Norte, Brazil.
[2] Postgraduate Program in Phytotechnics, Universidade Federal Rural do Semiárido, Mossoró, Rio Grande do Norte, Brazil.
[3] Zootechnics Department, Universidade Federal do Ceará, Fortaleza, Ceará, Brazil.
[4] Agronomic Engineering Course, Instituto Federal de Educação, Ciência e Tecnologia de Alagoas, Piranhas, Alagoas, Brazil.
[5] Department of Agronomic and Forestry Sciences, Universidade Federal Rural do Semiárido, Mossoró, Rio Grande do Norte, Brazil.

Corresponding author:
Flávio Pereira da Mota Silveira
flaviopms@hotmail.com

How to cite: SILVEIRA, F.P.M., et al. Agronomic performance of cassava fertilized with phosphorus doses. *Bioscience Journal*. 2023, **39**, e39077. https://doi.org/10.14393/BJ-v39n0a2023-65423

Abstract

We have evaluated the agronomic performance of table cassava cultivars fertilized with phosphorus doses in the Brazilian Semiarid Region. Two agricultural crops were grown at the Rafael Fernandes Experimental Farm, Mossoró, RN, from June/2018 to April/2019 and from June/2019 to April/2020. The experimental design was in randomized blocks, arranged in subdivided plots, with four replications. In the plots, doses of phosphorus were applied (0, 60, 120, 180 and 240 kg P_2O_5 ha^{-1}), and in the subplots, the table cassava cultivars (Água Morna, BRS Gema de Ovo, Recife and Venâncio). The following were evaluated: dry matter of leaf, stem, and commercial root; harvest index; commercial root number; commercial productivity and aerial part productivity. The cultivars used had high root and aerial part productivities indicating that their irrigated cultivation is appropriate under the conditions of the Semiarid region of Rio Grande do Norte. The cultivars Água Morna, BRS Gema de Ovo and Recife are more efficient in the use of phosphorus, obtaining high productivity even in the absence of phosphate fertilization. The cultivar Venâncio is more responsive to phosphate fertilization, as it needs an input of this nutrient to increase its productivity.

Keywords: Commercial root. Genotypes. *Manihot esculenta*. Phosphate fertilization. Productivity.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is among the seven most cultivated agricultural crops in the world (FAOSTAT 2018). In 2017, Brazil produced 6.6 million tons of table cassava in an area of 740,611 hectares and an average productivity of 8.9 t ha^{-1} (IBGE 2017). The Brazilian Semiarid region produced 625 thousand tons of root, representing 9.5% of the national production, and an average productivity of 4.8 t ha^{-1}.

The adaptability of cassava varieties to various edaphoclimatic conditions, even in regions with dry climates and poor soils, has made it widely cultivated (Isitor et al. 2017). The low productivity of the crop among the majority of producers occurs due to the insufficient use of agricultural inputs and the rudimentary management system (El-Sharkawy 2004; Alves et al. 2012), that substantially limit the potential that the crop could reach. Another important factor is the successive cultivation in the same area, without the adequate replacement of nutrients in the soil. Research has proven that it is possible to obtain production in the face of adverse situations and with abiotic stresses (Howeler 2002; El-Sharkawy 2004; Carvalho et al. 2007), which proves the efficiency of cassava in absorbing nutrients, even when grown in soils with low fertility. However, it is a crop that responds well to fertilization (Howeler 2002).

The supply of nutrients through the use of fertilizers in the cassava culture is an indispensable practice, despite being recognized as a rustic culture (Silva et al. 2013). Alves et al. (2012), Alves Filho et al. (2015), Cuvaca et al. (2017) and Biratu et al. (2018) observed the effect of fertilization in increasing productivity for cassava. However, studies in which the isolated effect of phosphorus (P) on root production are still scarce (Sieverding and Howeler 1985; Pellet and El-Sharkawy 1993a; Pellet and El-Sharkawy 1993b; Enck et al. 2017; Lima et al. 2018; Omondia et al. 2019), which demonstrates that it is necessary to intensify this line of research.

Cassava is efficient in absorbing P (Howeler 2002) and also responsive to its application (Lima et al. 2018), which makes it a key nutrient for the high productivity of the crop (Akanza and Yao-Kouame 2011). In conditions of low availability of this nutrient, cassava is able to extract from the soil what it needs for its metabolic activities. In addition, according to Howeler (2002), the response of cassava to the application of P may also be related to the association with mycorrhizal fungi and the variety used. Phosphorus provides an increase in the leaf area index, an increase in shoot biomass production, an increase in liquid photosynthesis rates and an increase in root yield (Omondia et al. 2019).

The cassava genotypes have different absorption and efficiency capacities for the use of P (Pellet and El-Sharkawy 1993a). Varieties that have a higher density of thin and elongated roots have a greater capacity for P absorption. Thus, there are varieties that have the ability to grow better in soils with low levels of P.

Cassava reaches increases in root productivity with the application of increasing doses of P (up to 160 kg ha^{-1} of P_2O_5) in soils with low nutrient availability: 1.44 mg dm^{-3} (Lima et al. 2018), 2 mg dm^{-3} (Burgos and Cenoóz 2012; Enck et al. 2017), 2-15 mg dm^{-3} of P (Silva et al. 2013). Pellet and El-sharkawy (1993b) observed different cassava cultivars responded differently in terms of their production of roots and aerial parts, with cultivars showing an increase in the production of roots and aerial part, while one cultivar did not obtain an increase in yield for the roots, only presenting an effect for the aerial part.

The objective of the presented research was to evaluate the agronomic performance of table cassava cultivars fertilized with different doses of P in the Brazilian Semiarid Region.

2. Material and Methods

Site description

The experiments were carried out at the Rafael Fernandes Experimental Farm (5°03'31.00"S, 37°23'47.57"W and 80 m altitude), belonging to the Federal Rural University of the Semi-arid (UFERSA), located in the district of Alagoinha, a rural area of the city of Mossoró, Rio Grande do Norte, in two agricultural crops 2018/19 and 2019/20.

The local climate, according to the Köppen classification, is of the BSh type (Alvares et al. 2013), characterized as being dry and very hot, with two climatic seasons: a rainy one that covers the months from February to May, and another dry one which goes from June to January. The meteorological variables were collected in a station present at the Experimental Farm during the period of the experiments (Figure 1).

The local soil was classified as Typical Rhodustults (Rêgo et al. 2016). Soil samples were collected at depths of 0-0.20 m and 0.20-0.40 m for chemical (Silva 2009) and physical (Donagema et al. 2011) characterization of the agricultural crop areas (Table 1).

Experimental design and treatments

The experimental design was in randomized blocks, in split plots, with four replications. In the plots the five P doses were applied in foundation, corresponding to each treatment: 0; 60; 120; 180 and 240 kg ha^{-1} of P_2O_5. In the subplots, the four table cassava cultivars were arranged: Água Morna, BRS Gema de Ovo, Recife e Venâncio

