Water balance and technical-financial performance of irrigation in the cassava cultivation[1]

Ricardo Barros Silva[2*], *Iêdo Teodoro*[2], *José Leonaldo de Souza*[2], *Ricardo Araújo Ferreira Júnior*[2], *Marcos Alex dos Santos*[2], *Gleica Maria Correia Martins*[2]

10.1590/0034-737X202370050007

ABSTRACT

The objective, in this research, was to evaluate the agricultural productivity and the financial performance of levels of irrigation in the cassava. For this, experiment was carried out, under a randomized block design, with six irrigation levels, as a function of crop evapotranspiration (L_0 = 0% (rainfed), L_1 = 40%, L_2 = 80%, L_3 = 120%, L_4 = 160% and L_5 = 200% of ET_C) and four repetitions. Was evaluated: length and mass of roots, productivity of maximum physical and economic efficiency of roots and productivity of the aerial part. The irrigation level L_5 or total useful water of 1,023 mm, got greatest productivity of the aerial part, 57 Mg ha^{-1}. With a total useful water of 926 mm, this irrigation level, generated the greatest length and mass of roots per plant and the maximum physical productivity, 94 Mg ha^{-1}. As well as the root yield of maximum economic efficiency, which is achieved with a total usable water, 914 mm. Among the irrigation levels studied, L_3 (963 mm) is the one that provides the greatest productivity of roots, 90 Mg ha^{-1}, and gross revenue 167% higher than in areas cultivated under rainfed conditions. Therefore, irrigation of cassava is economically viable.

Keywords: *Manihot esculenta* Crantz; total useful water; root mass; physical productivity and maximum economic efficiency.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has been cultivated for about 9 thousand years, making it one of humanity's oldest agricultural crops. This is because this plant has attractive characteristics for small and medium producers, such as: good adaptation to poor and acidic soils, tolerates rainfed conditions, cheap planting material and with great tolerance to pests and diseases, which makes it capable of generating returns finance with low production cost. For these reasons, cassava is considered one of the most socioeconomically important crops in the world (Howeler *et al.*, 2013).

In the 2021 harvest, world production was 314.80 million tons of cassava roots. In this harvest, Nigeria produced 63.03 million tons, consolidating itself as the world's largest producer. Meanwhile, Brazil stood out as the five largest global producer in this crop, with production 18.09 million tons of roots and an average productivity of 15.00 Mg ha^{-1} (FAO, 2023). Among the Brazilian regions, the North is the largest national producer, with 36% of production, followed by the South and northeast regions, which are responsible for 24 and 20% of production, respectively. In 2021, the state of Alagoas produced 527 thousand tons, with an average productivity of 12.90 Mg ha^{-1}, and ranked 10th among Brazilian states (IBGE, 2023). Despite the

Submitted on July 23rd, 2022 and accepted on March 22nd, 2023.

[1] This paper was extracted from a doctoral thesis entitled "Growth and Productivity of Cassava Under Irrigation Levels" of the Programa de Pós-Graduação em Agronomia of the Universidade Federal de Alagoas. All authors belong to the same institution. There was no research funding.

[2] Universidade Federal de Alagoas, Campus de Engenharia e Ciências Agrárias, Laboratório de Irrigação e Agrometeorologia, Rio Largo, AL, Brazil. ricardoufal2010@gmail.com; iedoteodoro@gmail.com; leonaldojs@yahoo.com.br; ricardo_ceca@hotmail.com; marcosalex.ma@gmail.com; gleicamaria@hotmail.com
*Corresponding author: ricardoufal2010@gmail.com

root system being the most economically important part of cassava, it should be emphasized that the aerial part of the plant is also commercialized. The branches and leaves are used in animal feed and have high nutritional value. In addition, the leaves are also destined, mainly in Africa, to feed the local population (Tinini et al., 2021).

In the Northeast region of Brazil, most crops are rainfed and are cultivated by small and medium producers. This region is characterized by the irregular distribution of rainfall and prolonged periods of drought (Silva *et al.*, 2011) which contribute to the low productivity of cassava and other agricultural crops. Therefore, studies are needed to indicate the appropriate levels of irrigation for the cassava crop, especially in the initial phase, when the establishment of seedlings depends on the level of moisture in the soil to promote bud sprouting and the root and leaf growth. In conditions of semi-arid locations, this becomes even more relevant, since water is one of the main limiting resources for agricultural production (Mélo Neto *et al.*, 2018).

Research has been carried out with the objective of determining the ideal water management for the cultivation of cassava under different soil and climatic conditions (Odubanjo *et al.*, 2011; Pipatsitee *et al.*, 2018). In this context, Neves *et al.* (2021) state that performing economic analysis on irrigated crops helps decision making, generates savings in materials used and greater economic profitability, since the rational use of water provides lower production costs and increased final revenue.

However, when comparing the amount of research carried out for other agricultural crops, it is concluded that the research directed to the cultivation of irrigated cassava in the Northeast of Brazil is still few (Mélo Neto *et al.*, 2018). In Alagoas, these studies are even more scarce, so that, for the most part, research focuses on tests to determine the productivity of genotypes (Morais *et al.*, 2017). Therefore, the development of new research aimed at determining the ideal water management of cassava under the edaphoclimatic conditions of Alagoas is quite relevant, since irrigation combined with adequate management can enable a good initial development of the crop, give greater vigor to the plants to overcome the adversities of the environment.

In this context, this research aimed to evaluate the components of production, agricultural productivity and the financial performance of different levels of irrigation in the cultivation of cassava in the Forest Zone of Alagoas.

