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CROP PRODUCTION

Growth, productivity and viability of irrigation in cassava crop in the Alagoas Coastal Plateaus

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ABSTRACT: *This research evaluated the effects of the irrigation on growth and productivity of irrigated cassava in the Coastal Plateaus of Alagoas. The planting was done in randomized blocks, with six treatments and four replications. The treatments were irrigation levels in 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 applied was defined as the total irrigation plus the effective rain. The annual evapotranspiration of the cassava plantations in the Costal Plateaus of Alagoas, was 1,030 mm. Plant growth increased significantly with irrigation and the maximum values of the following variables are: leaf area index = 7.6, length of commercial roots = 49 cm, maximum productivity (physical and economic) of commercial roots = 94 Mg ha*$^{-1}$ *and total biomass = 149 Mg ha*$^{-1}$ *and the harvest index = 0.66, all obtained with total irrigation depths (effective rain plus irrigation) between 817 and 963 mm. Finally, it is ratified that understanding the growth, the agricultural and economically viable productivity of irrigated cassava, is an indispensable factor for good management of the crop, especially in regions with irregular rainfall such as the Northeast of Brazil.*
Key words: *Manihot esculenta Crantz, leaf area index, total biomass, dry matter, harvest index.*

Crescimento, produtividade e viabilidade da irrigação na cultura da mandioca nos Tabuleiros Costeiros de Alagoas

RESUMO: *Esta pesquisa avaliou os efeitos da irrigação no crescimento e na produtividade da mandioca irrigada nos Tabuleiros Costeiros alagoanos. O plantio foi feito em blocos casualizados, com seis tratamentos e quatro repetições. Os tratamentos foram níveis de irrigação em função da evapotranspiração da cultura –* ET_C *(*L_0 *= 0% (sequeiro),* L_1 *= 40%,* L_2 *= 80%,* L_3 *= 120%,* L_4 *= 160% e* L_5 *= 200% da* ET_C*). A lâmina total foi definida como o total da irrigação mais a chuva efetiva. A evapotranspiração anual da cultura da mandioca nos Tabuleiros Costeiros de Alagoas é 1.030 mm. O crescimento das plantas aumentou significativamente com a irrigação e os valores máximos das seguintes variáveis são: índice de área foliar = 7,6; comprimento de raízes comerciais = 49 cm; produtividades (física e econômica) máximas de raízes comerciais = 94 t ha*$^{-1}$ *e biomassa total = 149 t ha*$^{-1}$ *e o índice de colheita = 0,66, todos obtidos com lâminas de irrigação totais (chuva efetiva mais irrigação) entre 817 e 963 mm. Por fim, ratifica-se que entender o crescimento, as produtividades agrícola e economicamente viáveis da mandioca irrigada, é fator indispensável para se fazer um bom manejo da cultura, principalmente, em regiões com irregularidade de chuvas como o nordeste brasileiro.*
Palavras-chave: *Manihot esculenta Crantz, índice de área foliar, biomassa total, matéria seca, índice de colheita.*

INTRODUCTION

Cassava is one of the main agricultural crops of the world, especially for their socio-economic importance and ability to tolerate adverse conditions such as low rainfall, acid soils and poor nutritionally and crops with low s index s technological s (DARYANTO et al., 2016). In the 2018 harvest, Brazil produced 17.6 million tons of cassava roots, with an average productivity of 14.64 Mg ha^{-1}. The Northeast region was the second largest producer among the national regions, being

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responsible for 20% of the national production. In this harvest, Alagoas produced 394 thousand tons of cassava roots, with a yield of 11.62 Mg ha^{-1} (low productivity, in relation to the potential of the crop), ranking as the 13th largest Brazilian state producer (IBGE, 2018).

The low agricultural productivity of cassava plantations in Alagoas is, mainly, due to water deficiency and the low technological index used in the crops from Alagoas. The irrigation can solve problems related to water deficit but need to have a good technical knowledge about this technology, because the empirical adoption of irrigation are globally common problems that can generate water waste and soil salinization in places where there is the use of low quality water or bad management. Thus, the planning and use of efficient irrigation methods and management are important in optimizing agricultural systems and; consequently, increasing the productivity of crops, such as cassava, which are quite expressive for global agribusiness (HARRISON, 2018).

During the cassava production cycle, the phases most sensitive to water deficit are the first five months after planting (critical period), because in this period the formation of true roots and storage of carbohydrates begins. To achieve economically viable productivity, the cassava demand about 750 mm of rainfall well distributed in 12 months cultivation (TROCCOLI et al., 2014). Therefore, unlike other microregions in Northeast Brazil, the region of the Coastal Plateaus of Alagoas, has a favorable climate for the cultivation of cassava, because, according to SOUZA et al. (2005), in this region, the thermal conditions (average temperature) is 25 and the annual rainfall average is 1,800 mm which is enough to meet the water demand of the cassava crop. However, the distribution of rainfall occurs on a seasonal basis, with a dry season averaging from 5 to 6 months of duration per year and this justifies the use of irrigation in agricultural crops.