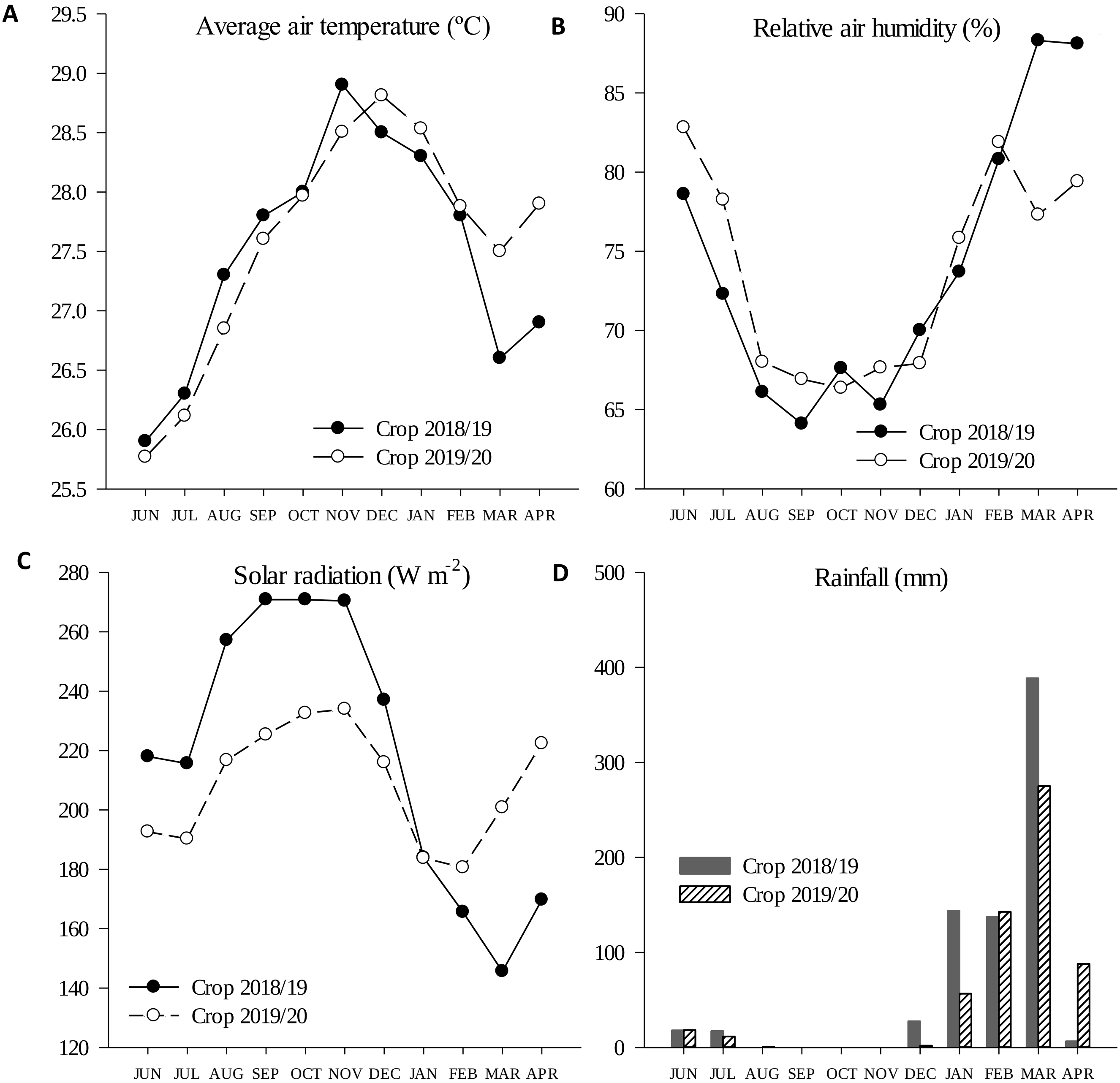

Figure 1. A - Average values of average air temperature, B - relative humidity, C - solar radiation and D - accumulated rainfall in the two agricultural crops of table cassava (2018/19 and 2019/20).

The cultivars worked had diversity in the characteristics of the root. The pulp color varied from cream (Água Morna) to yellow (BRS Gema de Ovo) and white (Recife and Venâncio). The colors of the root cortex included pink (Água Morna and Venâncio) and white or cream (BRS Gema de Ovo and Recife). The external root color was dark brown for all cultivars.

Each experimental unit consisted of four lines 6 m long, spaced 1.0 m apart, totaling an area of 24 m^2 (6 m x 4 m). The two central lines, discarding a plant at each end, were taken as the useful area of the experimental unit (9.6 m^2).

Table 1. Chemical and physical analysis of the soil in the experimental areas (depths 0-0.20 m and 0.20-0.40 m) in agricultural crops 2018/19 and 2019/20.

Depth	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Sand	Silt	Clay
m		-----mg dm^{-3}-----			--cmolc dm^{-3}--		-----kg kg^{-1}-----		
				1st Crop (2018/19)					
0-0.20	5.90	8.3	38.9	1.2	0.80	0.50	0.91	0.02	0.07
0.20-0.40	5.50	2.0	50.8	1.2	0.70	0.20	0.88	0.03	0.09
				2nd Crop (2019/20)					
0-0.20	5.90	3.7	41.1	9.3	0.60	0.20	0.91	0.02	0.07
0.20-0.40	4.90	0.9	24.3	8.3	0.50	0.10	---	---	---

Crop management

The soil preparation 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 before the installation of the experiments. Fertilization was carried out adapting the recommendations of Silva and Gomes (2008) based on soil analysis, with the exception of the P, in which the treatments were taken into account. In each agricultural crop, 30 kg ha^{-1} of nitrogen (N) and 40 kg ha^{-1} of potassium (K) were applied. As a source of N, P and K, urea (45% N), simple superphosphate (18% P_2O_5) and potassium chloride (60% K_2O) were used, respectively. The phosphate fertilization was done entirely in planting. Half of the recommended N dose was applied at 30 days after emergence (DAE) of the plants, together with the total dose of K, and at 60 DAE the second half of N fertilization was applied. Both N and K were applied via the irrigation system, through a bypass tank ("lung").

The propagating material was obtained from a multiplication area installed at the Rafael Fernandes Experimental Farm, planted ten months before the installation of the experiments, with cultivation conditions similar to those used in the research. The planting was done manually, with a handle of 0.10-0.15 m length and 5-7 buds, per pit, at 0.10 m depth, at 1.00 m spacing between rows by 0.60 m between pits, making for a population density of approximately 16,666.7 plants ha^{-1}.

The crop was irrigated by a drip system, with emitters spaced at 0.30 m and flow rate of 1.6 L h^{-1}, with a mean daily blade of 4.8 mm, suspending the irrigation eight months after planting. Culture coefficient (Kc) was used for each phenological phase of cassava. Three weeds were required for weed control. And due to the occurrence of mites, a commercial product with active ingredient spiromesifene (240 g L^{-1}) was used to control the infestation.

Harvest and evaluated variables

On the eve of the experiment harvest, two whole plants were collected from each subplot to evaluate the following characteristics: leaf dry matter (kg $plant^{-1}$), stem (kg $plant^{-1}$) and commercial root (kg $plant^{-1}$), obtained from a sample in the plot and placed to dry in a forced circulation oven at 65°C until weight stabilization, as well as plant dry matter (kg $plant^{-1}$) obtained by adding the dry matter of each part of the plant.

The production characteristics were recorded at the harvest of each crop, evaluating: harvest index (%), calculated by the ratio between the commercial root dry matter and the plant dry matter, the number of commercial root per plant, obtained by counting those root with a length greater than 0.10 m and a diameter greater than 0.02 m, commercial root productivity (t ha^{-1}), estimated from the weighing of commercial root per subplot, and the aerial part productivity (t ha^{-1}), estimated by weighing the stem and leaves of plants in the useful area of each subplot.

Statistical analysis

For each agricultural crop, the results obtained were subjected to an analysis of variance by the *F* test (P <0.05), using the SISVAR 5.6 program (Ferreira, 2014). Subsequently, a joint analysis was performed for characteristics with homogeneity of variances between agricultural crops. For the phosphorus doses, regression analyses were performed using the Table Curve 2D application v5.01 (Jandel Scientific 1991), the equations being chosen based on the coefficient of determination and its significance. The graphics were created using the SigmaPlot program, version 12.0 (Systat Software 2011). The averages for cassava cultivars were compared using the Tukey test at the 5% confidence level.

3. Results

Commercial root, stem, leaf and plant dry matter

In the first agricultural crop, the doses of P had different effects on the commercial root dry matter, depending on the cultivar (Figure 2A). It was observed that the cultivar BRS Gema de Ovo had a decrease in comercial root dry matter with increasin doses of P, reaching an estimated maximum dry matter of 0.998 kg plant^{-1} with the treatment without application of phosphate fertilizer in the soil. This may indicate that this cultivar is efficient on soils with reduced fertility, and is not sensitive to P deficiency. On the other hand the cultivar Venâncio responded to the application of the doses of the element, with an estimated maximum of 0.619 kg plant^{-1} with 151.05 kg ha^{-1} of P_2O_5. No regression adjustment was found for the cultivars Água Morna and Recife, with maximum comercial root dry matter 1.170 and 1.295 kg plant^{-1} with a dose of 120 kg ha^{-1} of P_2O_5.

