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Economic viability of irrigated cultivation of table cassava cultivars under phosphate fertilization

Viabilidade econômica do cultivo irrigado de cultivares de mandioca de mesa sob fertilização fosfatada

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ABSTRACT

Phosphate fertilization of cassava cultivars leads to increased production costs that may be economically viable depending on the quantity used and the corresponding productivity. In this sense, the objective of the work was to analyse the economic viability of the irrigated cultivation of table cassava cultivars in response to the application of phosphorus doses in the Brazilian semiarid region. Two agricultural crops were conducted at the Experimental Farm Rafael Fernandes, 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. The doses of phosphorus (0, 60, 120, 180, and 240 kg ha^{-1} of P_2O_5) were applied to the plots and the table cassava cultivars (Água Morna, BRS Gema de Ovo, Recife and Venâncio) arranged in the subplots. The total costs for one hectare of cultivation were estimated and the gross income, net income, rate of return, and profitability index were calculated. The use of phosphate fertilizer was economically viable for the cassava cultivars studied in the two crops. The cultivars Água Morna, BRS Gema de Ovo, and Recife are the best cultivation options for the semiarid region of Rio Grande do Norteas they give high yields with the highest profitability. The Recife cultivar was the region's most profitable cultivation, with a profit ranging from R$ 40,331.07 ha^{-1} to R$ 57,603.46 ha^{-1} in both seasons, with an average recommendation of 120 kg ha^{-1} of P_2O_5.

KEYWORDS: *Manihot esculenta*; genotypes; phosphorus; production costs; profitability.

RESUMO

A adubação fosfatada de cultivares de mandioca leva ao aumento dos custos de produção que podem ser economicamente viáveis dependendo da quantidade utilizada e da respectiva produtividade. Nesse sentido, o objetivo do trabalho foi analisar a viabilidade econômica do cultivo irrigado de cultivares de mandioca de mesa em resposta à aplicação de doses de fósforo no semiárido brasileiro. Foram conduzidos duas safras agrícolas na Fazenda Experimental Rafael Fernandes, Mossoró, RN, nos meses de junho de 2018 a abril de 2019 e junho de 2019 a abril de 2020. O delineamento experimental foi em blocos casualizados dispostos em parcelas subdivididas, com quatro repetições. As doses de fósforo (0, 60, 120, 180 e 240 kg ha^{-1} de P2O5) foram aplicadas nas parcelas e as cultivares de mandioca de mesa (Água Morna, BRS Gema de Ovo, Recife e Venâncio) dispostas nas subparcelas. Estimaram-se os custos totais de um hectare de cultivo e calcularam-se a receita bruta, a receita líquida, a taxa de retorno e o índice de lucratividade. O uso da adubação fosfatada mostrou-se economicamente viável para as cultivares de mandioca estudadas nas duas safras. As cultivares Água Morna, BRS Gema de Ovo e Recife são as melhores opções de cultivo para o semiárido do Rio Grande do Norte, pois apresentam altas produtividades com maior rentabilidade. A cultivar Recife foi o cultivo mais rentável da região, com rendimento variando de R$ 40.331,07 ha^{-1} a R$ 57.603,46 ha^{-1} nas duas safras, com recomendação média de 120 kg ha^{-1} de P_2O_5.

PALAVRAS-CHAVE: *Manihot esculenta*; genótipos; fósforo; custos de produção; lucratividade.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a crop that guarantees food security, because it is produced in regions with adverse conditions, dry climates and soils with low fertility and still promotes a financial return for the farmer. It is not a subsistence culture or cultivated only by small producers, as has always been reported historically (FERMONT et al. 2010). Farmers from all social classes plant, consume, and trade cassava. However, it is produced in large part by small farmers who have low technical resources, such as few inputs, lack of mechanized services, and lack of technical assistance (OTSUBO et al. 2002, ITAM et al. 2018), leading to unsatisfactory production and not always the expected financial return.

Brazil is the fifth largest producer of cassava in the world and the root is among the five agricultural commodities with the largest production volume in the country, 18,501,645 tons, behind only sugarcane, soy, corn, and cow's milk (FAOSTAT 2017). The production indicators have been declining in recent years, especially in the country's northeast region (IBGE 2018), reflecting the drought period that the region has experienced in the past seven years. This fact contributed to making cassava culture of little economic value for this region.

Some analyses have been carried out based on the costs and profitability of cassava cultivation in different production systems (SILVA & CHABARIBERY 2006, EBUKIBA 2010, ITAM et al. 2014, OLORUNSANYA 2014, NZEH & UGWU 2014, ALVARADO & CRUZ 2016, OMOTAYO & OLADEJO 2016, BUHARI 2017, SILVA et al. 2017). However, its production is vulnerable to the action of factors that hinder the success of investment, undermining profit and, in some cases, increasing production costs to the point of making it unfeasible.

The availability and high cost of fertilizers, in addition to the unavailability of improved genotypes, represent the causes of failure of this activity among most producers (ITAM et al. 2014, OMOTAYO & OLADEJO 2016, BUHARI 2017, ITAM et al. 2018). A combination of applying fertilizers and high-yield cultivars can expand the productive and economic indicators in cassava cultivation, making it increasingly attractive to farmers.

Surveys have been carried out in important areas of cassava production to characterize the management used by producers and show a great distinction in relation to the use of fertilizers, which are not used by most farmers (OTSUBO et al. 2002, CARVALHO et al. 2007, CARVALHO et al. 2009, FERMONT et al. 2010, NZEH & UGWU 2014, OMOTAYO & OLADEJO 2016). When fertilizer is used, animal waste produced on the property itself or by neighbours is used, without accounting for production costs. In turn, when applied, the dose of mineral fertilizer is not based on soil analysis and crop needs, reducing the potential for a productive response of the culture.

Among the macronutrients required by cassava, phosphorus is one of the least well-absorbed (GOMES et al. 2006). However, because of its low availability in tropical soils, it is a nutrient that causes a greater response when supplied to the crop (FIDALSKI 1999, BURGOS & CENÓZ 2012, SILVA et al. 2013, LIMA et al. 2018). This low concentration, added to the low mobility in the soil, justifies the application of chemical fertilizers to guarantee the use of the nutrient by plants, improving their yield (SHEN et al. 2011), including the need to increase these doses to prevent high sorption rates of the element in the soil, which would further reduce its availability to plants (CUVACA et al. 2017).

