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# CRESCIMENTO E RENDIMENTO AGRÍCOLA DA CULTURA DO MILHO SOB DIFERENTES DISPONIBILIDADES HÍDRICAS

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## 1 RESUMO

O objetivo deste trabalho foi avaliar o efeito dos déficits e excessos hídricos no crescimento e rendimento agrícola do milho em diferentes épocas de cultivo na região de Rio Largo, AL. Para isso, foi conduzido um experimento no Campus de Engenharia e Ciências Agrárias da Universidade Federal de Alagoas. O delineamento foi em blocos casualizados, com quatro tratamentos e cinco repetições ($E_1$= 28/05/14, $E_2$-11/06/14, $E_3$-25/06/14 e $E_4$- 23/07/14). A primeira época de plantio foi a que apresentou maior altura do dossel (2,25 m), índice de área foliar (4,0 $m^2$ $m^{-2}$) e rendimento agrícola (8,03 t $ha^{-1}$). A $E_4$ apresentou a menor altura do dossel (0,9 m) e a menor produtividade agrícola foi observada na $E_3$ (5,9 t $ha^{-1}$). Isso aconteceu porque com base no balanço hídrico da cultura, quando o plantio é realizado até o primeiro decêndio de junho há uma melhor distribuição da chuva o que maximiza o potencial da cultura.

**Palavras-chave:** produtividade de grãos, precipitação pluvial, balanço hídrico

**SOARES, M. A. S.; SILVA, S.; CUNHA, J. L. X. L.; MOURA, A. B A.; MOURA, A. C. A.; MOURA, A. H.**
**GROWTH AND YIELD OF MAIZE CROP UNDER DIFFERENT WATER AVAILABILITIES**

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## 2 ABSTRACT

This work aimed to evaluate the effects of hydric deficits and excesses on growth and yield of corn at different times of cultivation in the region of Rio Largo, Al. For this, an experiment was conducted at the Campus of Engineering and Agricultural Sciences of the Federal University of Alagoas. The statistical design was randomized blocks, with four treatments and five replications ($E_1$ = 28/05/14, $E_2$-11 / 06/14, $E_3$-25 / 06/14, and $E_4$- 23/07/14). The first planting season was the one with the highest canopy height (2.25 m), leaf area index (4.0 $m^2$ $m^{-2}$) and agricultural yield (8.03 t $ha^{-1}$). The E4 had the lowest canopy height (0.9 m) and the lowest agricultural yield was observed in the E3 (5.9 t $ha^{-1}$). This happened because based on the water balance of the crop, when planting is carried out until the first ten days of June, there is a better distribution of rain, which maximizes the crop's potential.

**Keywords:** yield of grains, rainfall, water balance

## 3 INTRODUCTION

Corn (*Zea mays* L.) is a cereal of great socioeconomic importance worldwide because of its use in both human and animal nutrition (SILVA et al., 2019). According to data from the National Supply Company - CONAB (MILHO, 2019), Brazilian corn productivity in the 2018/19 harvest was 5.71 t ha $^{-1}$. However, in Northeast China, agricultural productivity was 2.63 t ha -1, which was 53.94% lower than the national average. Among Brazilian states, Alagoas ranks 22nd in terms of agricultural yield, with a value of 1.43 t ha $^{-1}$. This low agricultural yield, compared with that in other states, is due to the poor distribution of rainfall during the growing season due to the presence of short dry spells during the rainy season (SOUZA et al., 2004).

Rainfall is the climatic factor that most interferes with the growth, development, and agricultural yield of corn. In Alagoas, it rains on average 1,800 mm annually (CARVALHO et al., 2013). However, this rainfall is distributed irregularly throughout the year, with 70% of the rainfall occurring between April and August and the remaining 30% occurring between September and March (SOUZA et al., 2004). The supply of water to crops is extremely important, especially during the reproductive phase, from tasseling to earing. Meeting a crop's water needs 15 days before and 15 days after tasseling is crucial (SOARES, 2019). If the corn crop, in the flowering phase, experiences two days of water stress, grain productivity can be reduced by more than 20%; if this water stress lasts for four to eight days, losses of more than 50% can occur, since it is in this development phase that the definition of grain productivity occurs (DURÃES et al., 2004).