MATERIAL AND METHODS

Characteristics of the experimental area

The experiment was carried out in Rio Largo region, Alagoas, Northeast of Brazil (9º27'58.7" S; 35º49'47.2" W; 127 m). The climate of the region, according to the classification of Koppen, is of the AS type, tropical with rainfall from autumn to winter, the average rainfall varies from 1,500 to 2,200 mm, and the average air temperature from 23 at 28 °C (Barros *et al.*, 2012). The soil is of the type cohesive yellow argisol with medium-clay texture (Santos *et al.,* 2018), whose physical-hydric and chemical properties are shown in Table 1.

Statistical design and treatments

The experimental design adopted was in randomized blocks (RB), with four replications and the treatments were six irrigation levels as a function of crop evapotranspiration – ET_C (L_0 = 0% (rainfed), L_1 = 40%, L_2 = 80%, L_3 = 120%, L_4 = 160% and L_5 = 200% of ET_C). The total water depths of the treatments, during the cultivation cycle, were: 522 (L_0), 656 (L_1), 817 (L_2), 963 (L_3), 1,018 (L_4) and 1,023 (L_5) mm. In each of the 24 experimental plots, measuring 6.0 x 8.0 meters (48 m²), 96 plants were planted. The total cultivation area was 1,740 m². Irrigation levels greater than 100% of ET_C were used for the cassava crop to reach potential productivity until it began to decline due to stress caused by water excess. The ET_C was obtained by Equation 1.

$$ET_C = ET_0 \times K_C \quad (1)$$

where, ET_C is crop evapotranspiration (mm d^{-1}), ET_0 is the reference evapotranspiration estimated by the Penman-Monteith-FAO method - mm d^{-1} (Allen *et al.*, 1998) and K_C is the crop coefficient.

The crop coefficient (K_C), during the irrigation period, was equal to 1.0 because the crop was in the middle phase of the phenological cycle. In the initial and final phases of the cultivation cycle, the K_C was 0.35 and 0.45, respectively, according to the Royal Irrigation Department – RID (2010).

Planting and cultural treatments

Cassava planting was carried out in June 2019, at a spacing of 1.0 x 0.5 meters to form a population of 20,000 plants per hectare. Soil preparation was done with two harrowing at 30 and 5 days before the planting. The variety used was the Caravela, with 20 cm long seedlings and at least 5 buds. After planting, a pre-emergence herbicide based on Flumioxazin (200 g i.a. ha^{-1}, 400 L of syrup ha^{-1}) was applied before emergence of the plants. During cultivation, invasive plants were eliminated by hand weeding.

The foundation fertilization and cover of the cassava were carried out according to the estimation of nitrogen (N), phosphorus (P) and potassium (K) absorption, according to Souza *et al.* (2009). In the foundation fertilization, 27 kg ha^{-1} of P were applied, and in the topdressing fertilization, 123 kg ha^{-1} of N and 146 kg ha^{-1} of K, the sources being urea (45% N), simple superphosphate (18% P_2O_5) and potassium chloride (57.8% K_2O). This last fertilization was divided into two applications at 45 and 90 days after planting (DAP) and the harvesting was done in June 2020.

Water balance and irrigation

The water balance of the crop was determined on a ten-day scale for each irrigation level by Thornthwaite and Mather method, according to Pereira *et al.* (2002). Effective rainfall during the growing season was determined by subtracting the excess water, determined by the water balance, from the total rainfall. Total useful water was determined as the amount of water applied via irrigation plus effective rainfall. The agrometeorological data (rain, global solar radiation, air temperature, relative humidity, wind speed and ET_0) from the experimental period were provided by the Laboratory of Irrigation and Agrometeorology (LIA) of CECA/UFAL, which has an automatic station (Micrologger – CR 1000, Campbell Science, Logan, Utah), installed next to the experimental area. With the daily values of the meteorological elements, figures were generated and the general means values and the standard deviation that represents the variation around the means (±) were obtained.

The irrigation was carried out from October 2019 to March 2020, during the dry period of the region that occurs in spring/summer. The irrigation system used was micro-sprinkler, in a spacing of 2.0 x 3.0 meters between emitters and an average flow of 50 L h^{-1}, an application intensity of 8.33 mm h^{-1}. The efficiency of the irrigation system was 95%, the irrigation shift adopted was 3 days depending on the ET_C and the effective rain, during the irrigation period, were deducted from the applied water.

Analyzed variables

The variables analyzed, during the cassava harvest (355 DAP), in three plants of the useful area of the plot (24 m²), were: length of commercial roots (LR, cm), mass of commercial roots per plant (MR, kg plant), commercial root productivity (RP, Mg ha^{-1}) and the aerial part, composed of branches and leaves (AP, Mg ha^{-1}).

The length of roots was obtained with the aid of a tape measure. The mass of plant parts was obtained by weighing on a scale with an accuracy of 0.002 kg (Toledo, Prix 3 Plus, São Bernardo do Campo, Brazil), and productivity was subsequently determined by multiplying the fresh mass by the number of plants per hectare (20 thousand plants). The roots with diameter greater than 2 cm and a length greater than 10 cm were considered commercial roots, according to Tironi *et al.* (2015).

Financial analysis

The cassava root production function was estimated as a function of total useful water, by second degree polynomial regression, similar to Equation 2.

$$Y = b_0 + b_1 x - b_2 x^2 \tag{2}$$

where, Y is the agricultural productivity of cassava (Mg ha^{-1}); x is the total useful water and b_0, b_1 and b_2 are the coefficients of the equation. The choice of regression type was based on the one that best represented the results and the main decision parameter was the coefficient of determination (R^2).

The estimate of the total irrigation depth that generates the physical maximum productivity was performed by equating the first derivative of Equation 2 to zero, which led to Equation 3.

$$X_{MAX} = \frac{b_1}{2b_2} \tag{3}$$

where, X_{MAX} is the amount of input (total useful water) that provides maximum productivity (Mg ha^{-1}), b_1 and b_2 are equation coefficients of the production equation. The maximum productivity (Y_{MAX}) was obtained by substituting the value of X_{MAX} (Equation 3) in polynomial regression (Equation 1).