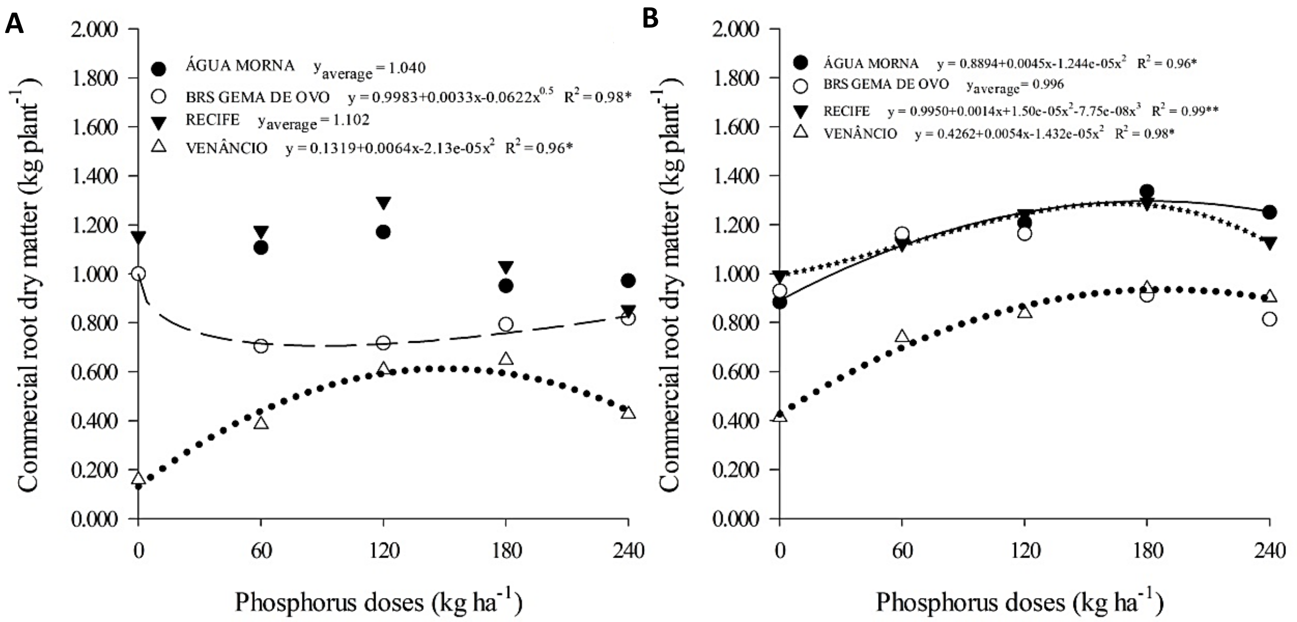

Figure 2. Commercial root dry matter of table cassava cultivars fertilized with doses of phosphorus in two agricultural crops, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

In the second agricultural crop (Figure 2B), all cultivars responded to the application of phosphate fertilizer. The cultivar Água Morna obtained the maximum commercial root dry matter estimated at 1.302 kg plant^{-1} with 182.10 kg ha^{-1} of P_2O_5; BRS Gema de Ovo had 1.163 kg plant^{-1} with 120 kg ha^{-1} of P_2O_5 (no regression adjustment model was found); Recife reached 1.291 kg plant^{-1} with 166.22 kg ha^{-1} of P_2O_5; and Venâncio 0.936 kg plant^{-1} with 188.64 kg ha^{-1} of P_2O_5.

The cultivars Água Morna and Venâncio reached maximum estimated values of stem dry matter of 0.956 and 1.280 kg plant^{-1} with 189.56 and 133.76 kg ha^{-1} of P_2O_5, respectively, in the crop 2018/19 (Figure 3A). The cultivar BRS Gema de Ovo had the highest stem dry matter of 1.232 kg plant^{-1} with a dose of 60 kg ha^{-1} of P_2O_5. As for the cultivar Recife, the highest stem dry matter recorded was 1.317 kg plant^{-1} with a dose of 120 kg ha^{-1} of P_2O_5.

In the second year of cultivation (Figure 3B), the cultivar Água Morna did not show regression adjustment for P doses, with maximum stem dry matter of 0.512 kg plant^{-1} with the dose of 120 kg ha-1 of

P_2O_5. With the BRS Gema de Ovo cultivar, an estimated maximum stem dry matter of 0.779 kg plant^{-1} was observed with 114.47 kg ha^{-1} of P_2O_5. The cultivar Recife showed a linear increasing effect for this variable in this crop, obtaining a maximum of 0.674 kg plant^{-1} with 240 kg ha^{-1} of P_2O_5 and the cultivar Venâncio showed a quadratic effect for stem dry matter, reaching the estimated maximum of 0.790 kg plant^{-1} with a dose of 165.64 kg ha^{-1} of P_2O_5.

There was an interaction between P doses and cassava cultivars for the leaf dry matter variable (Figure 4). The cultivars Água Morna and Venâncio showed maximum leaf dry matter estimated with the maximum P dose applied to the soil (240 kg plant^{-1}), with 0.172 and 0.240 kg plant^{-1}, respectively. The cultivar BRS Gema de Ovo increased leaf dry matter with increasing P doses, reaching a maximum value of 0.229 kg plant^{-1} with 151.09 kg ha^{-1} of P_2O_5, then decreasing. There was no significant effect of the dose of P on the Recife variety, which presented an average of 0.163 kg plant^{-1}.

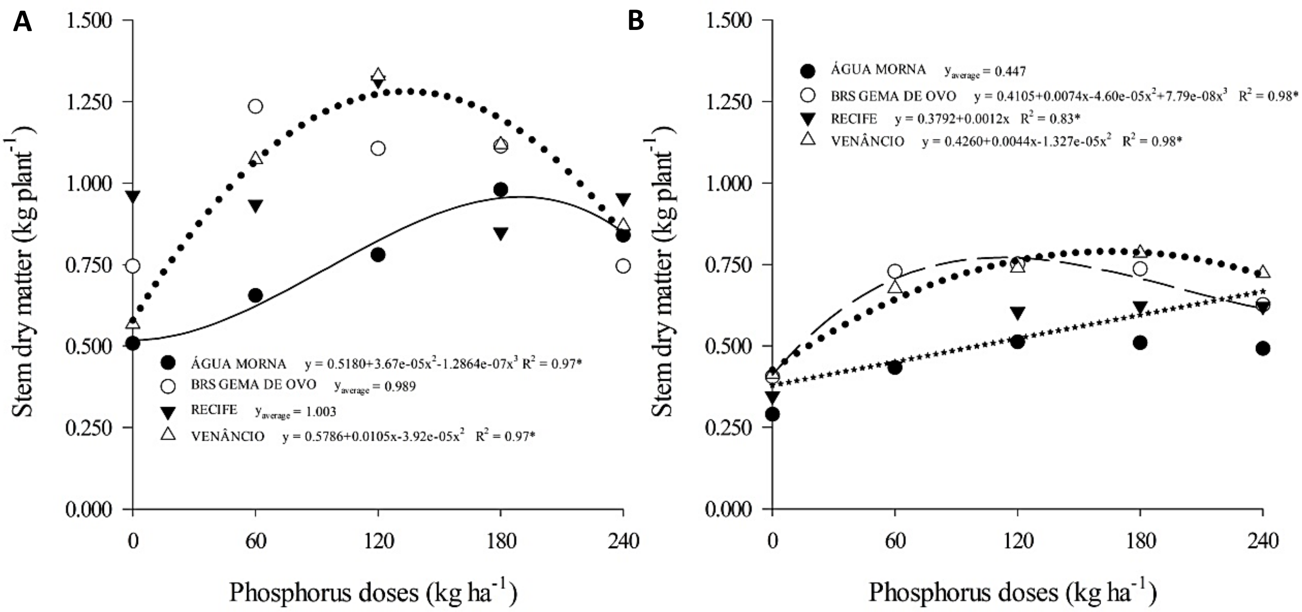

Figure 3. Stem dry matter of table cassava cultivars fertilized with doses of phosphorus in two agricultural crop, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

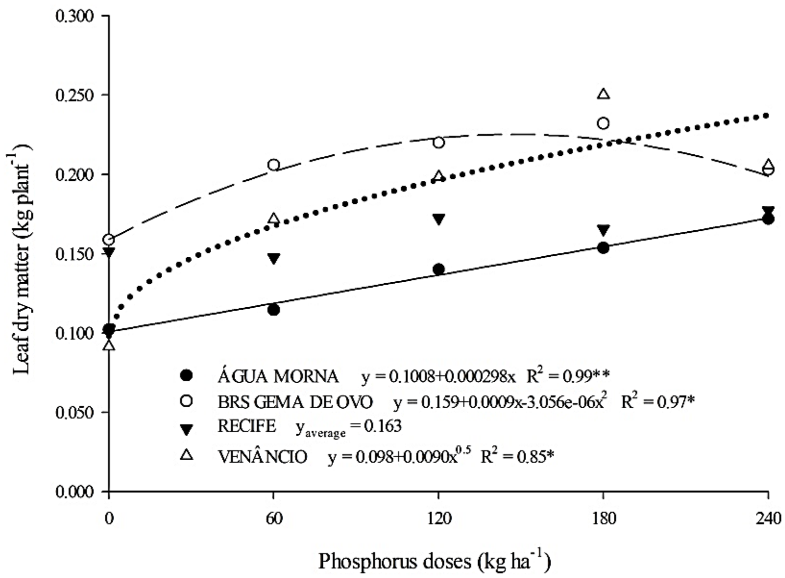

Figure 4. Leaf dry matter of table cassava cultivars fertilized with phosphorus doses in Mossoró-RN, Brazilian Semiarid.

