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PHYSIOLOGICAL AND PRODUCTIVE RESPONSES OF MAIZE SUBMITTED TO IRRIGATION DEPTHS AT DIFFERENT SEASONS OF CULTIVATION

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ABSTRACT

The use of agricultural techniques such as irrigation promotes physiological responses capable of significantly altering the growth, development and yield of maize, but water should be used in the appropriate amount for cultivation. Thus, the objective of this work was to evaluate physiological and productive responses of maize submitted to water levels. The experiment was conducted in two seasons (rainy and dry season) in Rio Largo, Alagoas, Brazil, with five treatments corresponding to five irrigation levels (40, 80, 120, 160 and 200% of crop evapotranspiration - ET_c) and four replications. The physiological rates, chlorophyll and dry matter, as well as grain yield, were evaluated. As a result, it was observed in the rainy season the maize has lower water requirement and lower grain yield than in the dry season. In the latter period there is greater significance in the physiological responses of the plant to treatments such as greater stomatal condutance and greater transpiration, allied to higher photosynthetic rates. Maize grain yield is only guaranteed by rainfall in the rainy season. In the dry season, the maximum yield can be obtained with irrigation level equivalent to 147% of ET_c.

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INTRODUCTION

Corn (*Zea mays* L.) is one of the most important grains in the world, as it is used in animal feed industries and to a lesser extent for human consumption, being transformed into oil, flour, starch, margarine, glucose syrup and flakes for breakfast cereals.Corn is also considered a crop with high water demand and also one of the most efficient in water use, ie it has a high ratio of dry matter production per unit of water absorbed. (Silva *et al*., 2012a). However, although Brazil is the world's third largest maize producer (Fiesp, 2018), Corn agricultural productivity in some Northeastern Brazilian states is very low compared to the potential of cultivars currently used in commercial crops.

The main reasons for this low agricultural productivity is the technological level used by farmers, without fertilization, control of inadequate native plants and the irregular distribution of rainfall in the region, which even during the rainy season, small summers that cause water deficiency in the soil (CARVALHO *et al*., 2013). Low technological and summer levels, as well as environmental factors such as light, temperature, CO_2 concentration and nutrient availability interfere with physiological indices such as CO_2 assimilation rate (A), perspiration (E), stomatal conductance (gs) and concentration. internal $CO_2(C_i)$ (SHIMAZAKI *et al*., 2007; TAIZ e ZEIGER, 2013; MELO *et al*., 2010). Thus, mesophilic and biochemical limitations may cause a decrease in the photosynthetic rate of plants (Grassiand Magnani, 2005), in which water deficit is one of the most limiting factors, especially when it occurs during corn flowering.

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In well-hydrated leaves, the [CO2]/[O2] ratio in vascular bundle sheath cells is higher than in mesophyll cells, which reduces RUBISCO's oxygenase activity, and consequently, photorespiration (RF), which does not contribute to the accumulation of dry matter in the plant. Thus, an occurrence of water deficit in maize crop with the inevitable decrease in gs causes a reduction in Ci and an imbalance in the [CO2] / [O2] ratio, which should reflect a decrease in A and an increase in RF (MAROCO *et al.* 1997; MASSAD *et al*., 2007). Brito *et al.* (2013) observed during the flowering phase that the physiological variable of maize most sensitive to water deficit was gs, where the plant under stress tended to close the stomata in order to minimize water loss and maintain turgidity, reflecting on carbohydrate formation by photosynthesis and phytomass accumulation in the plant, mainly of the stem.

Another important factor for photosynthesis and biomass production is the chlorophyll content of the leaves and since corn is a tropical grass (C4), which has high photosynthetic efficiency and high productivity when subjected to favorable environment (Bernardes, 1987), if water stress occurs, chlorophyll will be lost and the consequent progressive reduction of the photosynthetic capacity of the plants. The agronomic technique to mitigate the effects of lack of water on the soil is irrigation, where, when the appropriate amount of water is defined, it is possible to considerably increase the agricultural productivity of agricultural enterprises. The choice of the planting season is also fundamental to have better weather conditions and sufficient rainfall to meet the water demands of the crops. For this, it is necessary to know the behavior and the response of the plant facing different water availability. Given the above, this study aimed to evaluate the physiological and productive responses of corn under water levels in two growing seasons.