The financial analysis of cassava production was performed as a function of the price per millimeter of water applied and the product (ton of cassava roots). The irrigation depth of maximum economic efficiency (total useful water) was obtained by Equation 4.

$$W = \frac{\left(C_W - P_i b_i\right)}{\left(2 P_i b_2\right)} \tag{4}$$

where, W is the amount of input (total irrigation depth) that generates the maximum economic efficiency yield; C_W is the input cost; P_i is the price of cassava roots and b_1 and b_2 are the coefficients of the production equation.

As for the productivity of the area part (branches and leaves) of cassava, the financial analysis was based on the regression of the first degree equation, similar to Equation 5.

$$Y = b_0 + b_1 x \quad (5)$$

where, Y is the agricultural productivity of cassava (Mg ha^{-1}); x is the total useful water, and b_0 and b_1 are the coefficients of the equation. The choice of regression type also was based on the one that presented the best coefficient of determination (R^2).

The price per millimeter of water applied (R$ mm^{-1}) was obtained according to the implementation and operating costs of a conventional sprinkler irrigation system in one hectare of cassava, as shown in Table 2. The prices adopted were obtained from commercial houses in the region, in November 2020. In the amortization over 20 years, 30% of the value for maintenance and 20% for labor were added. The value of electricity for rural areas was considered. For the cost of labor per hectare, it was considered that a worker with a salary of 1,700 reais per month can manage 30 hectare.

Table 1: Chemical and physico-hydric properties of the soil of the experimental area

Physical-hydric properties	**Unit**	**Value**
Field capacity	m^3 m^{-3}	0.244
Permanent wilting point	m^3 m^{-3}	0.147
Available water capacity	mm	58.00
Soil density	g m^{-3}	1.50
Total porosity	m^3 m^{-3}	0.423
Basic infiltration speed	mm h^{-1}	52.00
Chemical properties		
pH in water	--	5.8
Phosphor	ppm	37
Potassium	ppm	111
Ca + Mg	meq 100 mL^{-1}	4.1
Ca	meq 100 mL^{-1}	2.4
Mg	meq 100 mL^{-1}	1.7
Na	ppm	36
Al	meq 100 mL^{-1}	0.06
Al + H	meq 100 mL^{-1}	4.8
Sum of Bases	--	4.5
Effective C.T.C.	--	4.6
V	(%)	48.6
M	(%)	1.3
Total M.O.	(%)	2.3
Fe	ppm	103.8
Cu	ppm	0.46
Zn	ppm	4.0
Mn	ppm	11.3

Table 2: Values used to calculate the price per millimeter of the applied water in the cassava through a conventional sprinkler system

Unit prices (R$/unit.)		
Electricity	R$ kW^{-1} h^{-1}	0.47
Labor	R$ $month^{-1}$	1,700.00
Labor	R$ ha^{-1} $month^{-1}$	56.67
Irrigation system	R$ ha^{-1}	11,420.00
Weighted amortization over 20 years	R$ ha^{-1} $year^{-1}$	878.00
Basic infiltration speed	mm h^{-1}	52.00
Annual operating costs		
Electricity	R$ ha^{-1} $year^{-1}$	1,052.00
Labor	R$ ha^{-1} $year^{-1}$	283.35
Applied millimeter cost		
Operational cost	R$ mm^{-1}	1.98
Fixed cost of the applied millimeter	R$ mm^{-1}	1.30
Total cost of applied millimeter	R$ mm^{-1}	3.28

Through a survey with producers and buyers of cassava, in the Forest and Agreste Zone of Alagoas, were obtained the minimum, average and maximum prices, in the year 2021, of the ton of roots (300, 375 and 450 reais, respectively) and part cassava aerial (100, 150 and 200 reais).

Statistical analysis

The collected data were submitted to analysis of variance and, when significant by the "F" test ($p < 0.05$), were submitted to regression analysis. The regression coefficients had their significance verified by the "t" test at 5% probability (Ferreira, 2018).

RESULTS AND DISCUSSION

Meteorological variables and water balance

The average air temperature, during cassava cultivation, was 25.1 (± 1.5) °C, the maximum air temperature mean was 30.1 (± 2.1) °C, and the mean minimum was 21.3 (± 1.6) °C. According to Aparecido et al. (2020), in research in the Midwest of Brazil, regions with an average temperature between 20 and 27 °C are considered suitable for the commercial cultivation of cassava, while regions with temperatures below 16 and above 38 °C are considered inadequate. El-Sharkawy (2004) states that temperatures below 17 and above 37 °C impair the initial sprouting of buds in the cassava and temperatures from 25 to 35 °C maximize the photosynthetic rate of cassava. In view of the above, it is possible to affirm that in the Forest Zone of Alagoas, the thermal conditions are adequate to cultivation of cassava, with temperatures that favor the growth, development and the agricultural productivity of the cassava. The mean wind speed was 1.5 (± 0.4) m s^{-1}, the maximum recorded value was 2.6 m s^{-1} (August 06, 2019) and the minimum was 0.5 m s^{-1} (April 24, 2020). In the Figure 1a it is possible to observe the variation of wind speed at 2 meters height and the air temperature in the experimental period.