The application of fertilizers significantly increases cassava production (ISITOR et al. 2017) and enables its use (ALVES et al. 2012, ALVES FILHO et al. 2015), but information on the economic return with use of these inputs is very scarce. There are studies on cassava production costs, mainly based on socioeconomic surveys of producers, but they do not present the profitability of the commercialization of the roots due to investments in inputs.

In addition to fertilization, another alternative that can increase cassava productivity is the replacement of local cultivars with improved genotypes. For example, ITAM et al. (2018) studied the economic viability of cultivation by comparing the use of improved and local cultivars and observed that the improved genotypes provided higher profit despite having higher production costs. On the other hand, the use of local cultivars was also profitable but there was an increase in production costs with the acquisition of fertilizers, since they were considered less efficient in using nutrients. In the same sense, OJIAKO et al. (2017) identified that the use of improved cultivars was the factor that contributed most to the increase in the productivity of cassava grown by small farmers in Nigeria.

Given this conception, the objective of this study was to analyse the economic viability of table cassava cultivars in response to the application of phosphorus doses in the Brazilian semiarid region.

MATERIAL AND METHODS

Site description

The experiments were carried out on two crops from June 2018 to April 2019 and from June 2019 to April 2020 at the Experimental Farm Rafael Fernandes (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 in the municipality of Mossoró, Rio Grande do Norte. According to the Köppen climate classification, the Mossoró climate is BSh type (ALVARES et al. 2013), dry and very hot, with a rainy season occurring between February and May and a dry season that begins in June and extends to January.

The soil of the experimental areas was classified as Typical Rhodustults (RÊGO et al. 2016). The data from the chemical (SILVA 2009) and physical (DONAGEMA et al. 2011) analyses for soil characterization of the experimental areas are presented in Table 1, and the data of the meteorological variables during the cultivation of the crops are shown in Figure 1.

Table 1. Chemical and physical characterization of the soil, at the depths of 0-0.20 m and 0.20-0.40 m, of the experimental areas related to the two agricultural crops (2018/19 and 2019/20).

Depth	pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Sand	Silt	Clay
m		-----mg dm^{-3}-----			--$cmol_c$ dm^{-3}--		-----kg kg^{-1}-----		
1st Crop (2018/19)									
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 (2019/20)									
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	---	---	---

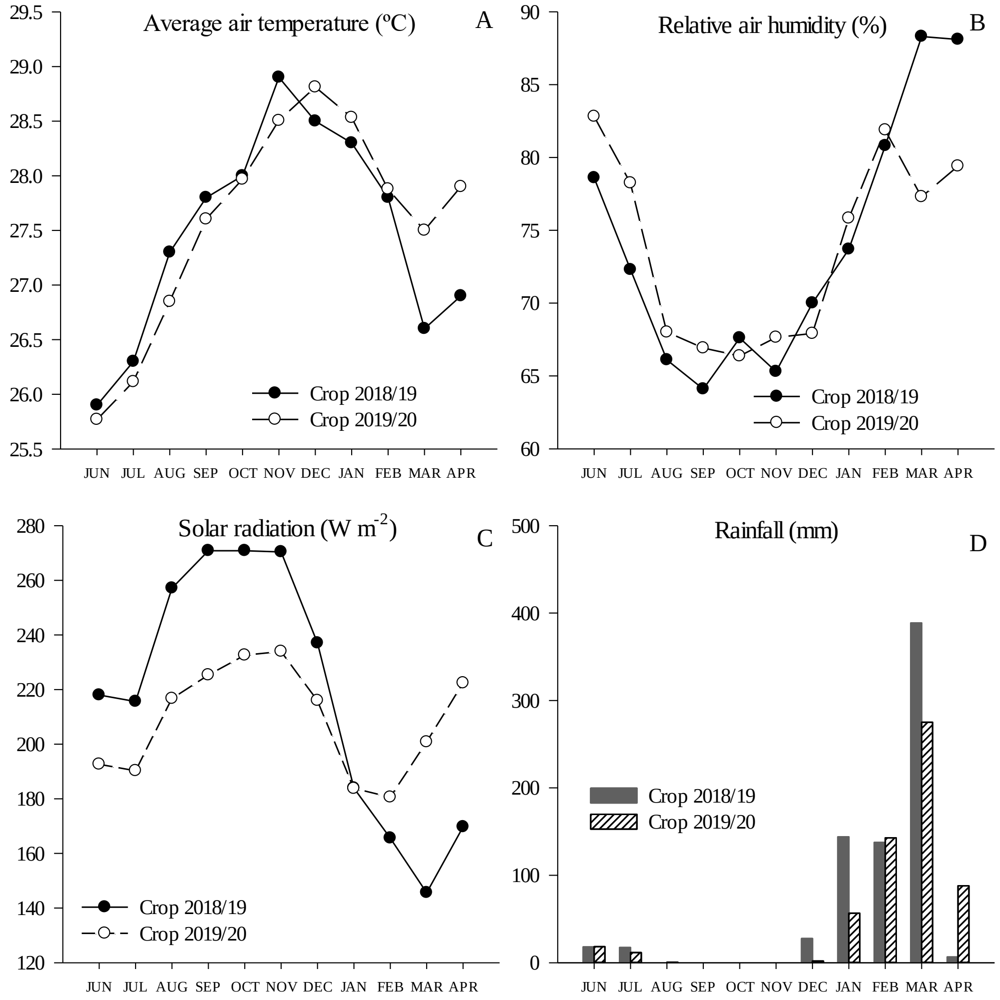

Figure 1. Average values of average air temperature (A), relative humidity (B) and solar radiation (C) and accumulated rainfall (D) in the two crops of table cassava (2018/19 and 2019/20).

Experimental design and treatments

The experimental design used randomized blocks, arranged in subdivided plots, with four replications. In the main plot, phosphorus doses (0, 60, 120, 180, and 240 kg ha^{-1} of P_2O_5) were applied, and in the subplots, cassava cultivars (Água Morna, BRS Gema de Ovo, Recife, and Venâncio) were grown.

The cultivars worked showed variation in the characteristics of the root, with the color of the pulp being cream (Água Morna), yellow (BRS Gema de Ovo), and white (Recife and Venâncio). The coloration of the root cortex was pink (Água Morna and Venâncio) and white or cream (BRS Gema de Ovo and Recife). All cultivars had a dark brown external root color.