For the variable plant dry matter, the cultivar BRS Gema de Ovo had no adjustment of regression equation in relation to P doses, obtaining an average value of 1.951 kg plant^{-1} in the first agricultural crop (Figure 5A). The cultivars Água Morna and Venâncio showed a quadratic response to the application of P in the soil, reaching a maximum plant dry matter estimated at 2.087 and 2.114 kg plant^{-1} with 169.68 and 142.83 kg ha^{-1} of P_2O_5, respectively. For the cultivar Recife, the largest plant dry matter, 2.770 kg plant^{-1}, was obtained with a dose of 120 kg ha^{-1} of P_2O_5 in the first year of cultivation.

In the second crop, all cultivars responded to the application of P (Figure 5B). The cultivars Água Morna, Recife and Venâncio obtained a quadratic response with increasing P doses, reaching 1.987 (177.10 kg ha^{-1} of P_2O_5), 2.076 (172.20 kg ha^{-1} of P_2O_5) and 1.958 kg plant^{-1} (178.10 kg ha^{-1} of P_2O_5), respectively. The BRS Gema de Ovo cultivar showed an estimated maximum plant dry matter of 2.210 kg plant^{-1} with a dose of 88.15 kg ha^{-1} of P_2O_5.

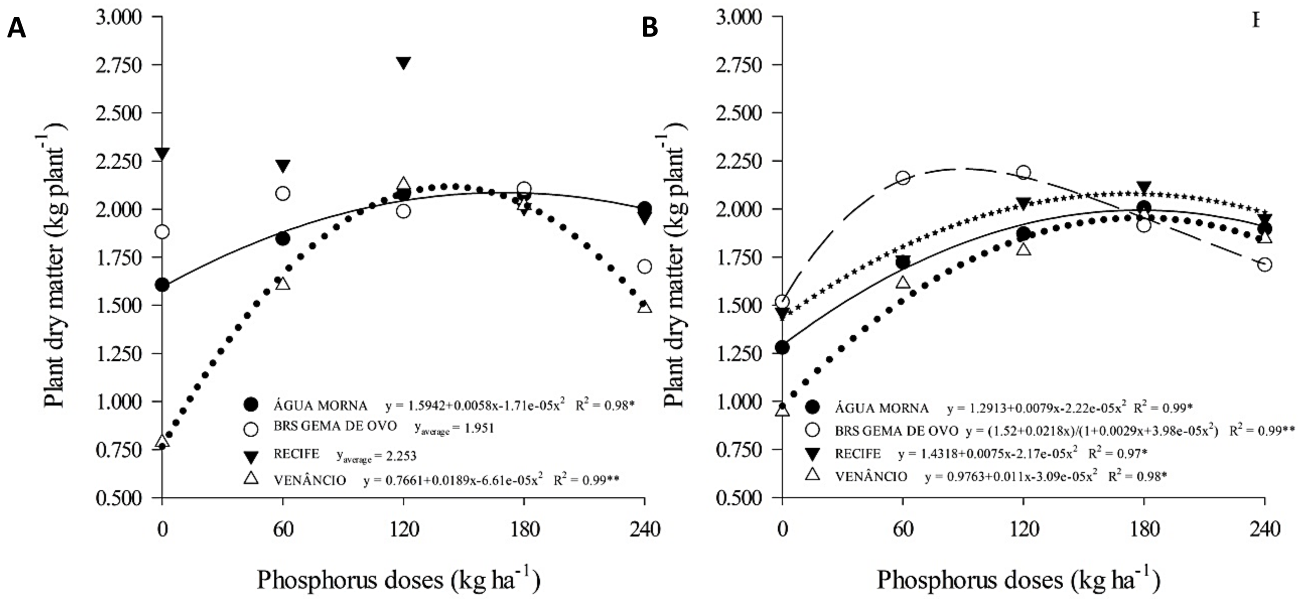

Figure 5. Plant dry matter of table cassava cultivars fertilized with doses of phosphorus in two agricultural crops, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

Harvest index

The harvest index was influenced by the interaction of phosphorus doses, cultivars and crops, with the cultivars Água Morna, BRS Gema de Ovo and Venâncio, presenting, in the first agricultural season, estimated maximum values of 59.26% (0 kg ha^{-1} of P_2O_5); 52.06% (0 kg ha^{-1} of P_2O_5) and 30.23% (173.09 kg ha^{-1} of P_2O_5), respectively (Figure 6A). For the first two cultivars, the maximum estimated value was obtained with the control treatment, due to the fact that they presented a lower value for the plant dry matter (Água Morna) and a higher value for the comercial root dry matter (BRS Gema de Ovo) making this index high. The highest harvest index obtained by the cultivar Recife in the crop 2018/19 was 51.63% obtained with the dose of 60 kg ha^{-1} of P_2O_5, however, no adjustment model was found for this regression.

In the second agricultural crop, for the cultivar Água Morna, there was no regression adjustment, presenting a higher harvest index of 64.40% with the treatment that did not receive phosphate fertilization (Figure 6B). The cultivar Venâncio showed an increasing linear behavior with phosphorus doses reaching the maximum harvest index of 48.83% with the highest phosphorus dose. The cultivars BRS Gema de Ovo and Recife had a decreasing linear response, with maximum estimated harvest index of 57.21 and 64.97%, respectively, for doses without application of P. The comercial root dry matter had little variation with the P doses for these two cultivars, while the plant dry matter expressed a greater range of variation, thus, with the increase of the plant dry matter, the harvest index decreased with the P doses for these two cultivars.

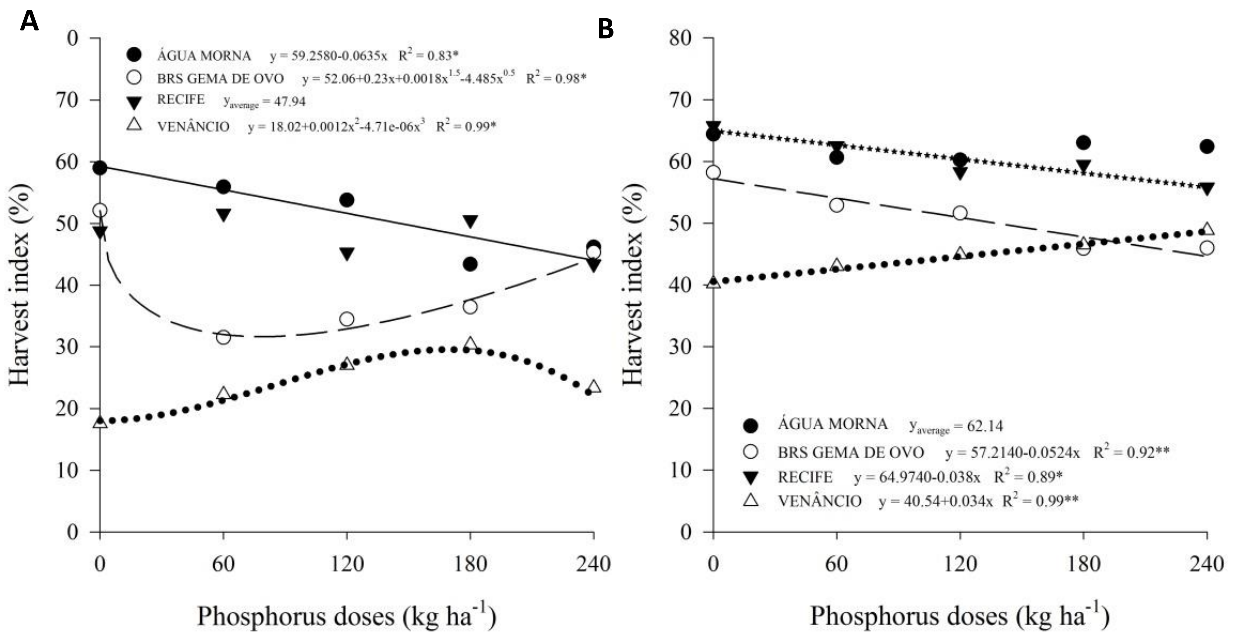

Figure 6. Harvest index of table cassava cultivars fertilized with doses of phosphorus in two agricultural crops, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

Commercial root number

In both crops, the cultivar Água Morna showed the highest averages for commercial root number (Table 2). The cultivars Água Morna, BRS Gema de Ovo and Venâncio showed no differences for commercial root number between the two evaluated agricultural crops. The cultivar Recife had higher commercial root number in the crop 2018/19 compared to the second crop. The cultivar Venâncio had the lowest number of roots among the cultivars evaluated in the two crops.