The adoption of irrigation to meet the water demand of cassava crop is a promising technique in the main producing regions of the world (XIE et al., 2017), mainly in northeast Brazil, where the largest part of the plantations happens in regime rainfed. It is estimated that the cultivations of cassava under rainfed conditions have a drop in productivity above to 59% (EZUI et al., 2018). Studies to estimate the irrigation levels in crops, such as cassava, should know the potential crop yield when irrigated, identifying to what extent the irrigation it is economically viable, and the point of start decline in agricultural productivity by excess water. In the cassava crop, several irrigation methods are used; however, the most common are: sprinkling, located and surface (MANICKASUNDARAM et al., 2002).

In this perspective, it is necessary to develop research that attempts to increase the water use efficiency (through knowledge of the irrigation level of maximum economic efficiency, methods and more adequate irrigation systems) and productivity of cassava crops in various region and climatic conditions. Therefore, this research evaluated the effects of irrigation on growth, productivity, harvest index and the technical and economic benefits in the cassava cultivation in the region of the Coastal Plateaus of Alagoas.

MATERIALS AND METHODS

The experiment was carried out at the Campus of Engineering and Agricultural Sciences (CECA) of the Federal University of Alagoas (9º27'58.7" S; 35º49'47.2" W; 127 m), municipality of Rio Largo, Alagoas, region of the Coastal Plateaus Northeastern Brazil. According to Koppen classification, the climate is of the type AS, with tropical occurrence of rains from autumn to winter, with average annual rainfall ranging from 1,500 to 2,200 mm, the average temperature of the air, between 23 e 28ºC (BARROS et al., 2012). The soil in the experimental area is classified as an argisolic cohesive yellow Latosol with a clayey texture, with field capacity (Θ_{CC} = 0.244 m^3 m^{-3}), permanent wilting point of (Θ_{PMP} = 0.147 m^3 m^{-3}), soil density of 1.50 g m^{-3}, total porosity of 0.423 m^3 m^{-3}, available water capacity of 58 mm and basic infiltration speed of 52 mm h^{-1}.

The fertilization of the cassava foundation and cover was carried out according to the nutrient absorption estimate, according to SOUZA et al. (2009), with a total level of 123 kg ha^{-1} of nitrogen (N), 27 kg ha^{-1} of phosphorus (P) and 146 kg ha^{-1} of potassium (K). The cover fertilization was divided into two applications, at 45 and 90 days after planting (DAP).

The planting was done in June 2019, at a spacing of 1.0 x 0.5 meters to form a population of 20 thousand plants per hectare. The variety of cassava used was Caravel, from early to intermediate cycle (12 to 18 months), high productivity and medium tolerance to pests and disease. Seedlings of 20 cm long and with at least 5 buds were used. After planting, it was applied pre-emergent herbicide base of flumioxazin (200 g p.c./ ha, 400 L of mixture/ha).

The experimental design adopted was randomized blocks (RB), with four replications and the treatments were six levels of irrigation: L_0 = 0% (rainfed), L_1 = 40%, L_2 = 80%, L_3 = 120%, L_4 = 160% and L_5 = 200% of ET_C, in function of the crop evapotranspiration (ET_C), total of 24 experimental plots of 6.0 x 8.0 meters (48 m²). The irrigation levels above 100% of ET_C were used in order to obtain the potential productivity of cassava in response to irrigation and the ET_C was obtained by the Equation 1.

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

where, ET_0 is the reference evapotranspiration estimated by the Penman-Monteith-FAO (ALLEN et al., 1998) and K_C is the crop coefficient.

The irrigation was carried out from October 2019 to March 2020, dry season in the region. In the irrigation period, the K_C of the cassava adopted was 1.0 because the crop was in the intermediate stage of growth and development. In the initial and final phases of the crop cycle, the K_C of cassava is 0.35 and 0.45; respectively, according to ROYAL IRRIGATION DEPARTMENT – RID (2010).

The irrigation system used was micro sprinkler, with emitters spaced at 2.0 x 3.0 meters, average flow rate of 50 L h^{-1} and application intensity of 8.33 mm h^{-1}. The irrigation shift was 3 days and the rains that occurred during the irrigation period were deducted from the applied water. The water balance of the crop was carried out by the method of Thornthwaite and Mather, on a decendial scale, according to PEREIRA et al. (2002). The effective rain was obtained by subtracting the water excess, obtained by the water balance of the crop, from the total rain. The total irrigation depth was defined as water applied via irrigation plus effective rain. The meteorological data for the cultivation period were provided by the CECA/UFAL Irrigation and Agrometeorology Laboratory (LIA), which manages an automatic agrometeorological station (Micrologger – CR 1000, Campbell Scienntifc, Logan, Utah) located next to the experimental area.