Each experimental unit consisted of four lines 6.0 m long, spaced 1.0 m apart, totalling an area of 24.0 m^2 (6.0 m × 4.0 m). The two central lines, discarding a plant at each end, were considered the useful area of the experimental unit (9.6 m^2).

Crop management

The soil preparation was carried out with heavy harrowing to incorporate the remaining plant material in the area, in addition to a levelling harrow to homogenize the soil surface before the installation of the experiments.

Fertilization followed an adapted recommendation of SILVA & GOMES (2008) based on soil analysis, except for phosphorus, whose recommendation was defined according to the treatments. To each crop, 30 kg ha^{-1} of nitrogen (N) and 40 kg ha^{-1} of potassium (K) were applied. Urea (45% N), simple superphosphate (18% P_2O_5), and potassium chloride (60% K_2O) were used as sources of N, P, and K, respectively. All phosphate fertilization was applied at the time of planting. N and K sources were applied in coverage via a bypass tank (“lung”) associated with the irrigation system. The N was split into two applications, half applied 30 days after emergence (DAE) of the plants, together with any recommendation for K, and the other half applied at 60 DAE.

The propagation material was obtained from a multiplication area installed at the Experimental Farm Rafael Fernandes, 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 handles of 0.10–0.15 m length and 5–7 buds per pit, at a depth of 0.10 m. The spacing used was 1.00 m between rows of plants and 0.60 m between plants in the same row, giving a density of 16,666.7 plants ha^{-1}.

The crop was irrigated by a drip system with emitters spaced at 0.30 m and a flow rate of 1.6 L h^{-1}, with a mean daily depth of 4.8 mm, and irrigation was suspended at eight months after planting. The culture coefficient (Kc) was used for each phenological phase of cassava.

Weed control was carried out through manual weeding in three seasons before the establishment of the canopy when the control of invasive plants was no longer necessary. However, mite control was necessary and was carried out by applying a commercial product with the active ingredient spiromesifene (240 g L^{-1}).

Harvest and evaluated variables

Cassava was harvested at 292 and 309 days after planting the seedlings in the 2018/19 and 2019/20 agricultural crops, respectively. The productivity of commercial roots was obtained by weighing roots in the useful area with a length greater than 0.10 m and a diameter greater than 0.02 m, with data extrapolated to tons per hectare (Table 2).

Economic indicators were analysed to evaluate the efficiency between the combinations of phosphorus doses and cassava cultivars. The methodology proposed by CONAB (2010) was adapted to estimate the total costs of production (TC) of one hectare of cassava at the end of each production cycle, which were represented by the sum of variable costs (labour, fertilizers, pesticides, and others), administrative expenses, technical assistance, rural land tax, fixed costs (depreciation of machinery and periodic maintenance of improvements), and expected remuneration over fixed capital and leasing. The values established in the Safra Plans were used for the financing interest, corresponding to 2.5 and 3.0% year^{-1} for the 2018/19 and 2019/20 crops, respectively (BNB 2020).

Gross income (GI, R$ ha^{-1}) was calculated for each agricultural crop, corresponding to the value obtained from the price paid per kilogram of commercial cassava root in the local production areas at harvest time: R$ 0.80 and R$ 1.10, in April 2019 and 2020, respectively, multiplied by the production in tons of commercial root per hectare. Net income (NI, R$ ha^{-1}) was obtained by subtracting GI from the TC for both crops. The rate of return (RR) was calculated as the ratio between GI and TC, expressing the capital obtained for each Brazilian real invested in cassava cultivation. Finally, the profitability index (PI, %) was obtained by dividing the NI by the GI multiplied by 100.

Table 2. Commercial root productivity of cassava cultivars of table fertilized with doses of phosphorus, in two agricultural crops, in the Brazilian semiarid region.

Commercial root productivity (t ha^{-1})			
Doses de P	Cultivars	1st Crop	2nd Crop
0 kg ha^{-1}	Água Morna	45.95	41.11
	BRS Gema de Ovo	47.70	45.65
	Recife	55.57	43.22
	Venâncio	9.09	19.44
60 kg ha^{-1}	Água Morna	52.70	51.49
	BRS Gema de Ovo	36.88	55.81
	Recife	56.97	51.91
	Venâncio	19.61	31.75
120 kg ha^{-1}	Água Morna	54.87	59.99
	BRS Gema de Ovo	38.32	57.43
	Recife	61.19	57.80
	Venâncio	27.99	35.64
180 kg ha^{-1}	Água Morna	45.07	63.66
	BRS Gema de Ovo	38.64	45.97
	Recife	52.01	61.38
	Venâncio	28.94	42.10
240 kg ha^{-1}	Água Morna	44.95	60.82
	BRS Gema de Ovo	38.40	39.36
	Recife	42.32	51.78
	Venâncio	19.94	38.22

Statistical analysis

The results obtained were subjected to analysis of variance for each agricultural crop by the F test ($P < 0.05$) using the SISVAR 5.6 program (FERREIRA 2014). Observing homogeneity of variances between agricultural crops, the data were analysed together, considering crops as a new factor. For phosphorus doses, regression was performed using the program Table Curve 2D v5.01 (JANDEL SCIENTIFIC 1991), with the equations being chosen according to the determination coefficient and its significance. The graphics were created using the program SigmaPlot version 12.0 (SYSTAT SOFTWARE 2011). The averages for cassava cultivars were compared using the Tukey test at 5% probability.

RESULTS AND DISCUSSION

For all variables, it was possible to perform joint analysis of variance and it was found that there was a triple interaction ($p < 0.01$) between treatment (phosphorus dose, cultivar, and crop).

Gross income

In the first agricultural crop (Figure 2A), the highest estimated gross incomes were obtained with the cultivars Recife (R$ 47,958.22 ha^{-1}), BRS Gema de Ovo (R$ 38,157.40 ha^{-1}), and Venâncio (R$ 22,783.33 ha^{-1}) with doses of 107.41, 0, and 148.04 kg ha^{-1} of P_2O_5. For the cultivar Água Morna, no regression adjustment model was found for phosphorus doses, and a maximum gross income of R$ 43,984.22 ha^{-1} was obtained with a dose of 120 kg ha^{-1}.

In the second crop (Figure 2B), the highest values of gross income were R$ 70,129.15 ha^{-1} (Água Morna), R$ 64,207.48 ha^{-1} (BRS Gema de Ovo), R$ 66,387.02 ha^{-1} (Recife), and R$ 45,803.39 ha^{-1} (Venâncio), with doses of 187.33, 89.47, 158.77, and 240.00 kg ha^{-1} of P_2O_5, respectively. The values obtained in the second crop were higher due to the higher yields obtained and the higher market value found at the time of commercialization (Figure 2), which was R$ 0.30 more per kilogram of the root.