The mean relative humidity, during cultivation, was 74.2(± 6.8) %, the maximum daily value was 96.2% (July 5, 2019) and the lowest value was 57.9% (November 24, 2019). The average daily global solar radiation was 18.3 (± 4.8) MJ m^{-2}, with a daily maximum value of 27.6 MJ m^{-2} (February 8, 2020) and a daily minimum of 5.4 MJ m^{-2} (June 12, 2020). Cock & Connor (2021) confirm that the equatorial region of the planet has an ideal global solar radiation incidence for the growth and development of cassava. The Forest Zone region of Alagoas is close to the equator and, in this region, Ferreira Júnior (2012) observed average daily values of 20.9 MJ m^{-2} from February to April, 14.9 MJ m^{-2} from May to August and 23.3 MJ m^{-2} from September to January. Therefore, with base in the incidence of global solar radiation observed in this research and values described by Ferreira Júnior (2012), in the studied region, it is possible to affirm that there is avail-

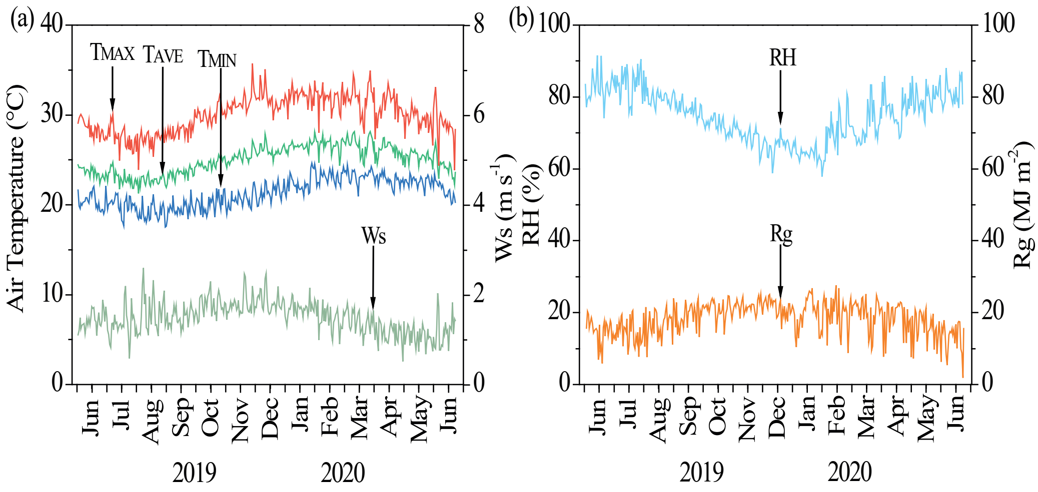

Figure 1: (a) Air temperatures: minimum – TMIN, average – TAVE, maximum – TMAX and wind speed at 2.0 meters high – Ws; (b) Relative air humidity – RH and global solar radiation – Rg, in Rio Largo, Alagoas, Brazil, from June 2019 to June 2020.

ability of solar radiation ideal for cassava cultivation. And, this enables the economic exploitation of this agricultural crop without impediments due the availability of energy for the photochemical process of the plant. In the Figure 1b is observed the variation of the relative air humidity and global solar radiation during the experimental period.

The total rainfall during the cassava cultivation was 1,847 mm. The month of November 2019 had the least rain (7.4 mm) and April 2020 was the rainiest (364 mm). The period between the last ten days of September 2019 and the first ten days of February 2020 (143 days) stood out for having accumulated only 103 mm. This highlights the scarcity of rain during spring and summer in the region (Figure 2a). Aparecido *et al.* (2020) state that accumulated rainfall of 1,000 to 1,500 mm, well distributed throughout the cassava crop cycle, is important to obtain high productivity. Meanwhile, Troccoli *et al.* (2014) emphasize that rainfall accumulations from 400 to 750 mm are sufficient for a high yield of cassava roots. Therefore, according to what the researchers claim, and the distribution of rainfall during the growing season, it is possible to say that the Forest Zone region, in the state of Alagoas, has enough annual rainfall to meet the demand for cassava, however, the seasonality of the rain generates a dry period in the region that justifies the adoption of irrigation, given that the deficit water generates a reduction in the productivity of cassava. During the dry period of the region, irrigation was applied according to the irrigation levels studied, as can be seen in Figure 2a. The irrigation depth applied ranged from 134 to 906 mm, in the levels L_1 and L_5. Meanwhile, the total water consumed by the plant, which represents the effective rain plus irrigation, were: 522 (L_0), 656 (L_1), 817 (L_2), 963 (L_3), 1,018 (L_4) and 1,023 (L_5) mm. In rainfed areas (L_1) the effective rainfall observed was 522 mm.

The accumulated reference evapotranspiration (ET_0), during the cassava cycle, was 1,454 mm, with a daily mean of 4.1 (± 1.1) mm. The highest daily value of ET_0 was 7.4 mm (January 29, 2020), and the lowest was 1.2 mm (May 30, 2020). Crop evapotranspiration (ET_C) had a daily mean of 3.0 (± 1.8) mm, and totaled 1,030 mm. The highest daily value of ET_C was 7.4 mm, equal to ET_0, because K_C of cassava, in this period, was 1.0 and the lowest ET_C value was 0.5 mm (August 1, 2019). In Figure 2b it is possible to observe the variation of ET_0 and ET_C during the field experiment period.