The harvest was carried out in June 2020 (355 DAP) and in three plants of the useful area (10 m²) of each plot, the following variables were evaluated: leaf area index (LAI), length of commercial roots (LR, cm), commercial root productivities (PR, Mg ha^{-1}) and total wet biomass (Root, Stem and Leaf – RT, Mg ha^{-1}) , root dry matter productivity (RDMP, Mg ha^{-1}) and total dry matter (TDM, Mg ha^{-1}) and harvest index (HI) , the other variables, plant height (PH, cm), number of leaves (NL), stem length (SL, cm), stem diameter (SD, mm), root diameter (RD, mm), stem productivity (SP, Mg ha^{-1}), leaf productivity (LP, Mg ha^{-1}) , stem dry matter productivity (SDM, Mg ha^{-1}) and leaf dry matter productivity (LDMP, Mg ha^{-1}) were not significant at 5% probability; and therefore, were not discussed in the study.

The LAI was obtained at bimonthly intervals during the cultivation cycle, with the aid of the LAI 3100 device (Model Li-Cor, Lincoln, Nebraska, USA). For this, leaves were removed from a plant in the useful area, then submitted to the apparatus. The values of leaf area (LA cm²) obtained were used to estimate the ratio between soil area and vegetation cover (LAI).

Height, length and diameter was measured with the aid of a tape measure and a digital caliper. The height of plants was measured from the soil surface to the apex of the plant, while the length of the stem was measured from the ground level to the insertion of the last leaf. The stem diameter was measured 30 cm above the ground level and the root diameter was obtained in the central region of the roots. The root, stem and leaf weighing were carried out on a scale with an accuracy of 0.001g. The dry matter was obtained by drying samples in a forced air circulation oven, with a temperature of 65°C, for 72 hours, according to SAGRILO et al. (2008). The commercial root harvest index was obtained by dividing the root mass by the total plant mass. Commercial roots were considered those with a diameter greater than 2 cm and a length greater than 10 cm, according to TIRONI et al. (2015).

The collected data were submitted to analysis of variance and, when significant by the F test ($P<0.05$), they were submitted to regression analysis. The regression coefficients had their significance verified by the t test ($P<0.05$).

The function of producing responses from cassava to the total irrigation depths of the experiment was determined by second degree polynomial regression curves, similar to Equation 2.

$$Y = b_0 + b_1 x + b_2 x^2 \quad (2)$$

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

The estimate of the total irrigation depth that provides maximum physical productivity was made by equaling the first derivative of Equation 2 to zero, according to Equations 3, 4 and 5.

$$Y = b_1 - 2b_2 x \text{ (first derivative of equation 2)} \quad (3)$$

$$\text{equaling zero, if it has: } Y = b_1 - 2b_2 x - 2b_2 x = -b_1 \quad (4)$$

$$X_{MÁX} = b_1 / 2 b_2 \quad (5)$$

where, $X_{MÁX}$ is the amount of input (total irrigation depth) that provides maximum productivity (Mg ha^{-1}). The maximum productivity ($Y_{MÁX}$) was calculated by Equation 6.

$$Y_{MÁX}=b_0-(b_1^2/4b_2) \quad (6)$$

The economic analysis of cassava production was carried out according to the price of the input (millimeter of water) applied and the price of the product (ton of cassava roots). The irrigation depth of maximum economic efficiency was calculated by Equation 7.

$$W=(C_W-Pi\,bi)/(2\,Pi\,b_2) \quad (7)$$

where, W is the amount of input (total irrigation depth) that provides maximum economic efficiency productivity; C_W is the cost of the input; Pi is the price of the cassava root and b_1 and b_2 are the coefficients of the production equation.

The price of the millimeter of water applied (R$ mm^{-1}) was calculated based on the costs of implementing one hectare of conventional sprinkler irrigation and the energy consumed for the application of one cubic meter of water, which was later converted to mm per hectare. The prices of materials used for the irrigation system were obtained from companies that sell irrigation equipment in Arapiraca, Alagoas, Brazil, in December 2020 (Table 1).

The minimum, average and maximum prices (180, 290 and 400 reals) of the ton of cassava roots were obtained through a survey with producers and buyers in the main producing region of Alagoas, Brazil, which is composed of the municipalities of Arapiraca, Junqueiro, São Sebastião and Teotônio Vilela.

RESULTS AND DISCUSSION

The average maximum temperature (T_{MAX}) during the experimental period was 30.1 (± 2.1) °C, ranging from 35.7°C (24 November 2019) to 23.9°C (15 June 2020). The average minimum temperature (T_{MIN}) was 21.3 (± 1.6) °C, ranging from 17.5°C (28 August 2019) to 23.6°C (23 January 2020) and the mean temperature (T_X) ranged from 21.2°C (August 1, 2019) to 28.1°C (June 6, 2020), with an overall average of 25.1 (± 1.5) °C. ALVES (2002) states that mean temperatures between 25 and 29°C are ideal for the growth and development of cassava. So, based on this affirmation, the region of Rio Largo, AL, is suitable for the cultivation of cassava in terms of thermal demand. The mean relative air humidity (RAH) ranged from 57.8% (January 26, 2020) to 90.5% (June 27, 2019) and the overall average was 74.2% (Figure 1).

The rainfall accumulated during the experimental period, from June 2019 to June 2020, was 1,847 mm. April was the wettest month (364 mm) and November the least rainy (7.4 mm). Of

Table 1 - Values used to calculate the price of the water millimeter applied in the cassava crop by conventional sprinkling.