In the first crop, Água Morna, BRS Gema de Ovo and Recife were the cultivars with the highest gross income with the corresponding doses of 0, 180, and 240 kg ha^{-1} of P_2O_5 (Figure 2A). At doses of 60 and 120 kg ha^{-1} of P_2O_5, only the cultivars Água Morna and BRS Gema de Ovo had the highest gross incomes. In the 2019/20 crop, at doses from 0 to 120 kg ha^{-1} of P_2O_5, the cultivars Água Morna, BRS Gema de Ovo, and Recife stood out with the highest gross income (Figure 2B). At the maximum doses of 180 and 240 kg ha^{-1} of P_2O_5, the cultivars Água Morna and Recife showed higher values for this variable. The cultivar Venâncio presented the lowest gross incomes for all doses of phosphorus in the two evaluated crops. The higher yields obtained with the cultivars Água Morna, BRS Gema de Ovo, and Recife with phosphorus doses reflect this performance for gross income, while the cultivar Venâncio showed lower yield than the other cultivars.

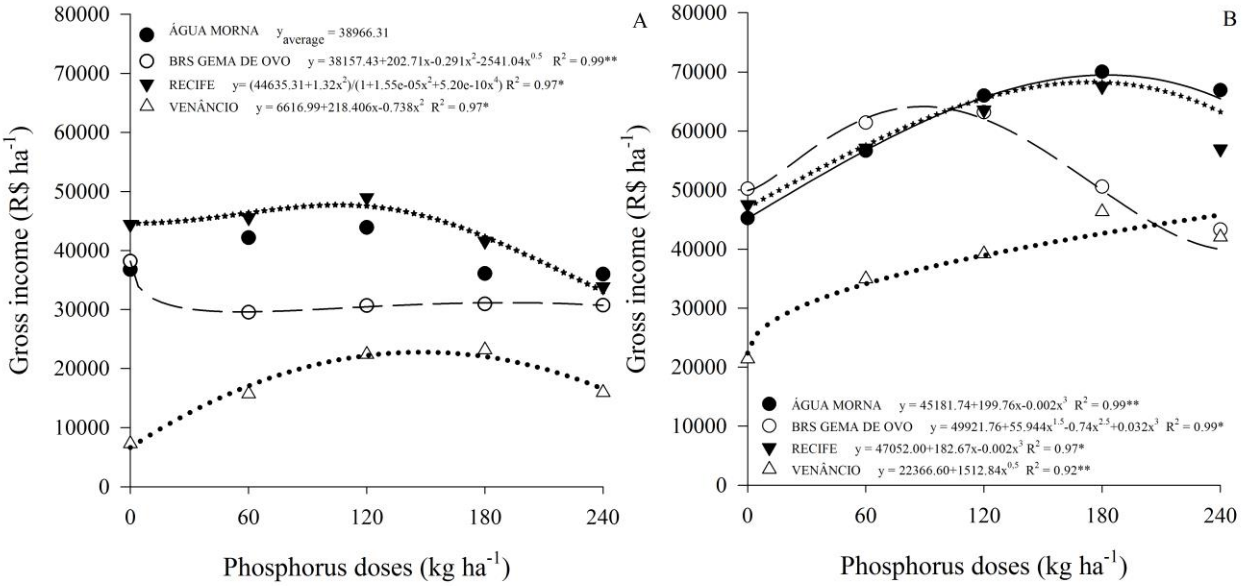

Figure 2. Gross income from the interaction between phosphorus doses, table cassava cultivars and two agricultural crops, 2018/19 (A) and 2019/20 (B), in the city of Mossoró-RN, Brazilian Semiarid region.

Production costs

In the two years of cultivation, the variation between production costs for maximum and minimum doses of phosphorus ranged at R$ 1,830.00 ha^{-1}, while the variation between doses was slightly less than R$ 460.00 ha^{-1} (Table 3). The variation between the two agricultural crops for each dose of phosphate fertilizer was approximately R$ 1,135.00 ha^{-1}.

In the second year of cultivation, there was an increase in production costs, caused by an increase in the value of the electricity tariff and, above all, by an increase in the daily rate paid for labour (Table 3). Notably, the number of services did not change, only the values.

In the 2018/19 crop, the average dose values for the variable costs, fixed costs, and income from factors were R$ 5,705.70 ha^{-1}, R$ 1,190.75 ha^{-1}, and R$ 1,410.83 ha^{-1} (Table 3). Among the variable costs, expenditure on labour and inputs represented 64.10% of the total production cost. Likewise, in the second year of cultivation, the variable costs, fixed costs, and factor from income were R$ 6,689.93 ha^{-1}, R$ 1,260.07 ha^{-1}, and R$ 1,492.96 ha^{-1}, respectively. Likewise, variable costs represented the largest share of production costs, and, in the case of this crop, around 65.80% of the total cost. ENIMU et al. (2016) found that variable and fixed costs of growing cassava in Southern Nigeria represented 89.0 and 11.0% of the total cost, respectively.

Variation phosphate fertilizer's contribution to production costs was also observed. For the 2018/19 crop, fertilization with phosphorus represented 0, 5.43, 10.27, 14.61, and 18.51% of production costs at doses of 0, 60, 120, 180 and 240 kg ha^{-1} of P_2O_5, respectivelly. For the 2019/20 crop, fertilizer costs did not vary because fertilizer with the same value as in the previous year was purchased, but the percentage in relation to total production costs decreased due to the increase in labour and energy costs. Thus, the contribution of phosphate fertilizer to production costs was around 0, 4.75, 9.04, 12.93, and 16.47% at doses of 0, 60, 120, 180 and 240 kg ha^{-1} of P_2O_5, respectively.

Total fertilizer expenses for the 2018/19 crop represented 2.43% (0 kg ha^{-1} P_2O_5), 7.73% (60 kg ha^{-1} P_2O_5), 12.44% (120 kg ha^{-1} P_2O_5), 16.66% (180 kg ha^{-1} P_2O_5), and 20.46% (240 kg ha^{-1} P_2O_5) of the total costs. For the 2019/20 crop, these values corresponded to 2.11% (0 kg ha^{-1} P_2O_5), 6.75% (60 kg ha^{-1} P_2O_5), 10.94% (120 kg ha^{-1} P_2O_5), 14.74% (180 kg ha^{-1} P_2O_5), and 18.21% (240 kg ha^{-1} P_2O_5) of all costs. ENIMU et al. (2016) found that fertilizer purchases represented 15% of the total cost of cassava production in southern Nigeria. SOUZA et al. (2014) evaluated the economic feasibility of research on cassava production in family farming under rainfed conditions and observed that fertilizer costs are significant in production costs, varying from around 18 to 30% of the production cost.