MATERIALS AND METHODS

The experiment was carried out at the Center for Agricultural Sciences of the Federal University of Alagoas, Rio Largo, Brazil (09 ° 28'02"S and 35 ° 49'43" W, 127 m altitude), in an argisolic cohesive Yellow Latosol of medium/clay texture in two seasons, the first being a rainy season cultivation carried out from February 29 to June 20, 2016, and the second a dry season cultivation from November 19, 2017 to March 19, 2018. The climate is, by the Thornthwaite and Mather classification, hot and humid (B_1), megothermal (A '), moderate water deficiency in summer (s), large excess water in winter (w_2), and rainfall the annual average of the region is 1,800 mm. The statistical design used was randomized blocks with four replications. The treatments were five irrigation levels (L1-40, L2-80, L3-120, L4-160 and L5-200% of ET_c). The soil preparation was performed with two plowing and grading harrows. Grooving was performed manually with 8.0 m long grooves spaced 0.8 m apart, resulting in 20 rows per plot (128 m^2). Liming was performed according to soil analysis to raise base saturation to 60%. Foundation fertilization was based on the expected yield of 10 t ha^{-1}, according to Coelho, (2007). For this, the source of phosphorus plus half of the potassium was applied. The second half of potassium plus nitrogen were applied as cover at 15 days after planting (DAP). Before planting the irrigation system was assembled and tested to ensure uniformity of germination and emergence. The AG7088 corn hybrid was sown by placing two seeds every 0.25 m, and when the plants reached 4 fully expanded leaves, thinning was done to remove one plant, leaving 50,000 plants per hectare. Native plants were controlled by hand weeding and herbicides, with atrazine at 2.6 L ha^{-1} and glyphosate at 6.5 L ha^{-1}. Insecticide was also applied due to the attack of the 0.6 c ha^{-1}metomil caterpillar. The irrigation system used was surface drip with 16 mm diameter drip tapes, drippers every 0.2 m and 0.8 m between rows, being one irrigation line per row of plants, measured service pressure of 5 mca and flow rate. 1.1 L h^{-1}. The water used for irrigation was collected in a dam and stored in two 10 m^3 boxes, from which it was pumped to the cultivation area through an automation system to control the application of irrigation levels. Agrometeorological data were obtained from an automatic data acquisition station (Model Micrologger CR10X, Campbell Scientific), installed next to the experiment. The actual crop evapotranspiration (ET_r) and soil water balance calculation procedures were based on the methodology described and adapted for dripping by Allen *et al.* (1998), Allen *et al.* (2005) and Silva *et al.* (2012b). The ET_0 was calculated by the Penman-Monteith method:

$$ETo=\frac{0{,}408\,\Delta(R_n-G)+\left(\gamma\frac{900}{T+273}\right)u_2(e_s-e)}{\Delta+\left[\gamma(1+0{,}34\,u_2)\right]}$$

(1)

Where: Δ is the slope of the saturated water vapor pressure versus air temperature curve (kPa ºC^{-1}); Rn is the measured radiation balance (MJ m^{-2} dia^{-1}); G is the heat flux in the soil (MJ m^{-2} dia^{-1}); γ is the psychometric coefficient; T is the average air temperature; u_2 is the average wind speed at 2 m height (m s^{-1}); e_s is the saturation pressure of water vapor from the air (kPa) and e is the vapor pressure of air water (kPa). Crop evapotranspiration (ET_c) was calculated by the "single" K_c method using the K_c values recommended by Food Agriculture Organization-FAO Bulletin 56 (Allen *et al*., 1998) and adjusted as recommended by the Bulletin itself. The initial K_c adjusted for dripping was 0.43 and 0.38 in seasons 1 and 2, respectively. The adjusted intermediate K_c was 1.13 and 1.15 at times 1 and 2, respectively. The adjusted final K_c was 0.54 and 0.56 in seasons 1 and 2, respectively. The actual crop evapotranspiration (ET_r) as presented in Equation 2. The K_s coefficient represents the effects of soil water deficit in the root zone on the ET_r.

$$ET_r = K_s \times ET_c = K_s \times K_c \times ET_0 \qquad (2)$$

Physiological indices were measured using an LCpro+® gas exchange analyzer containing an IRGA-Infra Red Gas Analyzer. The evaluations were carried out on the plants between 8 and 10 am in the flowering phase, at approximately 60 DAP. Measurements were made on the +3 leaf of 32 plants per plot, totaling 32 measurements per treatment to obtain the means of the variables: stomatal conductance -gs (mol m^{-2}s^{-1}), liquid photosynthesis -A (µmol m^{-2}s^{-1}), perspiration -E (mmol m^{-2}s^{-1}) e internal concentration of CO_2-Ci (µmol mol^{-1}). The instant efficiency of carboxylation –EiCwas obtained by the relation A/Ci. In these same plants, the chlorophyll content readings were also taken through the chlorophyll meter ChlorofiLOG model CFL 1030 (Falker Automação Agrícola, Brazil), which gives values called Falker Chlorophyll Index (ICF) proportional to chlorophyll absorbance (FALKER, 2018). Measurements took place between 10:00 am and 2:00 pm to avoid the least possible effect of irradiance variation on chlorophyll meter readings during the daytime. Dry matter analysis was performed in the physiological maturation phase, through the plant parts, using 4 plants per plot. These variables were submitted to the F test and regression analysis. Grain harvesting was performed at the physiological maturation phase, in which the grain yield (Mg ha^{-1}) was estimated by weighing the grains of the plants located in 3 m linear 12 rows of the plot, using a digital scale capable of weighing up to 30 kg. Water use efficiency (EUA) was calculated according to Equation 3, dividing grain yield by total water used (irrigation + effective rainfall). Thus, the EUA results were presented in kilograms of grains produced in one hectare per millimeter of water used (kg mm^{-1}):