---Unit prices (R$/unid.)---			
Item	Description	Uni	R$/Uni
01	Electric power[1]	R$ kW^{-1} h^{-1}	0.47
02	Labor	R$ month^{-1}	1,700.00
03	Labor[2]	R$ ha^{-1} month^{-1}	56.67
04	Irrigation system	R$ ha^{-1}	11,42
05	Weighted amortization[3]	R$ ha^{-1} year^{-1}	878.00
06	Applied depth	mm day^{-1}	4.50
---Annual operating costs---			
07	Electricity	R$ ha^{-1} year^{-1}	1,052.00
08	Labor	R$ ha^{-1} year^{-1}	283.35
---Millimeter cost applied---			
09	Operational cost	R$ mm^{-1}	1.98
10	Fixed Cost of Millimeter Applied	R$ mm^{-1}	1.30
11	Total Cost of Millimeter Applied	R$ mm^{-1}	3.28

[1]Price of the conventional rural tariff charged in December 2020 in Alagoas by Equatorial, AL.
[2]For the composition of the price of labor per hectare, it was considered that a paid farm worker can manage an irrigated area of 30 ha monthly.
[3]In weighted amortization, the 20-year period was considered for 70% of irrigation equipment, plus electrical installation and construction of a small pump house, with 30% of the amount added for maintenance and 20% for labor. The other 30% of the irrigation equipment was amortized over 10 years.

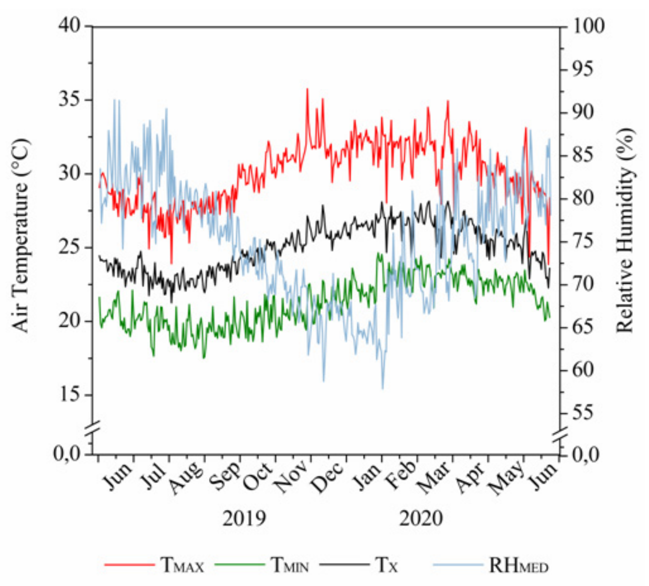

Figure 1 - Temperatures: daily minimum (T_{MIN}), mean (T_X) and maximum (T_{MAX}) and mean daily relative humidity air (RH_{MED}), in Rio Largo, AL, from June 2019 to June 2020.

the total rain, 1,744 mm (94.4%) was concentrated in two periods: between June 27 and September 17, 2019 and from February 4 to June 15, 2020. While from September 18, 2019, to February 3 of 2020, the accumulated rain was 103 mm (5.6%); therefore, there was a need for irrigation in this period, dry season in the region which runs from September to March. In the main cassava producing regions in the world, the accumulated annual rainfall is 800 mm, and this value is considered satisfactory for good cassava productivity (ALVES, 2002). Given the above, it is observed that the Rio Largo region has enough annual rainfall to meet the water demand of the cassava crop; however, due to the seasonality of the rains, it is necessary to adopt irrigation in crops. The ET_0 accumulated during cultivation (from June of 2019 to June of 2020) was 1,454 mm, with an average of 4.1 (± 1.1) mm.d^{-1} and the evapotranspiration of the crop (ET_C) accumulated during the cultivation period was 1,030 mm, with a daily average of 3.0 (± 1.8) mm.d^{-1}. And during the irrigation period (October of 2019 to March of 2020), the ET_C added 462 mm (Figure 2) and it rained only 212 mm.

Of the total of 1,847 mm that rained, 1,323 mm was lost as excess water (runoff or percolation in the soil). Standing out as effective rainfall (rain), only 522 mm and this is the amount of water that was available to the plants. In this perspective, there was a water deficit of 508 mm because the ET_C total was 1.030 mm. This water deficiency was concentrated between the last ten days of September 2019 and the first ten days of February 2020 (Figure 3). From the above, it is confirmed that the real evapotranspiration (ETr) of the cassava accumulated during the cultivation cycle, without irrigation (L_0), was 522 mm, correspondent to the effective rain.

In table 2 shows the total irrigation depths applied (total irrigation), which varied from 134 to 906 mm of the L_1 (40% of ET_C) and L_5 (200% of ET_C); respectively, the effective rainfall (effective rain), sum of the effective rainfall plus irrigation (total depth), water deficit and excess (mm) from the water balance of the crop under irrigation levels.

Irrigation levels caused significant difference at 5% probability level for the variables: length of commercial roots, yields of commercial roots and total biomass, yields of dry matter of root, total dry matter, harvest index and leaf area index (Table 3).