Table 3. Coefficients of variable, fixed costs and opportunity in producing an irrigated hectare of table cassava cultivated with different doses of phosphorus, in two crops (2018/19 and 2019/20).

		1st Crop		2nd Crop	
Discrimination	Unity	Amount	R$	Amount	R$
I - Expenditure on crop cultivation costs					
1 – Machine rental					
Tractor with plow harrow, tractor with leveler harrow	h	2.50	300.00	2.50	300.00
2 - Labour					
Mounting the irrigation system	daily	6.00	240.00	6.00	300.00
Digging pits for planting	daily	2.00	80.00	2.00	100.00
Selection and preparation of the handles	daily	2.00	80.00	2.00	100.00
Foundation fertilization and planting	daily	5.00	200.00	5.00	250.00
Irrigation and fertigation	h	195.00	975.00	195.00	1,218.75
Manual weeding (hoe)	daily	24.00	960.00	24.00	1,200.00
Spraying (acaricide)	daily	4.00	160.00	4.00	200.00
Manual harvesting	daily	18.00	720.00	18.00	900.00
3 - Handles					
Handles	m^3	6.00	30.00	6.00	30.00
4 - Fertilizers					
Urea (45% N) - 30 kg ha^{-1} of N	kg	67.00	120.60	67.00	120.60
Potassium chloride (60% K_2O) - 40 kg ha^{-1} of K_2O	kg	33.00	59.40	33.00	59.40
Simple superphosphate (18% P_2O_5) - 240 kg^{-1} of P_2O_5	kg	1,333.33	1,706.66	1,333.33	1,706.66
5 - Agricultural defensive					
Acaricide (Oberon 1 L)	L	1.44	273.60	1.44	273.60
6 - Others					
Electric power for irrigation	kWh	429.00	163.02	429.00	197,34
Soil analysis	Unity	1.00	30.00	1.00	30.00
Individual protection equipment	Unity	1.00	80.00	1.00	80.00
Subtotal (A)			6,178.28		7,066.35
II - Others expenses					
7 - Administrative expenses (3% of crop costs)			185.35		211.99
8 - Technical assistance (2% of the cost of the crop)			123.57		141.33
9 - Rural territorial tax (R$ 10,00 year^{-1})			8.00		8.47
Subtotal (B)			316.91		361.78
III - Financial expenses					
10 - Interest on financing (2,5 – 3,0% year^{-1})			123.57		179.47
Subtotal (C)			123.57		179.47
Variable cost (A+B+C=D)			6,618.76		7,607.60
IV - Depreciation					
11 - Depreciation of facilities *			1,155.61		1,222.89
Subtotal (E)			1,155.61		1,222.89
V - Other fixed costs					
12 - Maintenance of facilities (1% year^{-1})			35.14		37.18
Subtotal (F)			35.14		37.18
Fixed cost (E+F=G)			1,190.75		1,260.07
Operacional cost (D+G=H)			7,809.51		8,867.67
VI - Income from factors					
13 - Remuneration on fixed capital (6% year^{-1})			210.83		223.10
14 - Rent (R$ 1,500.00 ha^{-1} year^{-1})			1,200.00		1,269.86
Subtotal (I)			1,410.83		1,492.96
Total cost (H+I=J)					
240 kg ha^{-1} de P_2O_5			9,220.34		10,360.64
180 kg ha^{-1} de P_2O_5			8,763.81		9,901.81
120 kg ha^{-1} de P_2O_5			8,307.28		9,442.97
60 kg ha^{-1} de P_2O_5			7,850.74		8,984.13
0 kg ha^{-1} de P_2O_5			7,394.21		8,525.30

*10.000 m of low density polyethylene hose, with emitters spaced at 0.30 m and nominal diameter of 16 mm (useful life of 2 years; value of the new good R$ 0.28 m^{-1}); PVC pipes and fittings (useful life of 16 years; new good value R$ 492.21); pump 3 hp (service life 16 years; new good value R$ 1,100.00).

Mechanization had a low impact on costs, averaging 3.63 and 3.19% for the 2018/19 and 2019/20 crops, respectively. This is because the use of mechanized service was only necessary to prepare the soil.

This is very characteristic of the region and for this cultivation system, in which agricultural machinery is used basically in the preparation of the soil. As a result, the exploitation of cassava demands a lot of labour for cultural treatments, especially for managing irrigation, weeding, and harvesting, resulting in a large portion of the costs. The labour costs were, on average, 41.36 and 45.42% of the total costs for the 2018/19 and 2019/20 crops, respectively. This variation was caused by the difference in the daily rate paid for each crop, that is, R$ 40.00 for the 2018/19 crop and R$ 50.00 in 2019/20.

Labour represents a significant expense in cassava production costs (ITAM et al. 2014, SOUZA et al. 2014, ITAM et al. 2018) and can be contracted by family, or both (OMOTAYO & OLADEJO 2016). Obviously, costs increase on hiring people and are lower when family members are predominant.

Among farmers in Kenya and Uganda, 36% of producers used hired labour (FERMONT et al. 2010), 36% for weeding, 10% for planting, and 6% for harvesting. NZEH & UGWU (2014) observed that the majority of farmers depend on hired labour, which results in an increase in production costs. According to SILVA & CHABARIBERY (2006), the cost of manual cassava harvesting should not be included in the total cost, as the harvest work is already rooted in the farmers' culture, the root buyer.

In the same way, the cost with a handles should not be included in the total costs (SILVA & CHABARIBERY 2006), since producers use their own planting material to implement a new area. In Rio Grande do Norte state, the costs of planting material in mandioculture are practically insignificant. This is because the producers themselves have their planting material. Even when commercialized, its value is very low (Table 3), unlike other crops whose seeds or seedlings fetch high prices. In the southwestern region of Bahia, CARVALHO et al. (2009) found that more than 70% of cassava producers use their own handles, around 23% obtain it from neighbours, and only 5.6% acquire it from another location. No producer/trader of handles was found in the region. Likewise, KAWA et al. (2013) in the Brazilian Amazon and FERMONT et al. (2010) in East Africa found that cassava producers, when they did not have their own material, obtained the planting material from the local community through donation or exchange with neighbours.