$$EUA = \frac{Pt}{W} \tag{3}$$

Where: Pt is agricultural productivity (kg ha^{-1}) e W is the total irrigation water used (mm). It was observed the duration in days of each phase and also the total duration of the cycle that had very great uniformity promoted by the seed genetic pattern (Table 1).

RESULTS AND DISCUSSION

The atmospheric water demand, represented by ET_o, ranged from 1.3 to 5.8 mm day^{-1}, with an average of 3.9 mm day^{-1} at season 1 and 0.8 to 6.3 mm day^{-1}, with an average of 4.8 mm day^{-1} at season 2 (Figure 1A and B). Rainfall totaled 599 and 369 mm in seasons 1 and 2, respectively. However, the distribution of rainfall was irregular, evidencing the need for irrigation, which was done with the quantities defined by the treatments. Irrigation during the initial phase, carried out so as not to cause water deficit to the plants, ranged from 3 to 6 mm in season 1 and from 4 to 14 mm in season 2. From the beginning of the growth phase, when the levels were differentiated according to the treatments, in season 1 the occurrence of intense rainfall made it difficult to apply and control the irrigation, in which the treatments L1, L2, L3, L4 and L5 were irrigated with totals of 4, 43, 57, 123 and 160 mm, respectively. At season 2 it was possible to have control of the treatments and the levels of irrigation events were on average 3, 7, 11, 16 and 20 mm day^{-1} for L1, L2, L3, L4 and L5, respectively. The estimated soil moisture as a function of water inlets and outlets - soil water balance - presented in Figure 2A and B shows that at the beginning of the cultivation cycle all treatments remained with soil water storage (ARM) near field capacity (maximum limit equal to CAD). However, from the growth phase (21 DAP) there is a reduction in ARM 1 and 2, where some rains eventually increased the ARM of these treatments, raising them to the easily available water zone (AFD), which is the critical humidity (UC) line, especially at time 1. At the end of the cycle, all treatments had a reduction in storage due to the suspension of irrigation, since it was already in stage R4 (farinaceous grain) and from that moment the productivity is no longer influenced by water deficit. The physiological evaluation performed on flowering of the plants showed no significant differences for the analyzed variables as a function of irrigation levels, however, it is possible to observe differences in the magnitude of the variables between the growing seasons (Figure 3). Due to the amount of water applied via irrigation, the internal CO_2 concentration levels averaged 180 μmol μmol m^{-2} s^{-1} at season 1, while at season 2 it was 111 μmol m^{-2} s^{-1}. The transpiration averages, stomatal conductance, photosynthesis and instantaneous carboxylation efficiency of season 1 were 3,65 mmol m^{-2} s^{-1}, 0,18 mol de H_2O m^{-2} s^{-1}, 11,7 μmol m^{-2} s^{-1} e 0,09, respectively. In season 2 this same sequence of variables had values of 7,91 mmol m^{-2} s^{-1}, 0,47 mol de H_2O m^{-2} s^{-1}, 30,6 μmol m^{-2} s^{-1} e 0,30, respectively. These differences in magnitude may have occurred due to temperature variation between seasons, because when all factors are constant, the temperature increase up to 25-30°C favors stomatal opening (warms the leaf and causes greater pressure difference vapor - air pain molecule expands as it heats up and travels, maintaining the potential difference). However, above this temperature, there is increased respiration (higher concentration of internal CO_2) and the plant tends to close the stomata (TAIZ and ZEIGER, 2013). Moreover, due to higher Ci in the leaf mesophyll there is a brief increase in the photosynthesis rate with consequent decrease of the same, which will only increase when the gs normalizes. This can happen in the hottest hours of the day, because it is during these times with the highest incidence of light that the plant can do the most photosynthesis, thus there is a mismatch between water loss and CO_2 uptake.