The highest estimated maximum LAI value, among the irrigation levels, was 7.6, observed with the total depth (effective rain plus irrigation) of 817 mm. Under the largest total depth (1,023 mm), the lowest estimated maximum LAI was identified, which was 4.4 (Figure 4). As for rainfed treatment

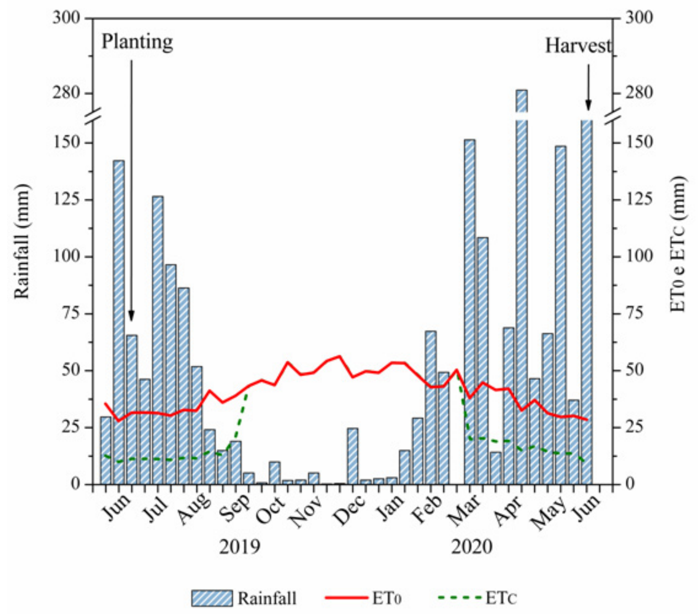

Figure 2 - Rainfall, reference evapotranspiration (ET_0) and crop evapotranspiration (ET_C), in Rio Largo, AL, from June 2019 to June 2020.

(L_0), there was a water deficit of 508 mm during the crop cycle, between the last ten days of September 2019 and the first of February 2020, which stopped the foliar growth of cassava and caused leaf fall. In these areas the resumption of leaf growth occurred only after the tenth day of February 2020, with the resumption of rain, when it rained 67 mm. In this scenario, the maximum estimated LAI of cassava cultivated

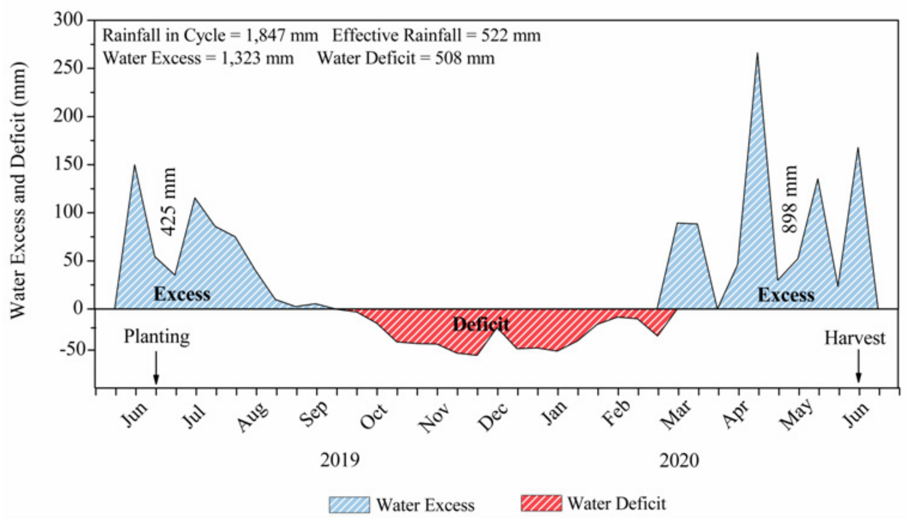

Figure 3 - Ten-day water balance of the cassava crop without irrigation (L_0), with emphasis on excess (water excess) and water deficit in the region of Rio Largo, AL, from June 2019 to June 2020.

Table 2 - Total (R_{TOTAL}) and effective rainfall (R_{EFFECT}), total gross applied irrigation depths (irrigation), the sum of R_{EFFECT} and Irrigation (Total Depth), deficit and excess water during the growth cycle of the cassava, in Rio Largo, AL, from June 2019 to June 2020.

Levels	R_{EFFECT}	Irrigation	Total Depth	Deficit	Excess
	---------- mm ----------				
Rainfed	522	0	522	508.0	1,323
L_1 – 40%	522	134	656	372.0	1,323
L_2 – 80%	510	307	817	211.0	1,335
L_3 – 120%	456	507	963	65.0	1,389
L_4 – 160%	317	701	1,018	5.0	1,528
L_5 – 200%	117	906	1,023	5.0	1,728
-------------------R_{TOTAL} = 1.847 mm-----------------		-	-	-	-

without irrigation was 8.4, at 700 DAP (Figure 4A). This period of 700 days of cultivation cycle is relatively long for the cassava to reach the maximum accumulation of leaf mass. It's a indicative that the cultivation under rainfed, possibly, did not complete its phenological cycle in the period of 1 year (time that the research lasted). This is a of the one reasons why in semi-arid regions, such as the Brazilian Northeast, normally, cassava cultivation cycles last around two years for its cycle to be completed and to reach economically sustainable yields. ALVES (2002) stated that there is a positive correlation between the LAI and root productivity, because the plant's leaf mass is responsible for the production of photoassimilates that are accumulated in the root system. In general, it was observed in this research, the LAI of cassava is reduced by water stress due to lack of water in cultivated areas under rainfed conditions (L_0).