The water balances of the cassava crop under different irrigation levels highlighted the importance of irrigation in agricultural crops in the studied region. Areas cultivated under rainfed regime showed a water excess of 1,323 mm, and the highest water deficit among the irrigation levels studied, 508 mm. This water deficit occurred between September 2019 and February 2020, during the spring and summer seasons, dry period in the Forest Zone of Alagoas, and affected the plants from the fourth to the seventh month after planting. According to Daryanto *et al.* (2016), cassava is more sensitive to water deficits in

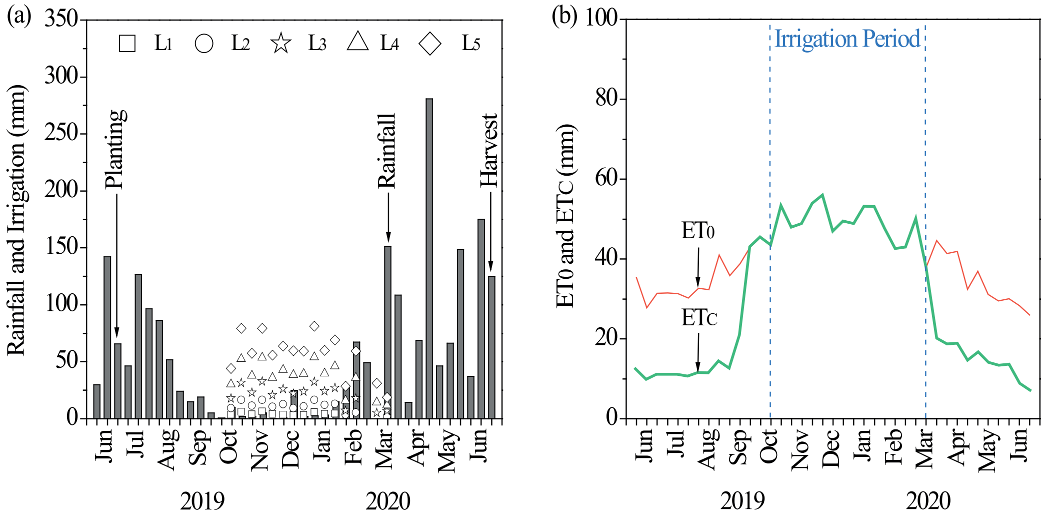

Figure 2: (a) Rainfall and irrigation levels; (b) Reference evapotranspiration – ET0 and crop – ETC, in Rio Largo, Alagoas, Brazil, from June 2019 to June 2020.

the first five months after planting (critical period) and the lack of water in this initial period can impair the initial growth of storage roots and the formation of the vegetative canopy.

The sub-irrigated areas, with the irrigation levels L_1 and L_2, suffered water deficit, as in areas under the rainfed regime. However, to a lesser extent. The water deficit in these areas were 372 and 211 mm, respectively, and the water excess 1,323 and 1,335 mm. Therefore, it is possible to observe, through of the water balances, performed in the cultivated areas under the levels L_0, L_1 and L_2, that the irrigation in cassava crops in the Forest Zone of Alagoas is essential to avoid the water stress of the plants and, consequently, reduction of the final productivity and lower financial return for the farmer. This being, the water stress, the main factor that prevents a better productive performance of the culture in the studied region. The water balances of the cassava crop, at the irrigation levels studied, are shown in Figure 3.

In irrigated areas with levels above 100% of the ET_C there were only small water deficits, 65 mm at area with irrigated the level L_3 (120% of the ET_C) and 5.0 mm in areas with L_4 (160% of the ET_C) and L_5 (200% of the ET_C). It happened because irrigation started after the end of the rainy season in 2019 and, due occasional problems, the irrigation system stayed stopped for a day or two. The water excess in these areas were 1,389, 1,528 and 1,728 mm, for levels L_3 (120% of ET_C), L_4 (160% of ET_C) and L_5 (200% of ET_C), respectively. It is important to observe the increase in excess water with the increase in the level of irrigation and this can cause stress by excess water. El-Sharkawy (2004) reports that higher cassava yields have been observed in studies with high availability of well-distributed water during the crop cycle. The researcher cites as an example, crops in Thailand, where it was found that the maximum yield of roots is correlated with accumulated rainfall of 1,700 mm, between the 4th and 11th months after planting, period in which occur the greatest accumulation of carbohydrate in the system root of plants. Therefore, under high water availability, cassava tends to present a greater productive response. This also reinforces the importance of even distribution of water throughout of the crop cycle.

Production variables

The irrigation levels caused a significant difference, at 5% probability, in the production variables, except for the productivity of the aerial part. However, due to the considerable difference between the irrigation levels regarding the productivity of the part aerial, and the significant adjustment for the first degree regression, the values obtained by the irrigation levels for this variable were presented. The analysis of variance is shown in Table 3.

The length of roots fitted very well to a quadratic regression curve. The maximum value of root length was 49.50 cm, in areas cultivated under total useful water (effective