Corn, being a C_4 plant, can reduce the opening of its stomata, aiming to balance the loss of water by perspiration, since in this metabolism system, it can store CO2 at night and in the milder hours of the day, to use it during the day and in the hours of greatest light incidence, keeping their stomata closed.Higher water availability may favor greater stomatal conductance and lead to greater leaf cooling (canopy) by perspiration. According to TATAGIBA *et al.* (2015), the main factor reducing photosynthetic performance would be stomatal conductance, since the larger the stomatal opening, the greater the diffusion of CO_2 into the substomatic chamber.This process causes reductions in photosynthesis and promotes the decrease of biomass accumulation by the plant. The Falker Chlorophyll Index (ICF) averaged 55.1 at season 1 and showed a significant quadratic adjustment at season 2 as a function of irrigation levels applied with R^2 of 95%, ranging from 48.4 (L1) to 56.4 (L4) and evidencing the deleterious effect of the lower water supply on the chlorophyll of the plant. Nascimento *et al.* (2015) also found variation in the chlorophyll index (ICF) of maize from 42 to 65 in irrigated treatments with 25 and 125% of ET_o, respectively. The dry matter content evaluated during the physiological maturation period showed no significant difference between the irrigation levels (Figure 4). In addition, it was also observed that there were different accumulations of dry matter between seasons, since the average values observed in season 1 for ear, stem, leaf and tassel dry matter were 155, 70, 52 and 7 g per plant, respectively, totaling 285 g $plant^{-1}$.While in season 2, these same variables had values equal to 327, 135, 51 and 3 g $plant^{-1}$, respectively, with a total of 516 g $plant^{-1}$.These spike, stem, leaf and tassel partitioned values are 54, 25, 18 and 7% of the total accumulated shoot in season 1, respectively, and in season 2, 63, 26, 10 and 0.5% of the total, respectively. It was observed that in the second growing season all variables presented higher dry matter accumulation, except for the tassel, which was smaller.According to Paterniani (1981), apical structures usually have priority in the use of available resources for plant growth, especially water, nutrients and photo assimilates. For this reason, the tassel, which has an apical position, tends to control the development of other organs of the corn plant. In relation to the dry mass of the stalk, the corn stalk functions as a carbohydrate reserve tank, which accumulates in the growing season and is then transported to the reproductive organs when necessary.

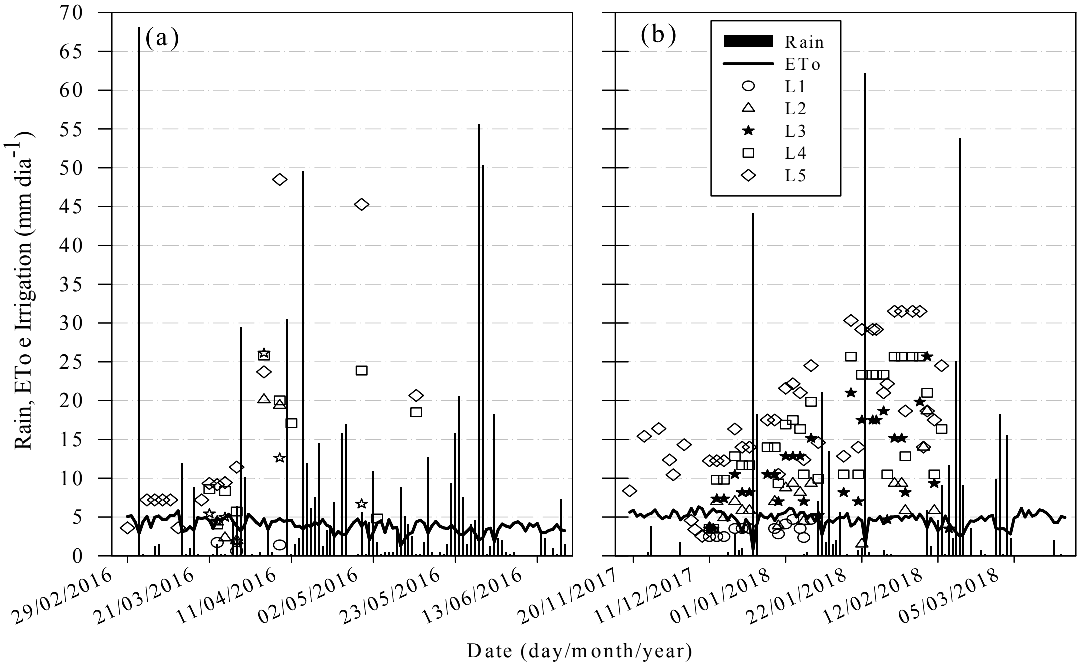

Figure 1. Daily values of rainfall, reference evapotranspiration (ET_0) and irrigation levels applied (L1, L2, L3, L4 and L5) during corn cultivation from February to June 2016 (A) and from November 2017 to March 2018 (B), in the Rio Largo region, Brazil