The maximum length of roots was 49 cm, observed in the irrigated areas with the total depth (rain plus irrigation) of 926 mm and the smallest LR was reported under rainfed (28 cm), a 43% reduction, in relation to the maximum LR obtained. When the soil was saturated with a total depth of 1,023 mm in the cassava cultivation cycle, there was a reduction in the LR to 48 cm (Figure 5). ALVES (2002) stated that the length of cassava commercial roots varies from 15 to 100 cm, which corroborated with the results

Table 3 - Analysis of variance of the variables: leaf area index (LAI), length of commercial roots (LR), productivity of commercial roots (PR) and total biomass (RT), productivity of dry root matter (RDMP) and total dry matter (TDM) and harvest index (HI) of cassava under irrigation levels in the Rio Largo, AL region, cultivated from June 2019 to June 2020.

		---------------Square Root---------------				
		LR	RT	PR	TDM	RDMP
Irrigation Levels	5	251.775*	3674.575*	2481.877*	852.045*	498.212*
Block	3	91.597 ns	350.899 ns	439.664 ns	44.800 ns	66.381ns
Linear	1	274.032 ns	10245.917*	6078.690*	2281.030*	1201.387*
Quadratic	1	810.694*	7682.608*	6132.062*	1898.528*	1269.229*
Resídual	15	77.197	1218.286	693.529	283.533	168.931
C.V. (%)		22.75	27.37	34.80	32.40	39.97
		HI	LAI			
Irrigation Levels	5	0.026*	2.923*			
Block	3	0.006 ns	0.909 ns			
Linear	1	0.050*	0.964 ns			
Quadratic	1	0.073*	9.052*			
Resídual	15	0.003	0.702			
CV (%)		9.60	15.94			

* - Significant at 5%; ns - Not significant by the teste F (P < 0,05).

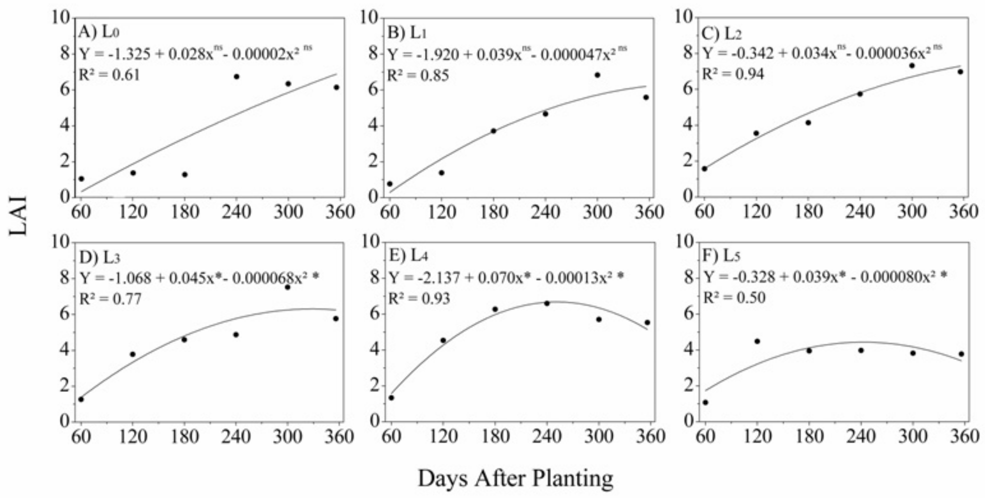

Figure 4 - Leaf area index (LAI) of the cassava cultivated with different irrigation levels L_0 (A), L_1 (B), L_2 (C), L_3 (D), L_4 (E) and L_5 (F), in Rio Largo, AL, from June 2019 to June 2020.
[*] Significant at 5% probability by "t" test.

obtained in this research. The results also indicate that cassava under water deficit suffers a reduction in root length. The lowest LAI values obtained under rainfed ness, may have favored the lowest LR under this treatment, since the plant's source-drain relationship has been compromised.