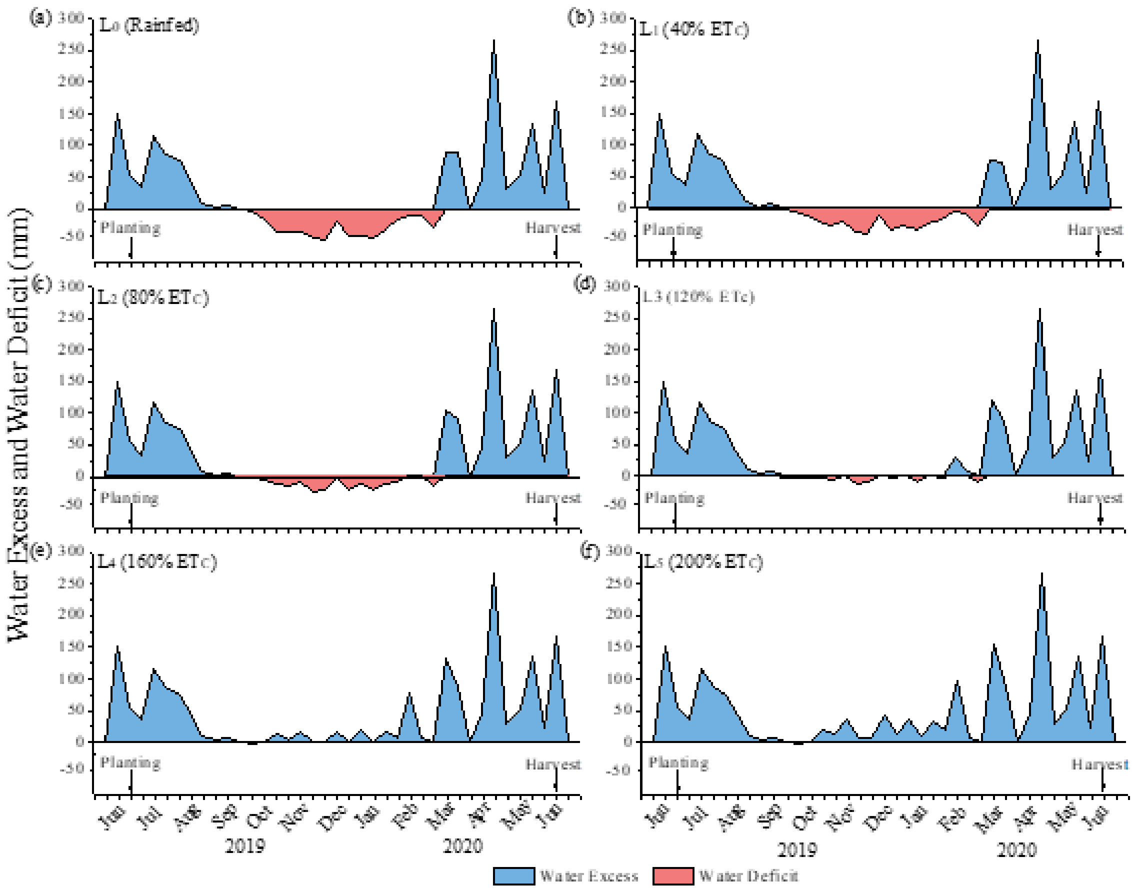

Figure 3: Ten-day water balance of cassava crop, under different irrigation levels, in Rio Largo, Alagoas, Brazil, from June 2019 to June 2020.

rain plus irrigation) estimated at 926 mm, this value is close to that obtained in irrigated areas with the L_3 level, equivalent to total useful water of 963 mm, which was 49.30 cm. In rainfed areas (L_0), with total useful water of 522 mm, was observed the shortest root length, only 28.0 cm (Figure 4a). In the plots irrigated with total useful water greater than 926 mm, it was observed that the length of the roots began to decrease due to water stress caused by excessive irrigation. Daryanto *et al.* (2016) report that, depending on the soil texture, cassava plants can reach up to 2.0 meters of length, and this provides for the use of water from the soil in deeper layers. Therefore, it is observed that in a clayey soil, such as the one area of this research, the cassava may have your root growth reduced. However, it was possible to observe that irrigated areas provided greater root growth, when compared with areas cultivated under rainfed conditions. This greater root length tends to generate roots with greater mass, which generates greater productivity, as can be seen in the Figure 4b.

The maximum root mass per plant was 4.73 kg, obtained with a total useful water of 926 mm. Among the levels studied, in L_3, with total water of 963 mm, a similar mass of roots, 4.50 kg, was observed. Meanwhile, the cultivated areas under rainfed regime had the lowest root mass, 1.62 kg (Figure 4b). As the highest root mass was obtained with a total water of 926 mm, this accumulation of water provided the highest physical productivity of roots, 94.0 Mg ha^{-1}, and areas under rainfed regime, with effective rainfall of 522 mm, the root productivity was only 32.0 Mg ha^{-1} (Figure 4c). According to Daryanto *et al.* (2016), this lower productivity in areas rainfed, is attributed to the fact that prolonged periods of water deficit tend to reduce the number of adventitious roots of cassava, and it is these roots that in the future become storage roots. Therefore, this characteristic can help it to tolerate periods of drought due to the smaller number of drains per plant (source-sink relationship), however, it impairs its ability to maintain a high yield of roots with commercial standards. This statement corroborates with the data obtained in this research, since in areas of rainfed crops, occurred the greater water deficit, as seen in the water balance, and the plants in these areas were the least productive.

Table 3: Values used to calculate the price per millimeter of the applied water in the cassava through a conventional sprinkler system

CAUSE OF VARIATION	MEDIUM SQUARES				
	D.F.	LR	MR	RP	AP
Levels	5	251.775*	6.2074*	2481.877*	136.26NS
Blocks	3	91.597NS	1.0997NS	439.664NS	31.447NS
Linear Regression	1	274.032NS	15.200NS	6078.690*	540.84*
Quadratic Regression	1	810.694*	15.334*	6132.062*	87.291NS
Residue	15	77.197	1.7334	693.529	112.54
CV (%)		22.75	34.80	34.80	20.46

CV – Coefficient of Variation; * - Significant at 5% and NS - Not significant by the F test ($p < 0.05$).