Depreciation expenses are included in production costs and are necessary because they reflect the loss of value of the physical material (drip tape, PVC tubing, motor-pump set, and other connections) used in irrigation due to its useful life and of the crop cycle. Therefore, although the value of the initial capital invested is higher, this cost reflects the amount spent on the equipment during the crop cycle. For the two crops, the value was fixed between doses because it does not depend on input or labour, but it varied over the years due to the duration of the crop cycle; therefore, R$ 1,155.61 ha^{-1}, or 13.91% of the total average cost, was paid for the 2018/19 crop and R$ 1,222.89 ha^{-1}, or 12.95% of the total average cost, was paid for the 2019/20 crop (Table 3).

The opportunity costs related to the expected remuneration for fixed capital and land lease are also relevant and did not vary depending on the dose but varied in relation to the crops, due to the crop cycle (Table 3), with R$ 1,410,83 ha^{-1}, or 16.98% of the total average cost, being paid for the 2018/19 crop and R$ 1,492.96 ha^{-1}, or 15.81% of the total average cost, for the 2019/20 crop.

Net income

The production cost figures for the 2019/20 crop increased by just over R$ 1,135.00 ha^{-1} (Table 3) at each dose compared to the values for the 2018/19 crop. Thus, the net income values showed a downward trend even though the amount paid per kilogram of the product was higher in this harvest.

In general, the net income was positive for both crops (Figure 3), except for the cultivation of Venâncio without phosphate fertilization in the 2018/19 crop (Figure 3A). The application of phosphate fertilizer to increase cassava productivity is feasible but its cost is high and can become an impediment for small farmers who do not have any initial investment capital. Forming cooperatives or associations can be an easier way to obtain credit or agricultural financing and purchase these inputs.

For the 2018/19 crop, as with gross income, there was no adjustment in the regression models for the cultivar Água Morna, with this cultivar reaching a maximum net income of R$ 35,586.94 ha^{-1} at a dose of 120 kg ha^{-1} of P_2O_5 (Figure 3A). The cultivars BRS Gema de Ovo, Recife, and Venâncio had maximum estimated net incomes of R$ 30,756.34 ha^{-1}, R$ 40,331.07 ha^{-1}, and R$ 14,282.33 ha^{-1} at doses of 0, 99.80, and 142.90 kg ha^{-1} of P_2O_5, respectively. For the 2019/20 crop (Figure 3B), the highest net incomes obtained were R$ 59,193.76 ha^{-1} (Água Morna), R$ 53,820.28 ha^{-1} (BRS Gema de Ovo), R$ 57,603.46 ha^{-1} (Recife), and R$ 34,484.16 ha^{-1} (Venâncio) at doses of 183.70, 89.12, 162.54, and 181.63 kg ha^{-1} of P_2O_5, respectively.

The cultivars Recife and Água Morna showed higher profits in the first crop at all doses of phosphorus (Figure 3A). The cultivar BRS Gema de Ovo equalled them at doses of 0, 180, and 240 kg ha^{-1} of P_2O_5. In the second crop (Figure 3B), at doses of 0, 60, and 120 kg ha^{-1} of P_2O_5, the cultivars Água Morna, BRS

Gema de Ovo, and Recife showed the highest profits. At the maximum doses of phosphorus, the cultivars Água Morna and Recife showed the highest profitability. The cultivar Venâncio was less profitable at all doses of phosphorus in the two crops evaluated. This cultivar has many branches in the aerial part; therefore, it would need a greater spacing between plants and between rows of plants to better express its potential. On the other hand, adopting this different spacing for the Venâncio cultivar that is different from the others would already add one more factor to be analyzed. The production costs and the amount paid for the product were the same for the four cultivars in each crop. Therefore, the yield at each dose of phosphorus was responsible for this differentiation in the profits presented above.

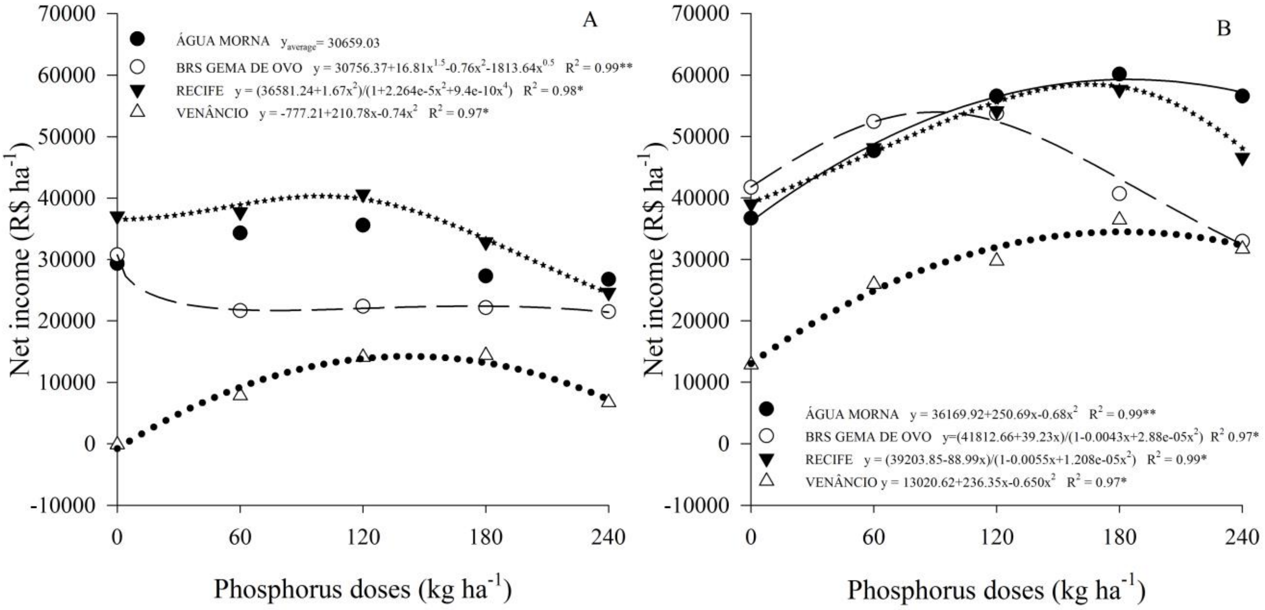

Figure 3. Net income from the interaction between doses of phosphorus, table cassava cultivars and two agricultural crops, 2018/19 (A) and 2019/20 (B), in the city of Mossoró-RN, in the Brazilian Semiarid region.