One way to improve agricultural productivity without increasing production costs is to plant at times when rainfall is better distributed and the average air temperature is suitable for cultivation (WAGNER et al., 2011), as these factors directly influence plant growth and development (MALDANER et al., 2014). Water balance is a very important agronomic technique for defining the best planting time, as it allows us to determine periods of excess and deficit soil water (CARVALHO et al., 2011). Its use allows us to identify periods of water deficit and prevent these periods from coinciding with the critical period for crop productivity. In this context, planning that aims to improve the use of environmental resources can increase corn agricultural yield.

The aim of this work was to evaluate the effects of water deficit and excess water on the growth and agricultural yield of corn cultivated at different planting times in the region of Rio Largo, AL.

## 4 MATERIALS AND METHODS

The experiment was carried out at the Center of Agricultural Sciences of the Federal University of Alagoas, Rio Largo, AL (09°28'02" S and 35°49'43" W, 127 m altitude), in an area of 2,752.0 m2 of cohesive argisol yellow latosol, with a - medium/clayey texture and a slope of less than 2%. The experimental design was a randomized block design with four treatments and five replicates. The treatments consisted of four sowing dates ($E_1$: 05/28/14, $E_2$: 06/11/14, $E_3$: 06/25/14 and $E_4$: 07/23/14). The plot consisted of twenty planting rows, each 7 m long and spaced 0.8 m apart, totaling 112 $^{m2}$.

Soil preparation was carried out with two harrowings. Foundation fertilization (level = 115 kg of $P_2O_5$ and 192 kg of $K_2O$ per hectare) was performed on the basis of the chemical analysis of the soil (Table 1), aiming for an average agricultural productivity of 10.0 t ha $^{-1}$ of grains, according to Coelho (2007). Nitrogen fertilization was carried out 15 days after planting (DAP), and 112.5 kg of N in the form of urea was applied.

**Table 1.** Chemical and physical characterization of the soil in the experimental area in the region of Rio Largo, AL, 2014.

| | Soil depth (cm) | |
|---|---|---|
| **Parameter** | **0-20** | **20-40** |
| **Chemical parameters** | | |
| pH (water) | 5.8 | 5.7 |
| $Ca^{2+}$ (cmolc $dm^{-3}$) | 3.5 | 2.7 |
| $Mg^{2+}$ (cmolc $dm^{-3}$) | 0.9 | 1.0 |
| $Ca^{2+}$+$Mg^{2+}$ (cmolc $dm^{-3}$) | 4.4 | 3.7 |
| $Al^{3+}$ (cmolc $dm^{-3}$) | 0.18 | 0.18 |
| $H^{+}$+$Al^{3+}$ (cmolc $dm^{-3}$) | 5.0 | 5.0 |
| SB (cmolc $dm^{-3}$) | 4.8 | 4.1 |
| T (cmolc $dm^{-3}$) | 9.8 | 9.1 |
| t (cmolc $dm^{-3}$) | 4.95 | 4.26 |
| %V | 48.4 | 45.3 |
| %M | 4.3 | 4.3 |
| $Na^{+}$ (mg $dm^{-3}$) | 29.0 | 33.0 |
| P (mg $dm^{-3}$) | 33.7 | 31.3 |
| $K^{+}$ (mg $dm^{-3}$) | 93.3 | 91.7 |
| **Physical parameters** | | |
| Density (mg $dm^{-3}$) | 2.41 | 2.60 |
| Clay (%) | 20.00 | 44.00 |
| Sand (%) | 73.62 | 50.00 |
| Silt (%) | 6.38 | 6.00 |

SB: (sum of bases) = $Ca^{2+}$ + $Mg^{2+}$ + $K^{+}$ + $Na^{+}$; T = total cation exchange capacity, CEC pH 7.0; t = effective cation exchange capacity; %V: base saturation; %M: aluminum saturation.

Planting was performed manually; 2 (two) seeds of the hybrid AG7088 were placed every 25 cm, and when the plants had 4 fully expanded leaves, thinning was carried out to obtain a density of 50,000 plants per hectare. Weed control was performed with the herbicides Soberan (260 mLha $^{-1}$) and atrazine (2.5 L ha $^{-1}$), both of which were applied after planting with a manual backpack sprayer.