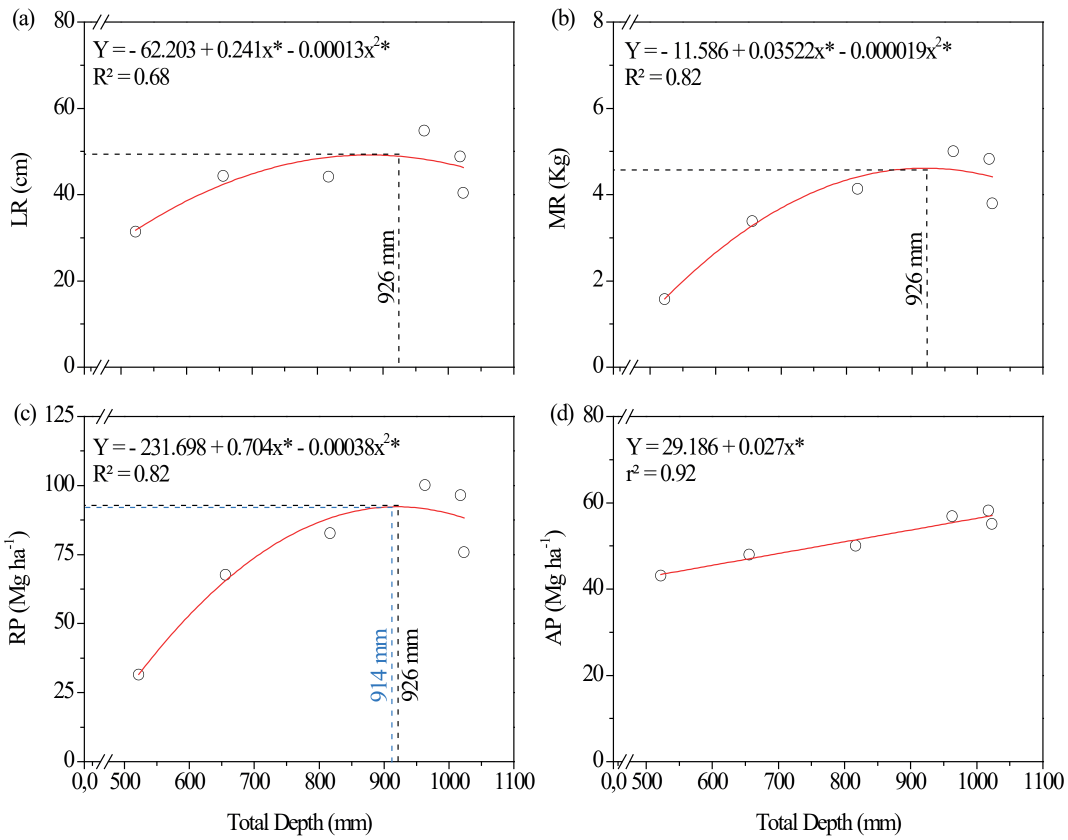

Figure 4: (a) Root length – LR; (b) Root mass per plant – MR; (c) Productivity of commercial roots – RP; and (d) Aerial part – AP, of cassava under irrigation levels in the Rio Largo region, Alagoas, Brazil, from June 2019 to June 2020.

As for the productivity of the aerial part of cassava cultivated under different irrigation levels, a linear adjustment was observed, with r^2 equal to 92% and this indicates that occurred a linear increase of aerial par with increase of irrigation depths, up to the highest level, used in this study, that generated greater mass gain of branches and leaves of the plants.

The highest productivity of fresh mass of the aerial part of cassava was 57.0 Mg ha^{-1}, obtained in irrigated areas with the highest quantity accumulated total useful water of 1,023 mm (L_5) and the lowest was 43.0 Mg ha^{-1} in rainfed areas (L_0), therefore, with the highest accumulated total useful water there was a productive increase in the aerial part of cassava of 32%, compared to the productivity obtained under rainfed regime (Figure 4d). Munyahali *et al.* (2017) state that in addition to the roots, the branches and the leaves are of economic interest, to use in the human and animal food in different regions of the world and the cultivation of cassava without water restriction favors the formation of the most vigorous plants. So, in general, it is observed that irrigated crops with high levels of water, such as L_5 (200% of ET_C), compared to areas under rainfed regime, generate higher productivity of branches and leaves in cassava and increase the profit of producers with its commercialization, mainly, for ruminants feeding, that is a common practice in the state of Alagoas.

The productivity of maximum economic efficiency varies depending on the price of the input applied and the final product of the enterprise. Therefore, the productivity of cassava roots of maximum economic efficiency, with minimum, average and maximum prices, is 94.0 Mg ha^{-1}, because the total water depths of maximum economic efficiency for these prices were very close, being 911, 914 and 916 mm, respectively. It is observed that the total water depths of maximum economic efficiency generate root productivity equal to the total water depth of maximum physical productivity (926 mm). This indicates that irrigation in cassava is economically viable. And, with the average price per ton of roots equal to R$375.00 reais, in one hectare of cassava, the total gross revenue would be R$35,250.00 reais, while that in rainfed areas gross revenue would be only R$12,000.00 reais, value 66% lower in relation to the highest value obtained. With a total cost of 3.28 reais per millimeter of water applied, and an irrigation depth of 507 mm applied in areas irrigated with L_3 (120% of ET_C), the irrigation level studied that generated the highest physical productivity of roots (90 Mg ha^{-1}), the cost of irrigation in a 12-month cassava cycle would be R$1,663.00 reais. Therefore, the difference in net revenue, in areas irrigated with L_3, discounting the cost of irrigation, would be R$32,087.00 reais, value 167% greater than the net revenue in non-irrigated areas.

With the average price of the aerial part of cassava, in Alagoas, equal to R$150.00 reais per ton and the total useful water of 1,023 mm (L_5), which provides the highest physical productivity among the levels studied (57.0 Mg ha^{-1}), the gross revenue obtained by producers would be R$8,550.00 reais per hectare, respectively. Meanwhile, areas cultivated under rainfed regime (L_0), with productivity of the part area of 43 Mg ha^{-1}, would provide gross revenue of only R$6,450.00 reais. Then the total gross revenue, from irrigated areas with the L_5 level, is only 32.55% (R$2,100.00) higher than the gross revenue obtained in rainfed areas. Therefore, if we were to take as a reference only the income obtained from the aerial part of the plants, irrigation would be economically unfeasible. But when added to the increased revenue obtained from the roots, the economic advantages are quite significant.

In general, it is possible to affirm that irrigation, in the cultivation of cassava in the Forest Zone of Alagoas region, is economically viable, because in addition to generating an increase in root productivity and part of the plant area, it can guarantee greater financial return to producers.