Similarly, SILVA et al. (2017) evaluated the costs and profitability of cassava exploitation in two family agro-ecosystems in Rio Grande do Norte. In this study, the authors used a conventional system using synthetic fertilizer, contracted labour, pesticides, and little mechanization. Complementary, the authors also conducted an alternative, and more rudimentary system, where the organic fertilizer itself was produced on the property, no synthetic product was applied, and exclusively family labour was used. As a result, the alternative system achieved greater profitability, reflecting the low operating cost, which did not include the costs of external inputs and mechanized operations.

Therefore, it could be said that the use of fertilizers, whether synthetic or organic, in the management of cassava makes cultivation economically viable as reported by SOUZA et al. (2014). Increasing production per unit area through the use of resources such as fertilizers and reducing labor costs are means of reducing production costs and obtaining greater profitability from the activity.

Rate of return

The highest values estimated for the rate of return of the 2018/19 crop were for the cultivar Recife (6.00–40.80 kg ha^{-1} of P_2O_5), BRS Gema de Ovo (5.16–0.0 kg ha^{-1} of P_2O_5), and Venâncio (2.70–139.45 kg ha^{-1} of P_2O_5) (Figure 4A). For the cultivar Água Morna, no regression adjustment model was found, with a higher rate of return of 5.37 at a dose of 60 kg ha^{-1} of P_2O_5.

In the 2019/20 crop (Figure 4B), the cultivar Água Morna had the highest estimated rate of return, 7.06, with a dose of 153.90 kg ha^{-1} of P_2O_5, followed by BRS Gema de Ovo, 6.95 with a dose of 72.79 kg ha^{-1} of P_2O_5, Recife, 6.91 with a dose of 151.89 kg ha^{-1} of P_2O_5, and Venâncio, 4.53 with a dose of 163.80 kg ha^{-1} of P_2O_5. In general, the highest values were obtained in the second cycle, resulting from the higher productivity (Table 2) and higher price paid for the product.

In the 2018/19 crop, the highest rates of return were observed for the cultivars Água Morna and Recife at all doses of phosphorus (Figure 4A). On the other hand, the cultivar BRS Gema de Ovo had a higher rate of return without phosphorus fertilizer and at the maximum dose. In the 2019/20 crop (Figure 4B), following the same behaviour for net income and gross income, the cultivars Água Morna, BRS Gema de Ovo, and Recife stood out with the highest rates of return at doses of 0, 60, and 120 kg ha^{-1} of P_2O_5 and the cultivars

Água Morna and Recife stood out at the maximum doses of 180 and 240 kg ha^{-1} of P_2O_5. In both crops, the cultivar Venâncio had the lowest values of the rate of return.

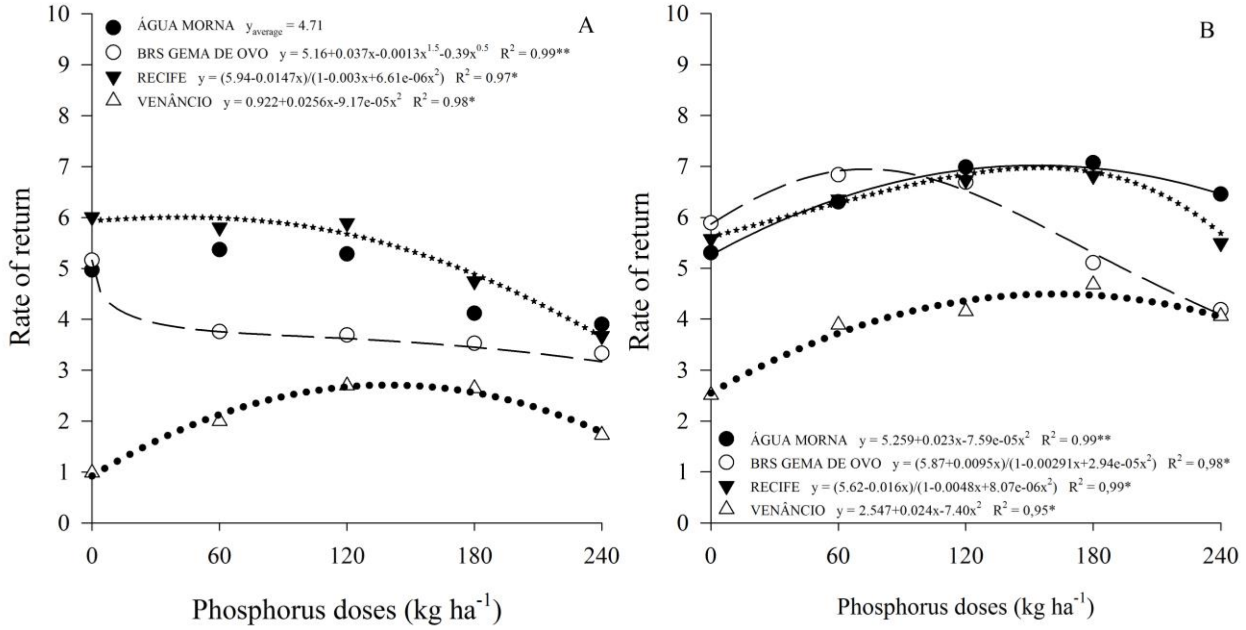

Figure 4. Rate of return on the interaction between phosphorus doses, table cassava cultivars and two agricultural crops, 2018/19 (A) and 2019/20 (B), in the city of Mossoró-RN, in the Brazilian Semiarid region.

Profitability index

In the two crops, the values of the profitability index were attractive at all doses for all cultivars evaluated, being at the level of 80%, with the exception of the cultivar Venâncio, which obtained the lowest values for this variable, especially in the 2018/19 crop, in which productivity was lower (Figure 5).