The agrometeorological data used to calculate the daily rainfall and temperature averages were provided by the automatic weather station of the Irrigation and Agrometeorology Laboratory (LIA), which is located near the experiment. The station is a Campbell Scientific® Micrologger-21X model.

The water balance was calculated via the Thorntwaite and Mather method (1955) according to the methodology recommended by Pereira, Angelocci, and Sentelhas (2002). Crop evapotranspiration ($ET_c$) was calculated by multiplying the reference evapotranspiration ($ET_o$) by the crop coefficient (Kc). The Kc used was that of the *Food Agriculture Organization* (FAO), whose values for the initial, intermediate, and final phases were 0.40, 1.2, and 0.6, respectively. The initial Kc was corrected graphically as a function of ET0 and irrigation frequency. The intermediate and final Kc values were corrected according to Equation (1):

$$\text{Final Kc} = \text{final Kc}_{(Tab)} + [0.04\,(U_2 - 2) - 0.004(RH_{min} - 45)]\,(H/3)^{0.3} \qquad (1)$$

where Kc final $_{(Tab)}$ is the value provided in the FAO-56 bulletin; $U_2$ is the average value for the daily wind speed measured at 2 m height over the grass during the last growth phase; $RH_{min}$ is the value of the average daily minimum relative humidity during the last growth phase [%], for 20% ≤ $RH_{min}$ ≤ 80%; and H is the average plant height during the last growth phase [m], for 0.1 m ≤ H ≤10 m (ALLEN et al., 1998).

Phenology was carried out on the basis of the scale proposed by Fancelli and Dourado Neto (2004) and Magalhães and Durães (2006), which divides the corn crop cycle into two main phases: the vegetative phase (V) and the reproductive phase (R), as shown in Table 2.

**Table 2.** Development stages of corn crops proposed by Fancelli and Dourado Neto (2004) and Magalhães and Durães (2006)

| VEGETATIVE | REPRODUCTIVE |
|---|---|
| $\mathbf{V_E}$ – Emergency; | $\mathbf{R_1}$ – Flowering; |
| $\mathbf{V_1}$ – 1st developed leaf; | $\mathbf{R_2}$ – Milky grain; |
| $\mathbf{V_2}$ – 2nd developed leaf; | $\mathbf{R_3}$ – Pasty grain; |
| $\mathbf{V_3}$ – 3rd leaf developed; | $\mathbf{R_4}$ – Flour grain; |
| $\mathbf{V_N}$ – Nth developed leaf; | $\mathbf{R_5}$ – Hard floury grain; |
| $\mathbf{V_T}$ – Tasseling | $\mathbf{R_6}$ – Physiological maturity |

The leaf area index (LAI) and the height of the vegetative canopy were measured biweekly starting 30 days after sowing via tape and calipers. The LAI was calculated via Equation 2:

$$IAF = \frac{AF \times NP}{\in \times H} \qquad (2)$$

where AF is the leaf area ($m^2$); Np is the number of plants per linear meter; $\epsilon$ is the average spacing between lines (m); and H is the length of the plant counting line (m).

The leaf area was determined via Equation 3 according to the methodology of Hermann and Câmara (1999):

$$AF = L \times W \times 0.75 \times (N+2) \qquad (3)$$

where C is the length of the “+3 leaf” (m); L is the width of the “+3 leaf” (m); 0.75 is the shape correction factor of the leaves; and N is the number of photosynthetically active leaves.