Table 2. Average values of commercial root number per plant of table cassava cultivars, in two agricultural crops, Mossoró-RN, Brazilian Semiarid.

Crop	Cultivar			
	Água Morna	BRS Gema de Ovo	Recife	Venâncio
2018/19	5.68 Aa[1]	4.23 Ba	4.40 Ba	3.16 Ca
2019/20	5.56 Aa	4.54 Ba	3.85 Cb	3.44 Ca

[1]Means followed by different lower case letters in the column and different upper case letters in the row differ, at the level of 5% probability, by the Tukey test.

Similar results for the commercial root number have also been reported by Tironi et al. (2015), who observed a difference in the commercial root number of five cassava cultivars, as well as a difference between the two agricultural crops evaluated.

Commercial root productivity

In the first crop, the commercial root productivity of the cultivars Recife and Venâncio were maximal, 59.36 and 28.48 t ha^{-1}, when 105.64 kg ha^{-1} and 148.05 kg ha^{-1} of P_2O_5, respectively, were applied (Figure 7A). This was a percentage increase of 6.82% and 213.31% in commercial root productivity with the maximum estimated dose in relation to the control for the cultivars Recife and Venâncio, respectively. The cultivar BRS Gema de Ovo had the highest productivity (47.64 t ha^{-1}) when there was no application of P. No adjustment equation model was found for the cultivar Água Morna, with the highest productivity of 54.87 t ha^{-1} at a dose of 120 kg ha^{-1} of P_2O_5, which corresponds to a 20% increase in relation to no fertilization by phosphates.

In the second crop, there was a significant effect of P doses for all cultivars. The maximum estimated commercial root productivity and respective doses were 62.86 t ha^{-1} (189.29 kg ha^{-1} of P_2O_5), 57.72 t ha^{-1} (79.42 kg ha^{-1} of P_2O_5), 60.35 t ha^{-1} (158.77 kg ha^{-1} of P_2O_5) and 40.38 t ha^{-1} (187.50 kg ha^{-1} of P_2O_5), respectively for the cultivars Água Morna, BRS Gema de Ovo, Recife and Venâncio (Figure 7B). The increments in relation to the treatment without application of P were 53%, 26.44%, 40% and 107.72%, respectively.

Aerial part productivity

There was interaction between treatments for the productivity in terms of the aerial part (Figure 8). In the first crop, the cultivar Água Morna obtained an estimated maximum aerial part productivity of 55.62 t ha^{-1} with a dose of 240 kg ha^{-1} of P_2O_5 (Figure 8A). The cultivar BRS Gema de Ovo reached maximum estimated aerial part productivity of 82.43 t ha^{-1} with 61.80 kg ha^{-1} of P_2O_5. The cultivar Venâncio had an estimated maximum aerial part productivity of 70.98 t ha^{-1} with a dose of 160.62 kg ha^{-1} of P_2O_5. The highest aerial part productivity obtained by the cultivar Recife in the crop 2018/19 was 73.06 t ha^{-1} with a dose of 120 kg ha^{-1} of P_2O_5. The percentage increases observed between the maximum aerial part productivity estimated in relation to the treatment where there was no application of P were 102%, 70%, 23% and 132% for the cultivars Água Morna, BRS Gema de Ovo, Recife and Venâncio, respectively.

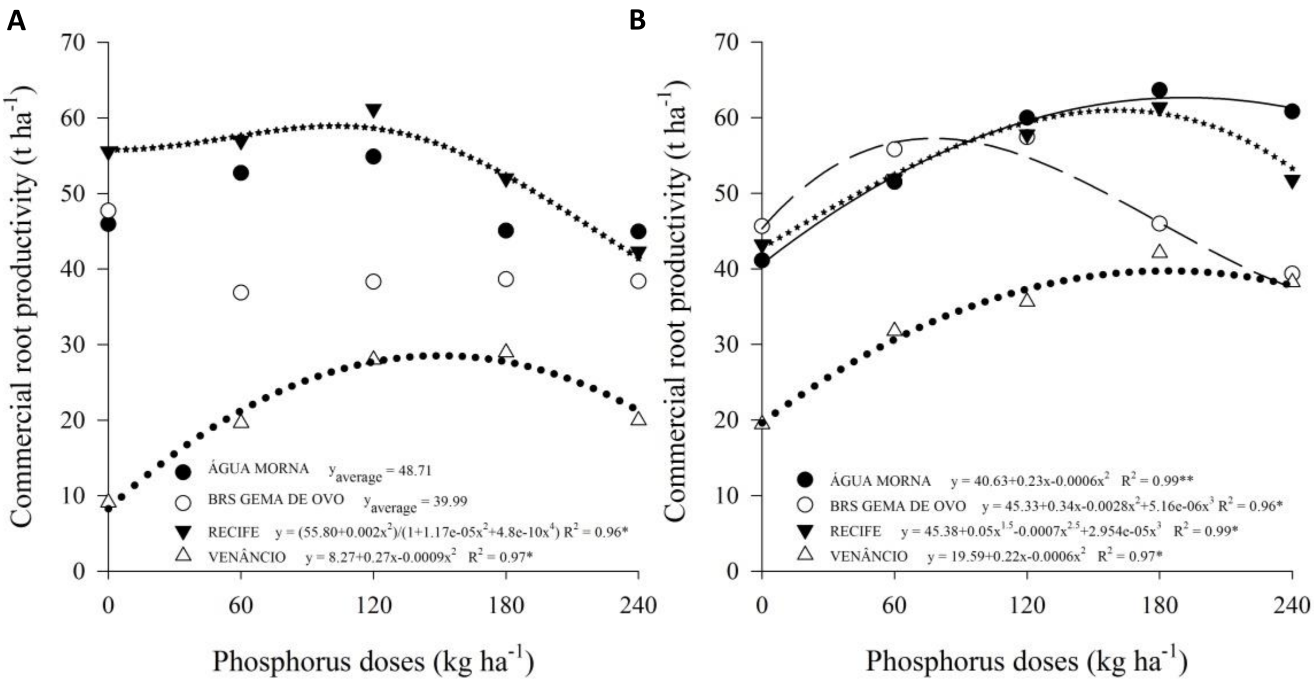

Figure 7. Commercial root productivity table cassava cultivars fertilized with phosphorus levels in two agricultural crops, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