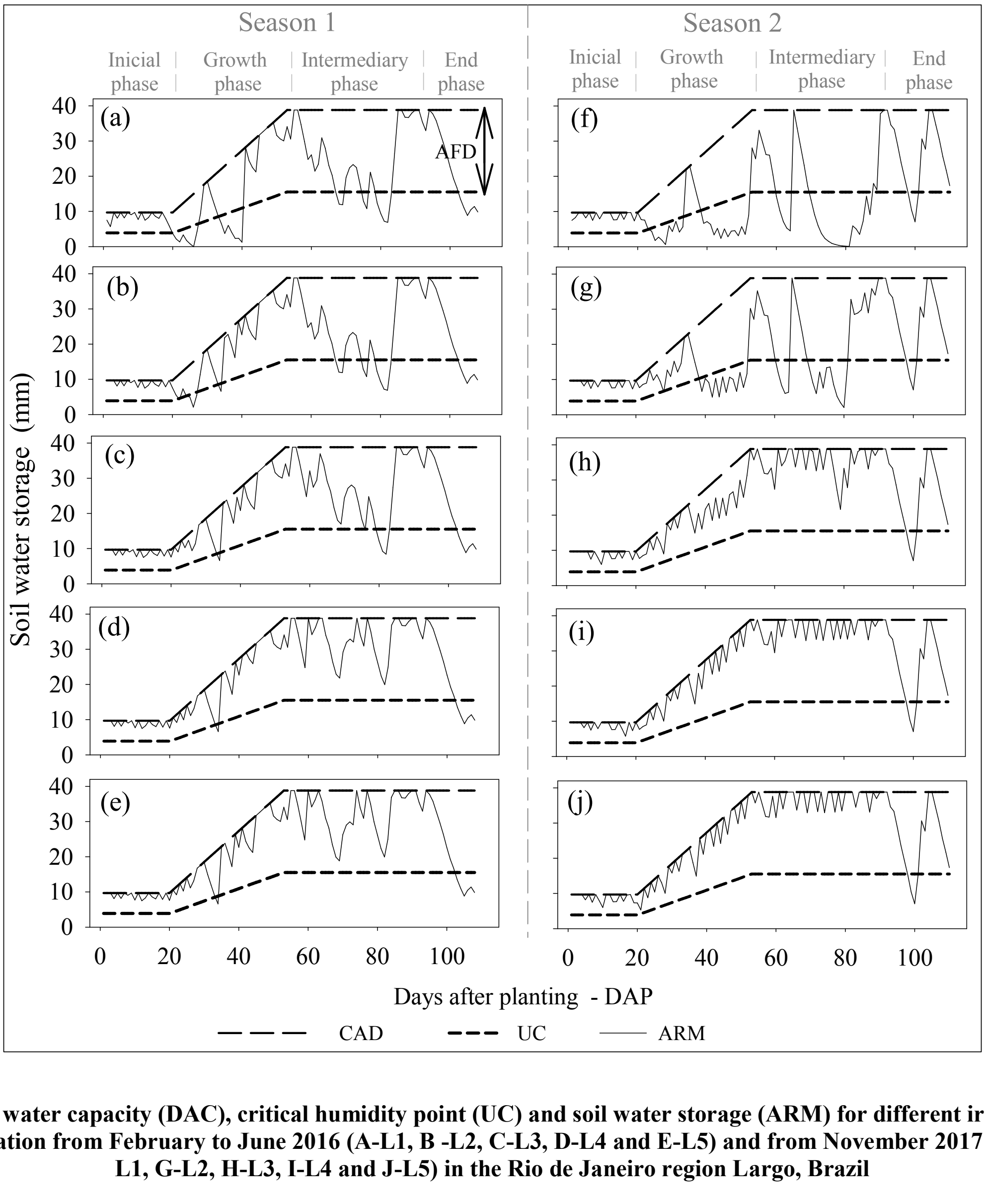

Figure 2. Available water capacity (DAC), critical humidity point (UC) and soil water storage (ARM) for different irrigation treatments during corn cultivation from February to June 2016 (A-L1, B -L2, C-L3, D-L4 and E-L5) and from November 2017 to March 2018 (F-L1, G-L2, H-L3, I-L4 and J-L5) in the Rio de Janeiro region Largo, Brazil