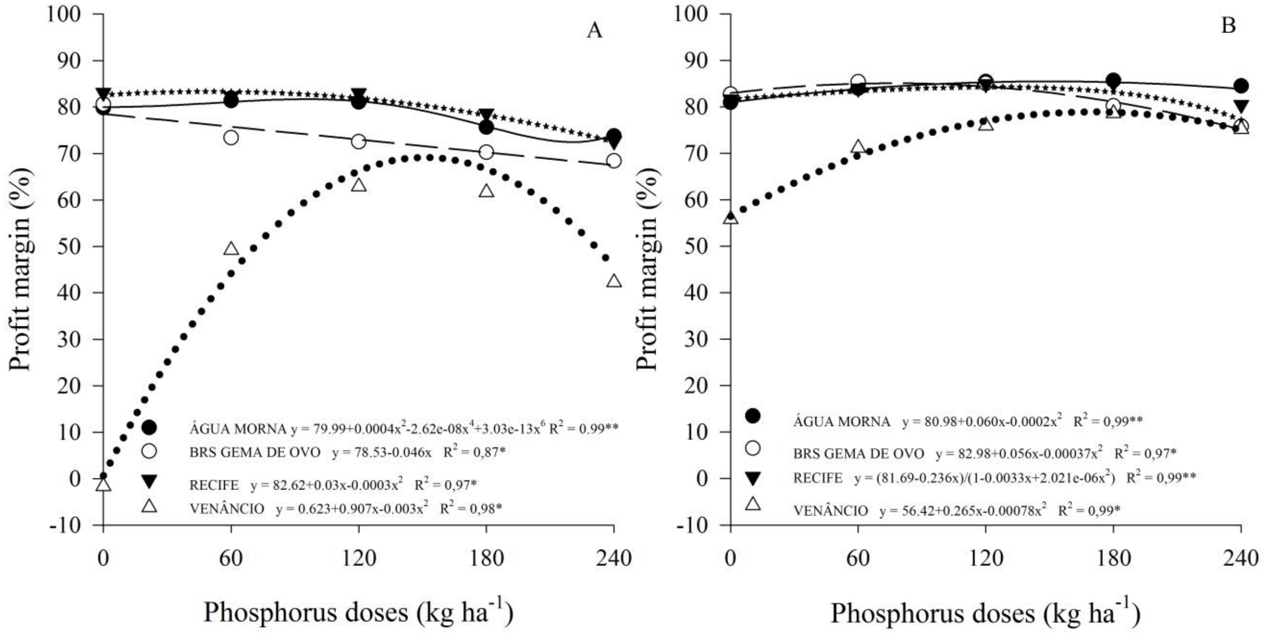

Figure 5. Profitability index of the interaction between doses of phosphorus, table cassava cultivars and two agricultural crops, 2018/19 (A) and 2019/20 (B), in the city of Mossoró-RN, in the Brazilian Semiarid region.

In the 2018/19 crop, the highest values of the profitability index were 83.49, 81.67, 78.53, and 67.31% for the cultivars Recife, Água Morna, BRS Gema de Ovo, and Venâncio with doses of 53.19, 94.67, 0, and 147.04 kg ha^{-1} of P_2O_5, respectively (Figure 5A). In the second crop (Figure 5B), the cultivars Água

Morna, Recife, BRS Gema de Ovo, and Venâncio had the highest estimated profitability rates of 85.77, 85.37, 85.16, and 78.88% with doses of 158.17, 146.15, 77.01, and 169.13kg ha^{-1} of P_2O_5, respectively. The profitability index values were higher in the 2019/20 crop compared to the first crop, due to the higher gross and net income observed for this crop.

Regarding the profitability index, the cultivars Água Morna and Recife stood out with the highest values obtained at all doses in both crops (Figure 5). The cultivar BRS Gema de Ovo was equal to these cultivars at doses of 0 and 240 kg ha^{-1} of P_2O_5 in the 2018/19 crop and at doses from 0 to 180 in the 2019/20 crop. On the other hand, the cultivar Venâncio presented the lowest indexes at all doses in both crops.

The return rate and profitability index variables are calculated from production costs, gross income, and net income, thereby giving a real sense of the viability of planting the crop using the dose with the highest agroeconomic efficiency. In addition, these variables make it possible for farmers to visualize the economic return of possible investments concretely.

Studying the economic viability of doses of commercial NPK formulations in cassava, ALVES et al. (2012) and ALVES FILHO et al. (2015) achieved the maximum productivity at the highest dose; however, at 33 and 50% of the maximum dose, respectively, they achieved a considerable reduction in the cost of fertilizers and little reduction in productivity. Thus, these doses would be the recommended ones because a favourable rate of return is achieved while requiring less investment.

The exploitation of cassava in the semiarid region of Rio Grande do Norte, predominantly by small farmers, can be an obstacle to the adoption of technologies. The low educational level of most cassava producers is an obstacle to the adoption of technologies in root cultivation (OLORUNSANYA 2014). Small production areas make little investment in inputs, use manual operations to perform plantings, and have a lack of knowledge of high-yield cultivars, difficulties in marketing, and difficulties in accessing credit and financing, culminating in unsatisfactory production (BUHARI 2017).

The best way for small producers to make their crops more technical is to join cooperatives and associations, which provide greater credit facilities for the purchase of inputs, mechanization, marketing and technical assistance (ENIMU et al. 2016, OGUNLEYE et al. 2017). In addition, the amount paid per kilogram of cassava in the production areas is very low, often causing losses to producers or an unfavourable profit margin. Producers must adopt other forms of commercialization of the root to add value to the product.

The cultivars evaluated in the research are potentially attractive for local commerce due to the characteristics of the roots. Dark brown outer skin colouring with a white pulp is a regional preference. Cultivars with yellow root pulp coloring are not widely explored but are well accepted in the market. It is important to note that it is possible to use the aerial part of the cultivars as a forage option for animal feed, either from the producer itself or marketed to third parties, making it another source of income. In the semiarid region, there are limited resources of this kind, with double aptitude.

The selection of genotypes that perform better with low phosphorus requirements or that respond to nutrient application with increased productivity are ways to ensure increased profitability with the crop. Furthermore, the use of family labour in the production and harvest stages can also dilute this cost of production, which is offset by the maximization of net income.

CONCLUSION

The use of phosphate fertilizer in the Brazilian semiarid region was economically viable for the evaluated table cassava cultivars.

The Recife cultivar was the region's most profitable cultivation, with a profit ranging from R$ 40,331.07 ha^{-1} to R$ 57,603.46 ha^{-1} in both seasons, with an average recommendation of 120 kg ha^{-1} of P_2O_5. Such results are extremely important to improve profit from small rural properties, showing that investment in technologies such as fertilization, for example, make it possible to obtain a return with increased productivity.

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