CONCLUSIONS

Under the irrigation level of 200% of the ET_C, or total useful water of 1,023 mm, the highest cassava shoot productivity of 57 Mg ha^{-1} is obtained. While, with a total useful water of 926 mm, the greatest length and mass of roots per plant and the maximum physical productivity of 94 Mg ha^{-1} are obtained. This is also the root productivity of maximum economic efficiency, which is obtained with the total useful water of 914 mm. Among the irrigation levels studied, L_3 (120% of ET_C) provides the highest productivity of commercial roots, 90 Mg ha^{-1}, and gross revenue 167% higher than in areas cultivated under rainfed conditions. Therefore, irrigation of cassava in Forest Zone of Alagoas is economically viable.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

This work received no funding. The authors have no conflict of interest to disclose.

REFERENCES

Allen RG, Pereira LS, Raes D & Smith M (1998) Crop evapotranspiration: Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome, FAO. 326p.

Aparecido LEO, Moraes JSC, Meneses KC, Lorençone PA, Lorençone JA, Souza GHO & Torsoni GB (2020) Agricultural zoning as tool for expansion of cassava in climate change scenarios. Theoretical and Applied Climatology, 142:1085-1095.

Barros AHC, Araujo Filho JC, Silva AB & Santiago GACF (2012) Climatologia do estado de Alagoas. Recife, Embrapa Solos. 32p. (Boletim de Pesquisa e Desenvolvimento, 211).

Cock JH & Connor DJ (2021) Cassava. In: Sadras & Calderini (Eds.) Crop Physiology Case Histories for Major Crops. London, Academic Press. p.588-633.

Daryanto S, Wang L & Jacinthe PA (2016) Drought effects on root and tuber production: A meta-analysis. Agricultural Water Management, 176:122-131.

El-Sharkawy MA (2004) Cassava biology and physiology. Plant Molecular Biology, 56:481-501.

FAO - Organização das Nações Unidas para Alimentação e Agricultura (2023) Crops. Available at: <https://www.fao.org/faostat/en/#data/QCL>http://www.fao.org/faostat/en/#data/QC. Accessed on: April 04th, 2019.

Ferreira Júnior RA, Souza JLD, Lyra GB, Teodoro I, Santos MAD & Porfirio A (2012) Crescimento e fotossíntese de cana-de-açúcar em função de variáveis biométricas e meteorológicas. Revista Brasileira de engenharia agrícola e ambiental, 16:1229-1236.

Ferreira PV (2018) Estatística experimental aplicada às Ciências Agrárias. Viçosa, UFV. 588p.

Howeler R, Lutaladio N & Thomas G (2013) Save and grow: cassava. A guide to sustainable production intensification. Rome, FAO. 142p.

IBGE - Instituto Brasileiro de Geográfico e Estatística (2023) Produção agrícola. Available at: <https://sidra.ibge.gov.br/tabela/188#resultado>. Accessed on: April 04th, 2019.

Mélo Neto DG, Coelho DG, Andrade MT & Alves JO (2018) Initial growth of cassava plants cv. Mossoró under different water regimes. Revista Agro@mbiente On-line, 12:191-199.

Morais L, Santiago AD & Cavalcante MHB (2017) Phenotypic stability in cassava estimated by the AMMI analysis with supplementary genotypes. Crop Breeding and Applied Biotechnology, 17:366-372.

Munyahali W, Pypers P, Swennen R, Walangululu J & Vanlauwe B (2017) Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. Fiel Crops Research, 214:194-201.

Neves JCB, Santana MJ, Fernandes ALT, Assis MP & Van Kempen JC (2021) Viabilidade econômica do feijoeiro, em função de lâminas de irrigação e doses de nitrogênio. Nativa, 9:202-208.

Odubanjo OO, Olufayo AA & Oguntunde PG (2011) Water Use, Growth, and Yield of Drip Irrigated Cassava in a Humid Tropical Environment. Soil & Water Research, 6:10-20.

Pereira AR, Angelocci LR & Sentelhas PC (2002) Agrometeorologia (Fundamentos e aplicações práticas). Guaíba, Livraria e Editora Agropecuária. 478p.

Pipatsitee A, Eiumnoh A, Praseartkul P, Taota K, Kongpugdee S, Sakulleerungroj K & Cha-um S (2018) Application of infrared thermography to assess cassava physiology under water deficit condition. Plant Production Science, 21:398-406.

RID - Royal Irrigation Department (2010) Crop coeficiente. Available at: <http://water.rid.go.th/hwm/cropwater/CWRdata/Kc/kc_th.pdf>. Accessed on: April 04th, 2019.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB & Cunha TJF (2018) Sistema Brasileiro de Classificação de Solos. Brasília, Embrapa. 356p.

Silva VPR, Pereira EMM, Azevedo PVD, Sousa FAS & Sousa IF (2011) Análise da pluviometria e dias chuvosos na região Nordeste do Brasil. Revista Brasileira de Engenharia Agrícola e Ambiental, 15:131-138.

Souza LS, Silva J & Souza LD (2009) Recomendação de calagem e adubação para o cultivo da mandioca. Cruz das Almas, Embrapa. 6p. (Comunicado Técnico, 133).

Tinini RCDR, Zambom MA, Dessbesell JG, Adamante D & Venturini T (2021) Silagem da parte aérea da mandioca como um alimento alternativo na dieta de vacas em lactação revisão de literatura. Arquivos de ciências veterinárias e zoologia, 24:e2405.

Tironi LF, Uhlmann LO, Streck NA, Samboranha KF, Freitas CPO & Silva MR (2015) Desempenho de cultivares de mandioca em ambiente subtropical. Bragantia, 74:58-66.

Troccoli A, Dubus L & Haupt SE (2014) Weather Matters for Energy. New York, Springer. 528p.