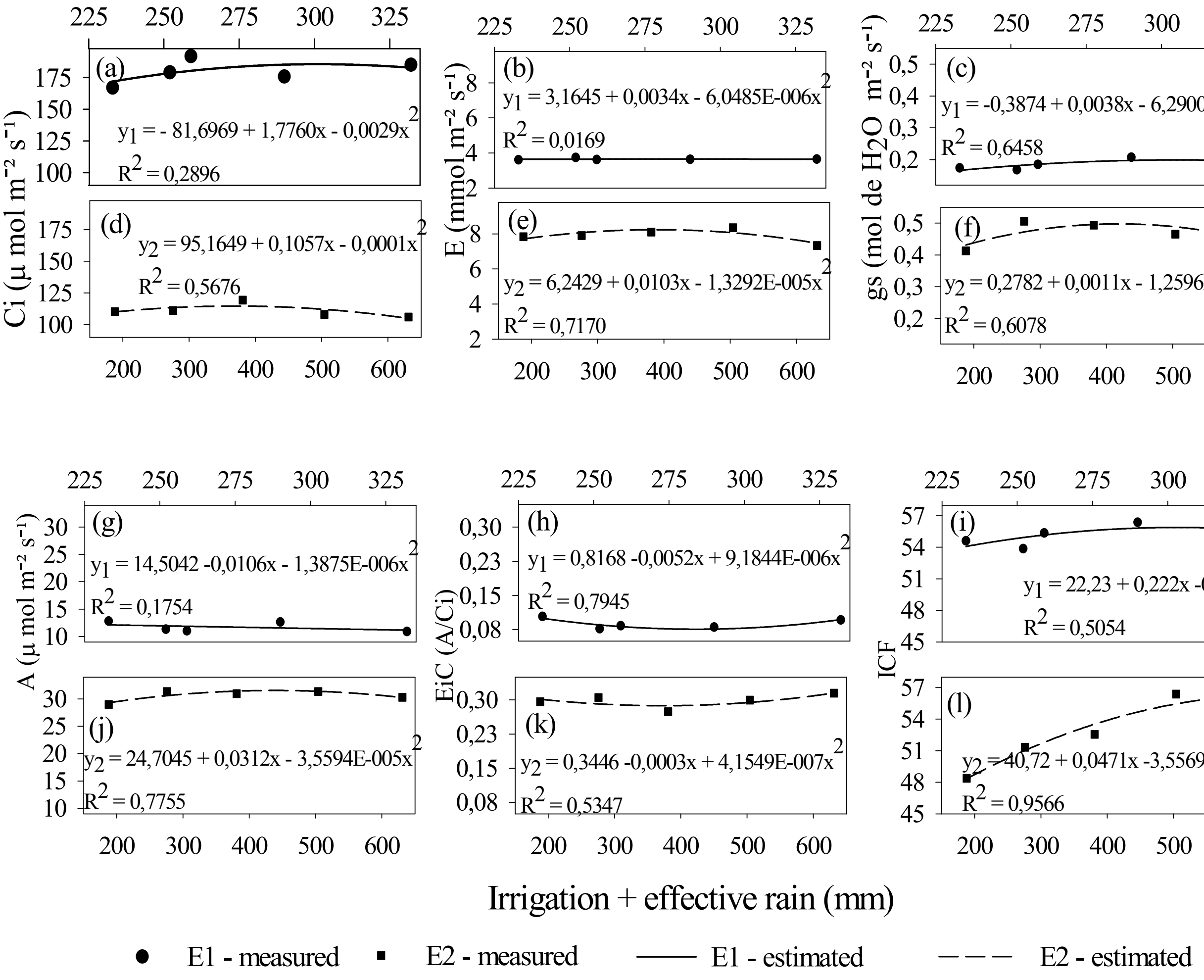

Figure 3. Ci - internal concentration of CO_2, E - perspiration, gs - stomatal conductance, A - liquid photosynthesis, EiC- instantaneous carboxylation efficiency e ICF- Chlorophyll Falker Index as a function of irrigation levels applied in a maize hybrid grown from February to June 2016 (A1, B1, C1, D1, E1 and F1) and from November 2017 to March 2018 (A2, B2, C2, D2, E2 and F2), in the Rio Largo region, Brazil