The maximum physical productivity of commercial roots (PR – 94 Mg ha $^{-1}$) and total wet

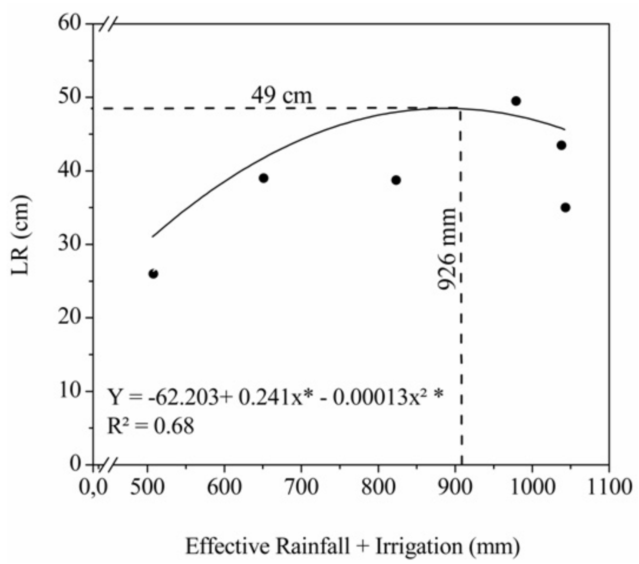

Figure 5 - Root length (LR) of cassava cultivated with different irrigation levels, in the region of Rio Largo, AL, in the period from June 2019 to June 2020.
[*] Significant at 5% probability by "t" test.

biomass (RT – 149 Mg ha^{-1}), were obtained in the irrigated plots with the estimated total depths of 926 mm and 963 mm, respectively, increment of 194 and 99% in relation to the lowest PR (32 Mg ha^{-1}) and RT (75 Mg ha^{-1}), observed in rainfed areas. The depth that provided the PR and maximum RT were close to the total gross depth applied in the areas irrigated with the L_3 (120% of ET_C), which was 963 mm, and this indicated that this level of irrigation, among those studied, is what provides greater crop productivity. When the plants were irrigated with a total depth of 1,023 mm (equivalent at 200% of ET_C), the estimated PR and RT were 91 and 148 Mg ha^{-1}, a reduction of 3 and 1% in relation to the maximum values obtained, this indicated that from that level of irrigation, the agricultural productivity begins to decline and becomes technically unfeasible (Figure 6A).

DANQUAH et al. (2016) in a study with and without irrigation in cassava, in the North of Ghana region obtained a 63% increase in root productivity under irrigation compared to rainfed cultivation. MORAIS et al. (2017) evaluated cassava genotypes in Alagoas under rainfed conditions and obtained root yields of 27.50 Mg ha^{-1}, 16 months after planting, with the Caravela variety. ANDE et al. (2008) reported that cassava under ideal management conditions, reaches root productivity of 80.0 Mg ha^{-1}. These results corroborate with the data of this research and confirmed that the productivity of roots and total biomass of cassava is higher when irrigated. And, under water stress due to lack of water, there is a reduction in growth and agricultural yield.

The maximum productivity of root dry matter (RDMP) was 47 Mg ha^{-1}, obtained in irrigated areas with an estimated total depth of 955 mm in the cassava growth cycle. The lowest estimated RDMP was 15 Mg ha^{-1}, produced in rainfed areas, 68% less than the maximum RDMP. As for the total dry matter productivity (TDM), the maximum TDM (69 Mg ha^{-1}) was obtained with the estimated total depth of 986 mm. Under rainfed conditions, the lowest estimated TDM was 29 Mg ha^{-1}, a reduction of 58% in the total dry matter accumulation in the plant in relation to the maximum value obtained (Figure 6B). ODUBANJO et al. (2011) studied different water regimes depending on the availability of soil water and obtained an average total dry matter productivity of 43 Mg ha^{-1} in the areas where they were maintained with 100% of the AFD, while plants without irrigation produced 6.5 Mg ha^{-1}, corroborating the values obtained in this research, which indicated that different levels of irrigation, in general, interfere in cassava productivity.

The productivity of roots of maximum economic efficiency (PMEE), with the average price of the root ton of R$ 290.00 reals and the applied millimeter of R$ 3.28 reals, was 94.27 Mg ha^{-1},

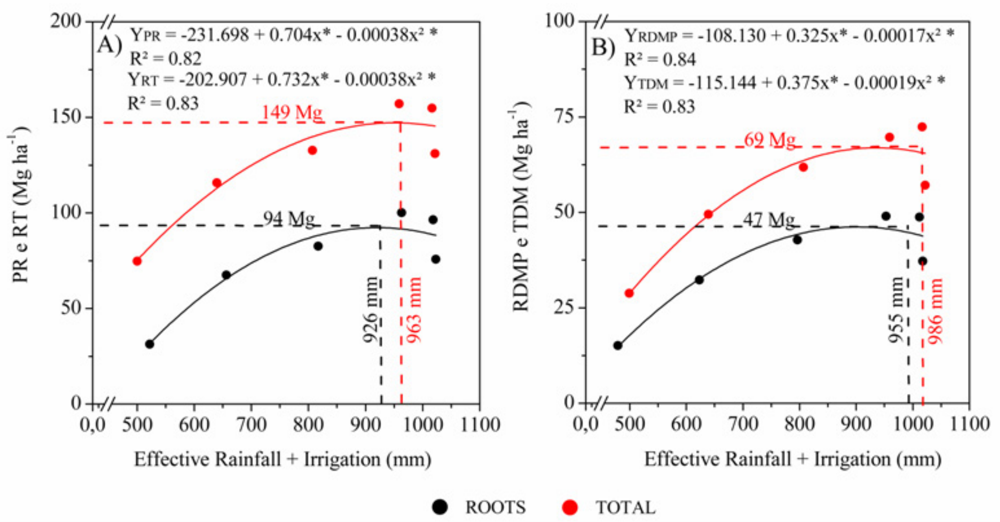

Figure 6 - A Productivity of commercial roots – PR and total – RT, and B – dry matter of roots – RDMP and total – TMD of cassava cultivated with different irrigation levels, in the region of Rio Largo, AL, in the period from June 2019 to June 2020.