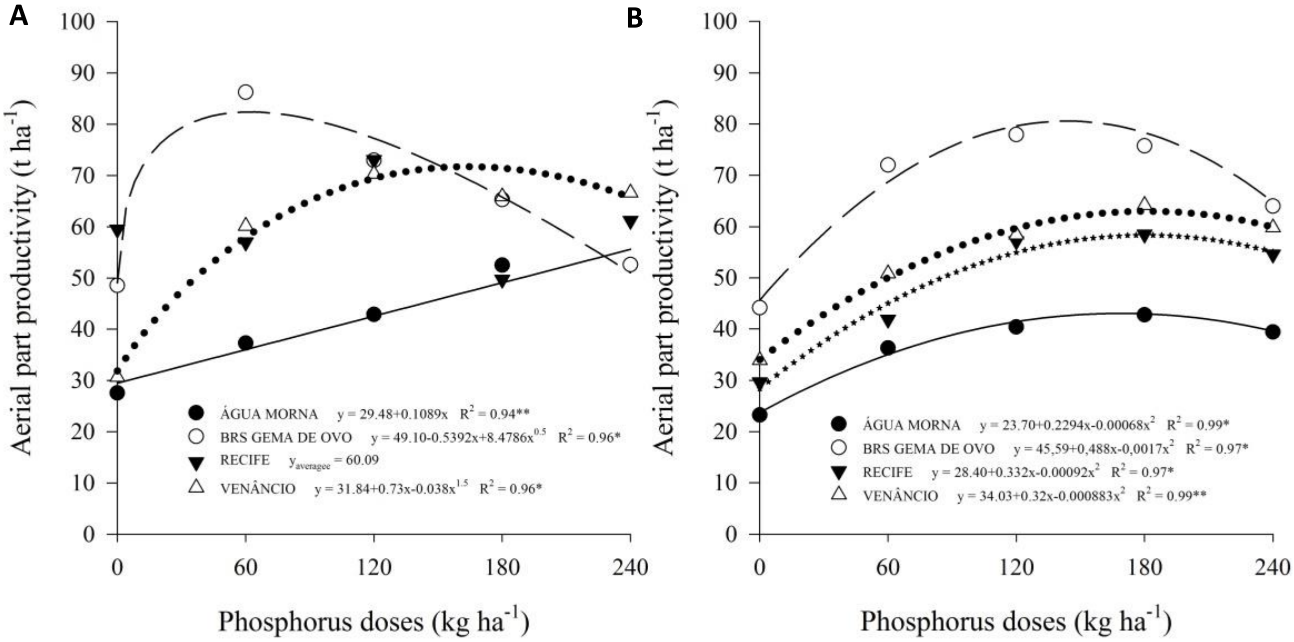

Figure 8. Aerial part productivity of table cassava cultivars fertilized with phosphorus doses in two agricultural crops, A - 2018/19 and B - 2019/20, Mossoró-RN, Brazilian Semiarid.

In the second crop, all cultivars showed a quadratic response to aerial part productivity in relation to P doses (Figure 8B). The maximum aerial part productivity obtained were estimated at 42.87 t ha^{-1} (167.10 kg ha^{-1} of P_2O_5); 80.00t ha^{-1} (140.89 kg ha^{-1} of P_2O_5); 58.32t ha^{-1} (180.40 kg ha^{-1} of P_2O_5) and 63.12 t ha^{-1} (181.52 kg ha^{-1} of P_2O_5) for the cultivars Água Morna, BRS Gema de Ovo, Recife and Venâncio respectively. These results correspond to increments of 85%, 81%, 97% and 86% was observed for the maximum aerial part productivity obtained in relation to the control for the cultivars Água Morna, BRS Gema de Ovo, Recife and Venâncio, respectively.

4. Discussion

The soil of the experimental area of the crop 2019/20 contained practically half of the P observed for the soil of the first crop 2018/19 (Table 1). This difference may have altered the composition and efficiency of mycorrhizal fungi species (Sieverding and Howeler 1985) making, for two different locations, cassava respond differently to the presence of P in the soil.

There different cassava cultivars had differences in their commercial root dry matter as a function of the dose of P (Figure 2), demonstrating that some cultivars are more efficient at nutrient absorption than others, and that some are more responsive to fertilizer application than others. This is a variable that can be indicative of the production of a cassava cultivar, as it reflects the greater accumulation of photoassimilates in the tuberous roots. Assessing the dry matter and root yield of 26 varieties of table cassava, Borges et al. (2002) observed significant variation between varieties.

The distinct behavior of cassava genotypes in soils with low P content and depending on the application of the nutrient occurs due to the difference in the dry matter partition patterns (Pellet and El-Sharkawy 1993b), the balance between aerial part production, and the behavior of the storage roots as a drain.

The estimated values in the first crop for stem dry matter were higher than in the second crop. The variations in meteorological parameters (Figure 1), highlighting the highest rainfall, especially in the first year, in the final months of cultivation, stimulated the vegetative development and the drain character of the stem of the cultivars.

There was variation between cultivars for the accumulation of leaf dry matter (Figure 4). It is observed that the cultivar Água Morna produced the least amount of dry matter for this organ. This cultivar has the highest height of the 1st branch among all evaluated and the lowest branch of the aerial part, with a tendency to produce less leaves. In the opposite direction, the BRS Gema de Ovo and Venâncio cultivars present a lower height of the 1st branch and are more likely to have a higher branch of the aerial part, thus producing a greater quantity of leaves.

The cultivars Água Morna, BRS Gema de Ovo and Recife showed, in general, higher plant dry matter in both crops for having obtained the largest comercial root dry matter and stem dry matter in both crops. On the other hand, the cultivar Venâncio expressed the lowest values for plant dry matter mainly because it obtained the lowest comercial root dry matter in both crops.

Analyzing the phenological cycle of the cassava culture, there is a greater accumulation of dry matter in the leaf and stem between 90 and 180 days after planting, the stage of crown establishment, in which the highest growth rates of these organs and the crown has its maximum size (Alves 2006). During this period, for both agricultural crops, an attack of mites followed, being more pronounced in the 2018/19 crop. This event may have caused a change in the behavior of some cultivars.

The leaves act as a source of photoassimilates, but at this stage of development they are also a drain like the stem, accumulating photoassimilates. After this phase, around December, the meteorological changes (Figure 1) favored the resumption of vegetative development of the aerial part of the cultivars. However, in the cassava phenological cycle, this is the period of greatest carbohydrate accumulation, with intense distribution of photoassimilates to the roots. With the resumption of vegetative development, the stem and roots acted as a drain. Thus, the cultivars BRS Gema de Ovo and Venâncio presented dry matter with a stem greater than or equal to the amount of dry matter of commercial root in the first year of cultivation, mainly in the treatments that suffered the most damage with the attack of the mites and high temperature and solar radiation (Figure 1).

In cassava culture, the partition of dry matter between the organs of the plants behaves in such a way that the leaves have the lowest accumulation and the roots the largest accumulation of dry matter (Beriguete et al. 2015). It is natural that this happens, since the priority of the plant is to accumulate nutrients in these reserve organs. However, Beriguete et al. (2015) observed behavior similar to that observed in this experiment for stem and commercial root dry matter for the cultivars BRS Gema de Ovo and Recife, once, to the occurrence of the attack of mites and the meteorological changes altering the phenological behavior of the culture in the photoassimilate partition. Lorenzi et al. (1981) found differences in dry matter production between two cassava cultivars due to the differentiated partition between them, with one cultivar showing higher stem dry matter than root dry matter.

The harvest index is a parameter that, by itself, is not sufficient to explain the behavior of a given cultivar (Cardoso Júnior et al. 2005). As it is obtained by the relationship between the commercial root dry matter and the plant dry matter, high values are obtained with the increase of the commercial root dry matter or with a decrease of the aerial part dry matter, indicating changes in the distribution of the dry matter between the biomass of the aerial part and the root biomass. The ideal harvest index value does not necessarily have to be high to be ideal. Appropriate values occur according to the purpose of the crop, and may be low and adequate if the purpose is to produce its aerial part, for example.

For the commercial root number, there is a tendency for variations to occur due to genetic factors inherent to each cultivar. There would not be an effect of the application of increasing P doses, a fact also observed by Enck et al. (2017), who found no difference in the number of roots between cassava cultivars fertilized with increasing doses of P. Similar results for the commercial root number have also been reported by Tironi et al. (2015), who observed a difference in the commercial root number of five cassava cultivars, as well as a difference between the two agricultural crops evaluated.

In general, it was observed that the cultivars showed high productivities, regardless of the P dose, and even without application of P, demonstrating that the cultivars are adapted to local climate conditions, even though they are influenced by the behavior of some parameters, and tolerant to soils with low P availability. The exception is the cultivar Venâncio, which showed the lowest productivities in the two agricultural crops, and it was the cultivar that showed the greatest response to the application of P in the soil, obtaining low productivity in soils without application of P, achieving increased productivity with the application of increasing doses of the element. The cultivars Água Morna, BRS Gema de Ovo and Recife were the most productive in both crops, with commercial root productivity between 35 and 65 t ha^{-1}.

It is worth mentioning that the cultivar Venâncio, among all those evaluated, had the largest shoot branch. And since the same population density was used for all evaluated cultivars, this may have impaired the performance of this cultivar, by limiting the development of the aerial part, reducing its area of light capture (production of photoassimilates) and, consequently, what would be translocated into the drain compartment (roots).