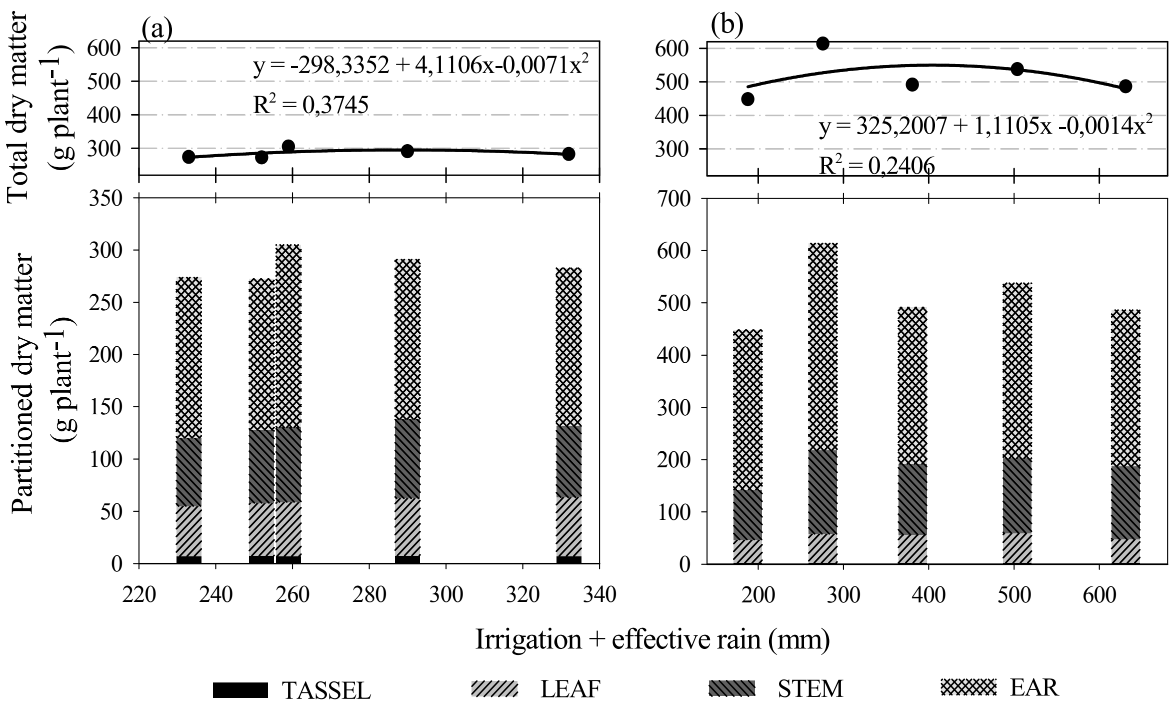

Figure 4. Dry matter content of ear, stem, leaf, tassel and total (g plant-1) at stage R5 of maize under different treatments with irrigation levels (A and B) during cultivation from February to June 2016 (A and B) and from November 2017 to March 2018 (C and D), in the Rio Largo region, Brazil

Table 1. Duration (days) between the stages of AG7088 hybrid corn during cultivation from February to June 2016 (E1) and from November 2017 to March 2018 (E2), in Rio Largo region, Brazil

Phenologicalphase	Duration (days)	
	Cultivationseason	
	E1	E2
Planting - Emergency	8	6
Emergency - Pendoamento	47	49
Piercing - R4	31	33
R4 –Physiologicalmaturation	22	22
Planting –Physiological maturation	108	110

Table 2. Total values of crop (ETc) and actual (ETr) evapotranspiration, rainfall, irrigation, grain yield and water use efficiency (EUA) by corn grown from February to June 2016 (season 1) and from November 2017 to March 2018 (season 2), in the Rio Largo region, Brazil

Time	Treatment (%ET_c)	ET_c	ET_r	Rain	Effectiverain	Irrigation	EffectiveRain + Irrigation	Grain Productivity	EUA
					(mm)			(Mg ha^{-1})	(kg mm^{-1})
1	L1 (40%)	238	205	349	229	4	233	6,68	28.66
	L2 (80%)		225		209	43	252	6,08	24.12
	L3 (120%)		233		202	57	259	6,81	26.31
	L4 (160%)		233		167	123	290	6,61	22.81
	L5 (200%)		237		172	160	332	6,46	19.47
2	L1 (40%)	308	181	219	149	39	188	6,64	35.32
	L2 (80%)		251		138	138	276	7,60	27.53
	L3 (120%)		308		65	316	381	8,10	21.26
	L4 (160%)		308		50	454	504	8,43	16.72
	L5 (200%)		308		46	585	631	8,15	12.92

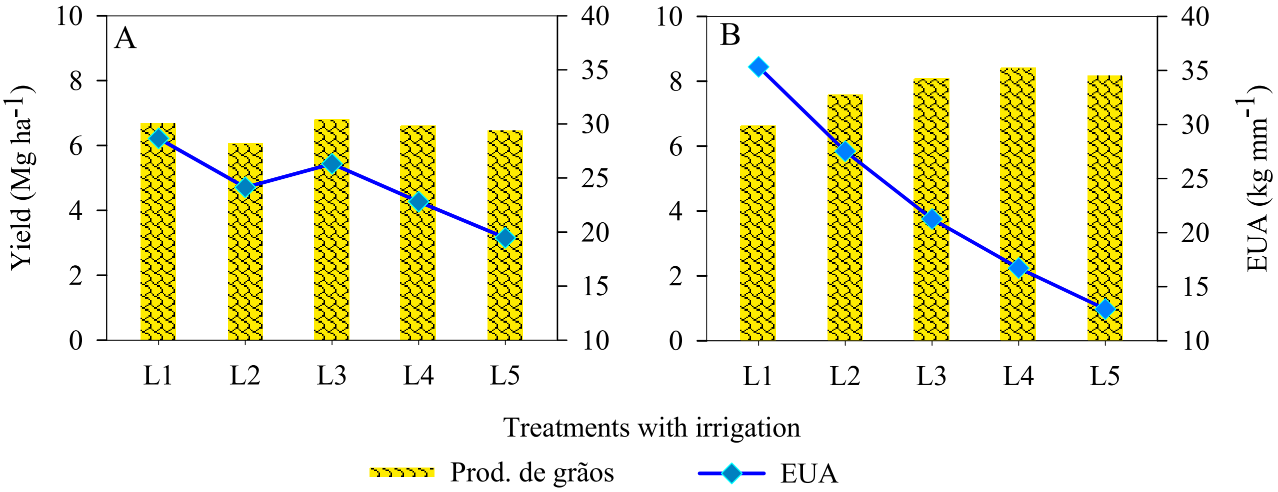

Figure 5. Water use efficiency (EUA) and corn grain yield for treatments with different levels of irrigation (L1, L2, L3, L4 and L5) in crops from February to June 2016 (A) and from November 2017 to March 2018 (B), in the Rio Largo region, Brazil