Harvests were carried out on 10/22/2014 ($E_1$), 11/04/2014 ($E_2$), 11/25/2014 ($E_3$) and 12/11/2014 ($E_4$) in the twelve central rows of the plot (useful area). The grain yield was obtained by weighing all the grains harvested in the useful area of each plot according to Equation (4):

$$RG = 10{,}000\ (M/C\ \epsilon) \qquad (4)$$

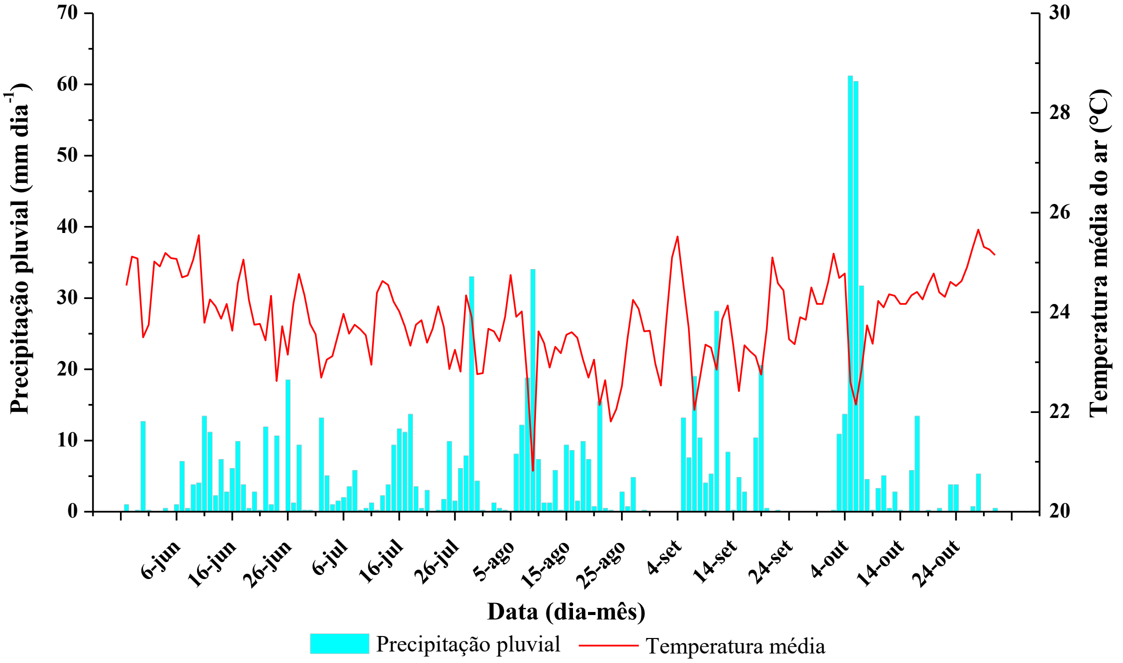
where RG is the grain yield (kg $ha^{-1}$); M is the mass harvested in the sampled area (kg); C is the total length of the harvested lines (m); $\epsilon$ is the spacing between lines (m); and 10,000 is the conversion factor for hectares.

The data were subjected to analysis of variance and regression via the F test ($p \leq 0.05$), in which regression was applied to quantitative variables and the mean test was applied to qualitative variables. The software used for the analyses was the Sisvar statistical program (Analysis of Variance System).

## 5 RESULTS AND DISCUSSION

The average air temperatures in the four seasons were 23.7°C, 23.6°C, 23.5°C and 23.7°C at $E_1$, $E_2$, $E_3$ and $E_4$, respectively (Figure 1), which are within the temperature range recognized by Grossi et al. (2011) as ideal for corn cultivation, which is 10°C to 30°C. The total rainfall in $E_1$, $E_2$, $E_3$ and $E_4$ was 457, 476, 478 and 584 mm, respectively (Figure 1), which was in the range of 400--600 mm per cycle, which, according to Machado (2016), is the water demand required for corn cultivation. These values were below the climatological normal, since for Souza et al. (2004), in this region, the averages corresponding to the times of this work are 862 ($E_1$), 545 ($E_2$), 670 ($E_3$) and 816 mm ($E_4$).