Rós et al. (2011) comment that the spacing between plants for cultivars that have greater shoot ramifications needs to be greater. The densification of these cultivars can result in a decrease in productivity as it does not allow the manifestation of their photoassimilated production potential. Add the fact that the cultivar Venâncio of this cultivar has the lowest number of roots per plant and we have the reasons for this low productivity compared to other cultivars. Pellet and El-Sharkawy (1993b) identified a positive correlation between productivity and number of roots for a cassava cultivar which showed low yield due to the reduced number of roots. On the other hand, it presented high production of aerial part, which may have limited the capacity of the root as a drain of photoassimilates. This competition for photoassimilates may also have contributed to the lower yield of cultivar Venâncio.

The cultivar Água Morna showed high productivity even without P application (Figure 7). The highest commercial root number (Table 2), with high accumulation of dry matter in the roots in the treatment without application of P (Figure 2) correlates with this effect. Likewise for the cultivar BRS Gema de Ovo, which presented a reasonable commercial root number (Table 2), regardless of the P dose used, but obtained a high comercial root dry matter (Figure 2) in treatments without application of P. Pellet and El-Sharkawy (1993b) observed a similar response in productivity roots, between two cultivars, in two crops, in the treatment without application of P.

The differences in the productivity responses of each cultivar are related to the efficiency in the use of P between them. Each cultivar has its maximum production limit and has its own particular nutritional requirements. The concentration of P in the soils (Table 1) studied was below the minimum critical point (10 mg dm^{-3} of P) for the crop (Silva and Gomes 2008).

The results obtained in each crop show what other studies have already found: Cuvaca et al. (2017) observed an increase in root productivity with the addition of phosphate fertilizer; Silva et al. (2014), Tironi et al. (2015), Omondia et al. (2019) and Kang et al. (2020) observed variation in productivity between cassava cultivars and variation for cultivars in different crops due to meteorological differences and the chemical attributes of the soil in the study sites; and Enck et al. (2017) found no difference in productivity between cassava cultivars fertilized with increasing doses of P.

Evaluating the different responses of four cassava cultivars to the application of P, Pellet and El-Sharkawy (1993b) found that one cultivar showed low productivity even with the highest doses of P. The result indicates that this cultivar has a reduced and little root system efficient in absorbing the nutrient.

The variation in the P content in the soil in the two crops changed the requirements of the same cultivar. This fact was also observed by Sieverding and Howeler (1985) and Pellet and El-Sharkawy (1993b), in which they verified different responses from cassava cultivars to phosphate fertilization between the evaluated sites, due to changes in soil characteristics. Osundare (2014) comments that P plays a fundamental role in the formation of the root system of plants, however for cassava it may or may not be linked to the processes of tuberization and increased root volume.

The variations occurring for commercial root productivity between cultivars in the two evaluated crops may be related to the diversification of mycorrhizal fungi species between the locations worked. The composition of mycorrhizal fungi species is influenced by the distinction in land use (Zobel and Öpik 2014), by the variation in soil fertility (Leff et al. 2015) and even by the cassava cultivar used (Begoude et al. 2016).

Sarra et al. (2019) observed variation in the composition of mycorrhizal fungus species between two cassava growing areas due to the variation in the available P content (9.33 and 3.88 mg dm^{-3} of P), with greater diversity in the area with lower availability of P. Similar differences in the doses of P available in the soil were observed in the experimental areas (Table 1), with a greater concentration in the soil of the first evaluated crop.

The evaluated cultivars responded significantly to the application of P doses for aerial part productivity, disagreeing with results found in other studies. Silva et al. (2013) and Burgos and Cenóz (2012) did not observe the influence of P on the aerial part production of cassava cultivars.

The high root and aerial part productivity observed in this work indicate the dual suitability of the evaluated cultivars, that is, production of root for human consumption and aerial part for animal feeding. This represents a very important strategic option for the Brazilian Semiarid region in maintaining plant and livestock production due to the limited choice of crops with this characteristic.

It is interesting to note that the cultivar Água Morna presented the lowest aerial part productivity in the two crops, which agrees with what was previously mentioned because its cultivar has the highest height of the 1st branch, and theoretically the lowest branch and crown. Cultivars that grow on a single stem and that have little branching produce a small aerial part (Rós et al. 2011). In addition, the cultivar Água Morna had the lowest values for stem dry matter (Figure 3) and leaf dry matter (Figure 4), which agrees with its lowest aerial part productivity. However, the cultivar BRS Gema de Ovo presented the highest values for stem dry matter (Figure 3) and leaf dry matter (Figure 4), which represents better aerial part productivity in both crops.

In the second crop, there was a positive correlation between aerial part productivity in the second crop (Figure 8B) and commercial root productivity (Figure 7B), in agreement with Pellet and El-Sharkawy (1993b).

The difference between crops was also reported by Silva et al. (2014) and Tironi et al. (2015), who attributed this behavior to changes in meteorological factors that occurred during growing seasons.

The change in weather conditions in the months before the cassava harvest modified the behavior of the plants that restarted their vegetative development in the two evaluated crops. For the cultivars studied, higher yields of aerial part productivity and lower productivities for comercial root productivity were observed in the first year of cultivation, reflecting the greater precipitation occurring in the four months preceding the harvest, promoting greater vegetative development in relation to the second crop, due to greater competition between the stem and the roots as a photoassimilate reserve organ.

In this research, variations were observed for the characteristics evaluated according to the studied crops, P doses and cultivars. It is to be expected that there is a natural variation, as a result of the genetic nature of the cultivars for the studied characteristics, which may be expanded or regressed in the face of the interference of abiotic factors. For the evaluated crops, the P doses caused this variation in some situations and the different meteorological conditions were also responsible for this aspect.

5. Conclusions

The doses of P influenced the agronomic performance of the cassava table cultivars in the Semiarid Region of Rio Grande do Norte.

The cultivars used obtained high root and aerial part productivity, indicating that their cultivation is appropriate under the conditions of the Semiarid Region of Rio Grande do Norte.

The cultivars Água Morna and Recife showed the highest productivities of commercial root with doses of P between 105.64 and 189.00 kg ha^{-1} of P_2O_5.

The cultivar Venâncio demanded a greater contribution of phosphate fertilization to obtain an increase in the productivity of commercial roots.

Authors' Contributions: SILVEIRA, F.P.M.: acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; LOPES, W.A.R.: conception and design, acquisition of data, analysis and interpretation of data, and critical review of important intellectual content; DE OLIVEIRA, P.R.H.: acquisition of data; DOS SANTOS, M.G.: acquisition of data; MONTEIRO, A.L.: acquisition of data; DOS SANTOS, G.L.: acquisition of data; DA SILVA, S.F.: acquisition of data; SOUZA, E.G.: critical review of important intellectual content; DA SILVEIRA, L.M.: conception and design; BARROS JÚNIOR, A.P.: conception and design and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: Not applicable.

References

AKANZA, K.P. and YAO-KOUAME, A. Fertilisation organo-minérale du manioc (Manihot esculenta Crantz) et diagnostic des carences du sol. *Journal of Applied Biosciences*. 2011, **46**, 3163-3172.

ALVARES, C.A., et al. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*. 2013, **22**, 711-728. https://doi.org/10.1127/0941-2948/2013/0507

ALVES FILHO, P.P.C., et al. Resposta da cultivar de mandioca roxinha à adubação NPK. *Revista Raízes e Amidos Tropicais*. 2015, **11**, 1-7. https://doi.org/10.17766/1808-981X.2015v11n1p1-7

ALVES, A.A.C. Fisiologia da mandioca. In: L.S. SOUZA, A.R.N. FARIA, P.L.P. MATTOS and W.M.G. FUKUDA, eds. Aspectos socioeconômicos e agronômicos da mandioca. 2006. Cruz das Almas: Embrapa Mandioca e Fruticultura Tropical, p. 138.

ALVES, R.N.B., MODESTO JÚNIOR, M.S. and FERREIRA, E.R. Doses de NPK na adubação de mandioca (*Manihot esculenta*, L) variedade Paulozinho em Moju – Pará. *Revista Raízes e Amidos Tropicais*. 2012, **8**, 65-70.