Thus, in the physiological maturation phase, these reserves have already been used and the stalk may not have a high dry mass content. Table 2 shows the totals resulting from water estimates during the period of application of irrigation treatments in corn. It is observed that between the two cycles of corn production there was a difference of 70 mm in ET_c. ET_r was similar to ET_cin treatments L3, L4 and L5, since in these treatments the water demand was met. In season 1, only rainfall is sufficient to ensure production, and irrigation is unnecessary, since effective rainfall corresponded to 96% of ET_c. At season 2, irrigation needs to be used to complement effective rainfall and to ensure a good water supply that results in satisfactory production. However, due to the annual weather fluctuations, it is impossible to predict a fixed level of irrigation to be applied and, in this case, a crop planning should be carried out in which the irrigation costs take into account all the water demand to be worked in the culture.

Grain yield as a function of irrigation levels showed significant difference only in the second season and ranged from 6,641 to 8,153 Mg ha^{-1}, where the difference between them was 23% in relation to the lowest treatment. It is observed that the maximum yield was reached with irrigation level higher than ET_c, which at first does not make sense, since it represents the maximum water demand of the crop.However, water absorption by the plant is regulated by its transpiration mechanism, which has a higher velocity than the rate of root absorption and conduction in the xylem (TAIZ and ZEIGER, 2013). Thus, the fact that the application of a higher irrigation level than the transpirometric demand promotes a greater response in productivity occurs because the transpiration rate is limited by atmospheric water potential or relative humidity and reaches higher values when there is maximum opening. which also favors greater CO_2 input and, consequently, higher production of photoassimilates for grain formation and filling, as long as there is a greater availability of water in the soil to maintain stomatal conductance always at its maximum. Souza *et al.* (2016) observed that for winter-spring cultivation, the irrigation depth that maximized ear weight was 87.8% of ET_c, while for summer-autumn the irrigation depth that maximized ear weight was 80.5% of ET_c. Silva *et al.* (2018) cultivated corn in Piranhas-AL (semi-arid region) and obtained maximum irrigation depth of 919 mm (175% of ET_c) for a yield of 11.3 Mg ha^{-1}. Souza *et al.* (2011) cultivated maize in the region of Petrolina-PE and verified linear response in the range of tested depths, where the maximum yield (3.86 Mg ha^{-1}) was reached with a 499 mm depth (125% of ET_o). Regarding water use efficiency (EUA) by corn, it is observed that in season 1, even though the crop did not show significant difference in yield, efficiency decreased as the level of irrigation increased, as this factor comes as a denominator of this relationship. Thus, at this time the EUA reduced from 28.7 to 19.5 kg of grains per millimeter of water consumed in L1 and L5, respectively (Figure 5A).

In season 2, the EUA was influenced by increased productivity and also the water depth, which decreased from 35.3 to 12.9 kg mm^{-1} from L1 to L5, respectively (Figure 5B). The average EUA was 24.3 and 22.8 kg mm^{-1} in seasons 1 and 2, respectively, but the respective average yields of these times were 6,5 and 7,8 Mg ha^{-1}. This smaller EUA of season 2 is mainly due to the excessive depthsapplied in the treatments. This variable is very important for the irrigant to use as a reference measure in crop planning and decision making, since it determines the unit yield as a function of the magnitude of the water quantity to be applied. Ashraf *et al.* (2016) observed EUA between 10.29 and 15.46 kg mm^{-1} when improving irrigation management. Souza *et al.* (2011) verified EUA in the order of 46 to 77 kg m^{-3} for irrigated maize in the region of Petrolina-PE. Silva *et al.* (2018) in a corn crop in Piranhas-AL, observed that the EUA as consumption decreased from 181.8 to 55.3 mm Mg^{-1} in treatments with 40 and 160% of ET_c, respectively, indicating that when irrigation approaches water-free crop conditions the EUA is lower.

CONCLUSIONS

- For the studied region, corn cultivation in the rainy season presents a lower water requirement and promotes lower grain yield than in the dry season;
- Maize plants respond physiologically better to water application when grown in the dry season, with higher stomatal aperture values and greater transpiration, allied to higher photosynthetic rates;
- Corn grain yield in rainy seasons does not vary with increasing irrigation level. However, in the dry season, maximum yield can be obtained with irrigation depth equivalent to 147% of ET_c.

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