* Significant at 5% probability by "t" test.

obtained with 911 mm of total depth of irrigation in a cultivation cassava cycle of 12 months. For the values of R$ 180.00 and R$ 400.00 reals, the minimum and maximum prices of the root ton, the PMEE were 94.14 and 94.31; respectively, obtained with total depth 902 and 915 mm. Therefore, the price variation implied a difference of 13 mm, only 1.43 % of total applied water, and the maximum yields, both physical and economic, were practically the same, which indicated that irrigation in cassava has a good financial return. And so, the use of this technology in the region of the tableland of Alagoas is economically viable. In the Figure 7A it is noted that the irrigation total depth of maximum economic efficiency showed values close to the irrigation total depth of maximum physical productivity (926 mm).

The maximum harvest index (HI) was 0.66, observed in irrigated areas with 833 mm, an increase of 37% compared to the lowest value, 0.48, verified in rainfed areas (Figure 7B). SOUZA et al. (2010) studied combinations of irrigation management and harvest times of cassava, in the region Northeast of Brazil, and found HI from 0.37 to 0.43 in rainfed crops and full irrigation system, respectively. Whereas, ALVES (2002) stated that, in general, the HI of cassava under normal cultivation conditions varies from 0.49 to 0.77, after 12 months of planting. The author also stated that prolonged water deficits, edaphic conditions and the cultivar used, can affect the source-drain relationship of the plant, which affects the HI. Thus, several factors can affect the HI of cassava; however, under the conditions of Coastal Plateaus in Alagoas, the irrigation total depth of 833 mm in the cassava cultivar Caravela, is significantly capable of increasing the HI. In addition, the water stress in upland areas, reduces the HI cassava due to stress caused by lack of soil water.

CONCLUSION

The adequate irrigation in the cassava crop significantly increases the leaf area index and the length of the commercial roots, which results in a significant increase in the crop agricultural productivity. For, for an annual evapotranspiration of the cassava culture, in the Coastal Plateaus of Alagoas, of 1,030 mm, in the rainfed areas, the effective rainfall is only 522 mm and the average water deficit is 508 mm. And in that region, the main variables of growth and production of cassava irrigated are: leaf area index = 7.6, commercial root length = 49 cm, productivity (physical and economic) maximum commercial roots = 94 Mg ha^{-1} and total biomass = 149 Mg ha^{-1} and the harvest index = 0.66, all obtained with total irrigation depths (effective rain plus irrigation) between 817 and 963 mm. Therefore, it is possible to confirm that understand the growth, agricultural yield and viable economically productivity of the irrigated cassava, is

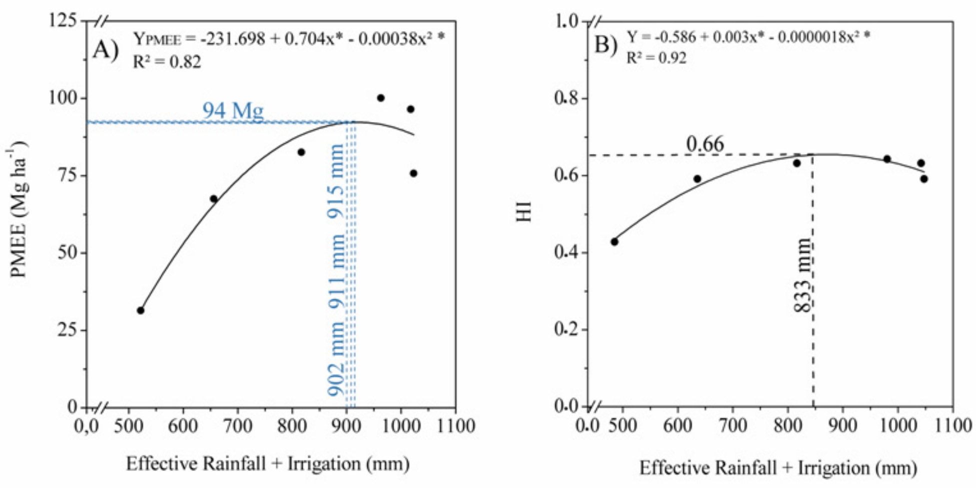

Figure 7 - A Maximum economic efficiency productivity – PMEE and B – harvest index – HI of cassava cultivated with different irrigation levels, in the region of Rio Largo, AL, in the period from June 2019 to June 2020.
* Significant at 5% probability by “t” test.

an essential factor to make a good crop management and to obtain highs yields, especially in regions with irregular rainfall as the Brazilian Northeast.

DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare.

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AUTHORS' CONTRIBUTIONS

The authors also contributed to the manuscript.

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