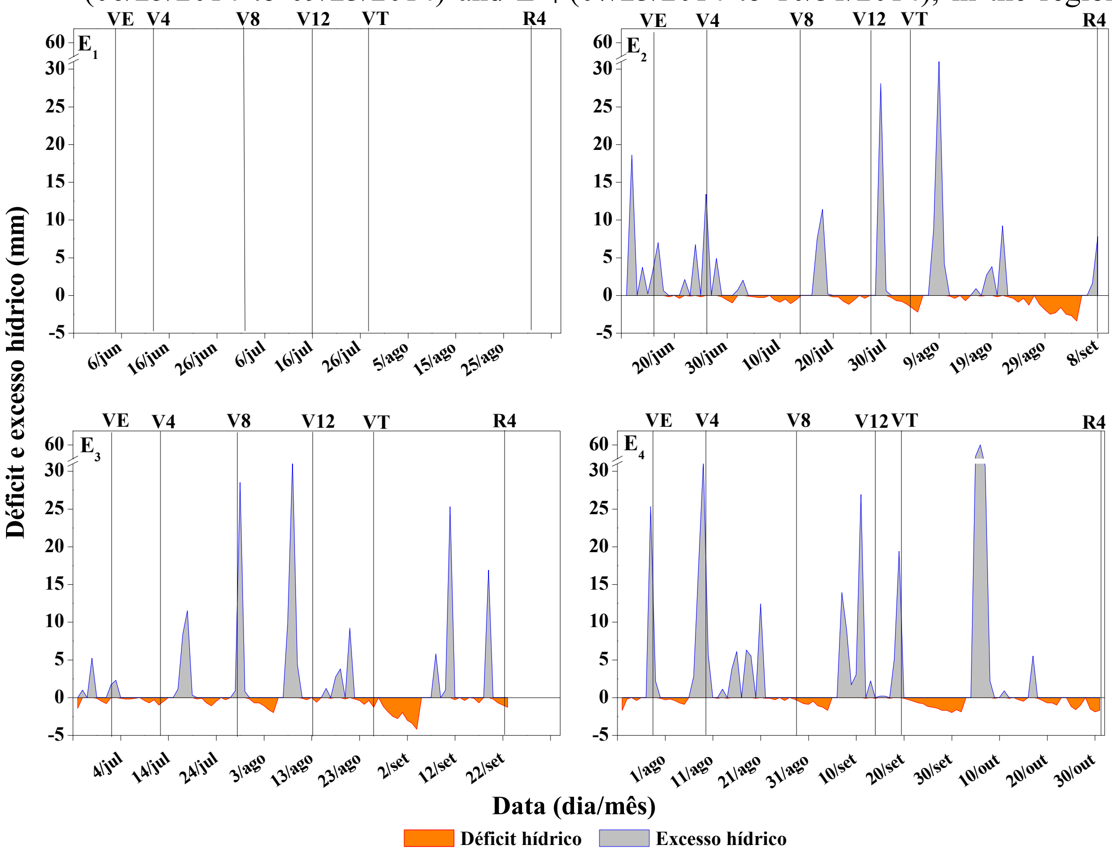
**Figure 1.** Rainfall and average air temperature (Tm) during the corn planting seasons ($E_1$, $E_2$, $E_3$ and $E_4$), from 05/28/2014 to 10/31/2014, in the region of Rio Largo – AL.




**Source:** Authors (2020)

For the water balance of the corn crop planted on 05/28/2014 ($E_1$), in the region of Rio Largo, Alagoas (Figure 2), a period of 16 days with a water deficit of 15.4 mm was observed from planting to the V4 phase (4 developed leaves - 06/13/2014). In the V8 and R4 phases, a period of water deficit of 11.2 mm also occurred. The water deficit recorded over the entire period evaluated was 44.9 mm. According to Oliveira et al. (2009), seed germination is one of the most critical stages in the plant life cycle and is an irreversible process that is directly affected by the occurrence of water deficit. Khajeh-Hosseini, Powell and Bingham (2003) stated that, of the various environmental factors capable of influencing germination, water availability is one of the most important, since it constitutes the main factor in most biochemical and physiological processes. On the other hand, in that same planting season, there was a total water excess of 147.6 mm, 27.0 mm of which were at VT (tasseling).

**Figure 2.** Water balance of corn crops with water deficits and excesses in the planting seasons: E $_1$ (05/28/2014 to 09/01/2014), E $_2$ (06/11/2014 to 09/08/2014), E $_3$ (06/25/2014 to 09/23/2014) and E $_4$ (07/23/2014 to 10/31/2014), in the region of




Rio Largo, AL.