BEGOUDE, D.A.B., et al. Composition of arbuscular mycorrhizal fungi associated with cassava (*Manihot esculenta* Crantz) cultivars as influenced by chemical fertilization and tillage in Cameroon. *Journal of Applied Biosciences*. 2016, **98**, 9270-9283. http://dx.doi.org/10.4314/jab.v98i1.4

BERIGUETE, P.F., PORTUGUEZ, S.T. and CARBALLO, W.A. Evaluación de la fertilización inorgánica en el cultivo de yuca en la región norte de Costa Rica. *Tecnología en Marcha*. 2015, **28**(2), 84-101. https://doi.org/10.18845/tm.v28i2.2336

BIRATU, G.K., et al. Cassava response to the integrated use of manure and NPK fertilizer in Zambia. *Heliyon*. 2018, 4. https://doi.org/10.1016/j.heliyon.2018.e00759

BORGES, M.F., FUKUDA, W.M.G. and ROSSETTI, A.G. Avaliação de variedades de mandioca para consumo humano. *Pesquisa agropecuária brasileira*. 2002, **37**(11), 1559-1565. https://doi.org/10.1590/S0100-204X2002001100006

BURGOS, Â.M. and CENÓZ, P.J. Efectos de la aplicación de fósforo y potasio en la producción y calidad de raíces de mandioca (*Manihot esculenta* Crantz) en un suelo arenoso y clima subtropical. *Revista Científica UDO Agrícola*. 2012, **12**(1), 143-151.

CARDOSO JÚNIOR, N.S., et al. Efeito do nitrogênio em características agronômicas da mandioca. *Bragantia.* 2005, **64**(4), 651-659. https://doi.org/10.1590/S0006-87052005000400015

CARVALHO, F.M., et al. Manejo de solo em cultivo com mandioca em treze municípios da Região Sudoeste da Bahia. *Ciência e Agrotecnologia*. 2007, **31**(2), 378-384. https://doi.org/10.1590/S1413-70542007000200017

CUVACA, I.B., et al. Nitrogen, phosphorus, and potassium fertilizer effects on cassava tuber yield in the coastal district of Dondo, Mozambique. *African Journal of Agricultural Research*. 2017, **12** (42), 3112-3119. https://doi.org/10.5897/AJAR2017.12619

DONAGEMA, G.K., et al. Manual de métodos de análises de solos. 2011. 2. ed. Rio de Janeiro: Embrapa Solos, p. 43-49.

EL-SHARKAWY, M.A. Cassava biology and physiology. *Plant Molecular Biology*. 2004, **56**, 481-501. https://doi.org/10.1007/s11103-005-2270-7

ENCK, B.F., et al. Cultivares de mandioca submetidas à adubação fosfatada na Amazônia sul ocidental. *Enciclopédia Biosfera*. 2017, **14**(25), 365-371. https://doi.org/10.18677/EnciBio_2017A34

FAOSTAT. Food and Agriculture Organization of the United States, 2018. Available from: http://www.fao.org/faostat/en/#home

FERREIRA, D.F. Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*. 2014, **38**(2), 109-112. http://dx.doi.org/10.1590/S1413-70542014000200001.

HOWELER, R.H. Cassava mineral nutrition and fertilization. In: R.J. HILLOCKS, J.M. THRESH and A.C. BELLOTTI, eds. Cassava: biology, production and utilization. 2002. Wallingford: CABI, p.115-147.

IBGE. Instituto Brasileiro De Geografia e Estatística, 2017. Censo Agropecuário 2017. https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017

ISITOR, S.U., ADEYONU, A. G. and ANIEGBOKA, U.N. An Analysis of Technical Efficiency of Smallholder Cassava Farmers in Anambra State, Nigeria. *Applied Tropical Agriculture*. 2017, **22**(2), 10-15.

JANDEL SCIENTIFIC. Table Curve: curve fitting software. 1991. Corte Madera, CA: Jandel Scientific. p. 280.

KANG, L., et al. Screening of diverse cassava genotypes based on nitrogen uptake efficiency and yield. *Journal of Integrative Agriculture*. 2020, **19**(4), 965-974. https://doi/10.1016/S2095-3119(19)62746-2

LEFF, J.W., et al. Consistent responses of soil microbial communities to elevated nutrient inputs in grasslands across the globe. *Proceedings of the National Academy of Sciences of the United States of America*. 2015, **112**, 10967-10972. https://doi.org/10.1073/pnas.1508382112

LORENZI, J.O., MALAVOLTA, E. and GALLO, J.R. Acumulação de matéria seca e macronutrientes por dois cultivares de mandioca. *Bragantia*. 1981, **40**, 145-156. https://doi.org/10.1590/S0006-87051981000100014

LIMA, A.G., et al. Produtividade de mandioca avaliada sobre adubação fosfatada e adubação de cobertura. *PUBVET*. 2018, **12**(8), 1-4. https://doi.org/10.31533/pubvet.v12n8a151.1-4

OMONDIA, J.O., et al. Phosphorus affects storage root yield of cassava through root numbers. *Journal of Plant Nutrition*. 2019, **42**(17), 2070-2079. https://doi.org/10.1080/01904167.2019.1655033

OSUNDARE, B. Implications of N, P, K, and NPK combined on cassava (*Manihot esculenta* crantz) root yield and soil nutrient status. *International Journal of Information Research and Review*. 2014, **1**(12), 206-210.

PELLET, D. and EL-SHARKAWY, M.A. Cassava varietal response to phosphorus fertilization. II. Phosphorus uptake and use efficiency. *Field Crops Research*. 1993a, **35**, 13-20. https://doi.org/10.1016/0378-4290(93)90132-7

PELLET, D. and EL-SHARKAWY, M.A. Cassava varietal response to phosphorus fertilization. I. Yield biomass and gas exchange. *Field Crops Research*. 1993b, **35**, 1-11. https://doi.org/10.1016/0378-4290(93)90131-6

RÊGO, L.G.S., et al. Pedogenesis and soil classification of an experimental farm in Mossoró, state of Rio Grande do Norte, Brazil. *Revista Caatinga*. 2016, **29**(4), 1036-1042. https://doi.org/10.1590/1983-21252016v29n430rc.

RÓS, A.B., et al. Crescimento, fenologia e produtividade de cultivares de mandioca. *Pesquisa Agropecuária Tropical*. 2011, **41**(4), 552-558. https://doi.org/10.5216/pat.v41i4.11075

SARRA, P.S., et al. Diversity and distribution of Arbuscular Mycorrhizal Fungi in cassava (*Manihot esculenta* Crantz) croplands in Cameroon as revealed by Illumina MiSeq. *Rhizosphere*. 2019, **2019**, 10. https://doi.org/10.1016/j.rhisph.2019.100147

SIEVERDING, E. and HOWELER, R.H. Influence of species of VA mycorrhizal fungi on cassava yield response to phosphorus fertilization. *Plant and Soil*. 1985, **88**(2), 213-221. https://doi.org/10.1007/BF02182447

SILVA, A.D.A. and GOMES, R.V.A. Macaxeira. In: CAVALCANTI, F.J.A., et al., eds. Recomendações de adubação para o Estado de Pernambuco: 2ª aproximação. 2008. 3ª ed. Revisada. Recife: Instituto Agronômico de Pernambuco – IPA, pp. 164.

SILVA, A.F., et al. Comportamento de variedades de mandioca submetidas a fertilização em comunidades dependentes de chuva no semiárido brasileiro. *Revista Brasileira de Agroecologia*. 2013, **8**(3), 221-235.

SILVA, F.C. Manual de análises químicas de solos, plantas e fertilizantes, 2.ed., Brasília: Embrapa Informação Tecnológica, 2009.

SILVA, K.N., et al. Potencial agronômico e teor de carotenoides em raízes de reserva de mandioca. *Ciência Rural*. 2014, **44**(8), 1348-1354. http://dx.doi.org/10.1590/0103-8478cr20130606

SYSTAT SOFTWARE. SigmaPlot for Windows Version 12.0. San Jose: Systat Software Inc., 2011.

TIRONI, L.F., et al. Desempenho de cultivares de mandioca em ambiente subtropical. *Bragantia*. 2015, **74**(1), 58-66. http://dx.doi.org/10.1590/1678-4499.0352

ZOBEL, M. and ÖPIK, M. Plant and arbuscular mycorrhizal fungal (AMF) communities which drives which? *Journal of Vegetation Science*. 2014, **25**, 1133-1140. https://doi.org/10.1111/jvs.12191

Received: 15 April 2022 | **Accepted:** 9 February 2023 | **Published:** 5 May 2023