**Source:** Authors (2020)

AE $_2$ was the planting season in which the total water deficit was lowest, with the deficit being lowest in the vegetative phase (17.5 mm) and highest in the reproductive phase (22.9 mm). However, approximately 7 mm of the total occurred during the transition period from the vegetative phase to the reproductive phase (July 31, 2014; August 5, 2014). The occurrence of water deficit before stigma emission can cause a decrease in productivity of up to 25%, as corn is relatively tolerant to water deficit during the vegetative phase. However, this reduction is 50% if water stress occurs during the flowering and grain-filling phases due to the extreme sensitivity of the crop to a lack of water during this period (Maldaner et al., 2014). In the VE, V4, and V12 phases, there was a water excess of 16.3, 4.9, and 12. and 28.1 mm, respectively, which ensured good germination and crop development. However, for the R4 phase, an excess water level of 9.4 mm was recorded.

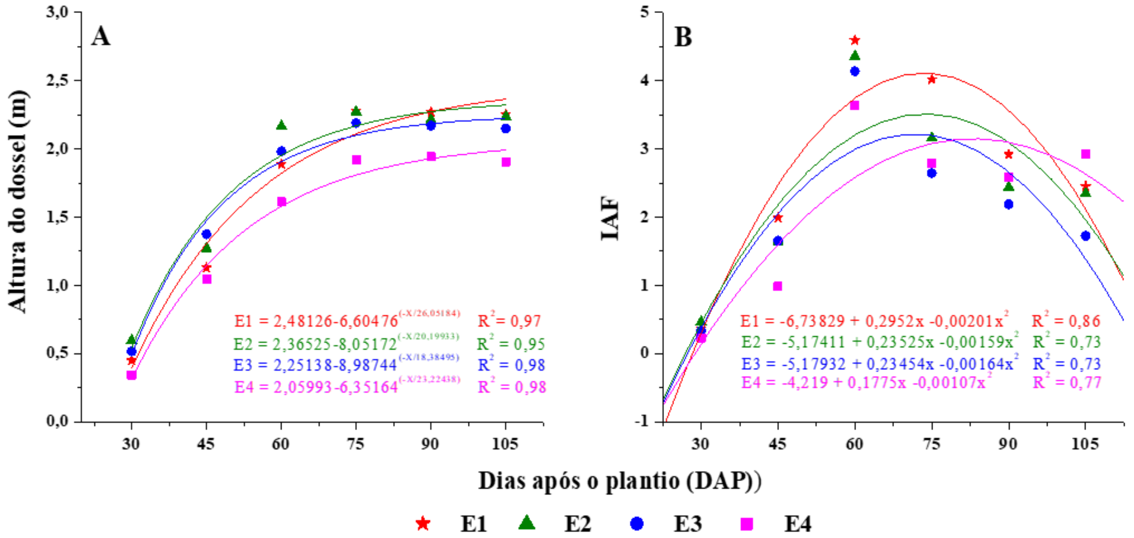
In the third planting season (E3), the total water deficit (45.7 mm) was greater than that in the other planting seasons, with 27.5 mm occurring during the tasseling to grain filling phase, a critical period for the crop, resulting in a low grain yield during this sowing season. Claassen and Shaw (1970) reported that water stress in corn, from tassel emergence to two weeks after earing, is what causes the greatest reduction in grain yield. In the present study, the second smallest total water excess (44.9 mm) was observed during this period.

AE4 was the second most affected by water deficit and excess, as during the critical period, approximately 40 mm of water stress occurred during the grain-filling phase, resulting in poor plant performance. However, during this planting season, there was a water excess of 132.3 mm during the vegetative phase and 131.3 mm during the reproductive phase, with approximately 50% (131.3 mm) of the total water excess occurring in just 4 days.

In general, C4 plants are relatively resistant to water stress; however, in critical periods (flowering and grain filling), the lack of water can cause a reduction in the grain yield of the corn crop (MALDANER et al., 2014) because even in favorable years, that is, with good water availability, if a water deficit occurs in the critical phases of preflowering and grain filling, there will be a reduction in the productive potential of the crop (BERGAMASCHI et al., 2006).

The canopy height in relation to the sowing date fit the first-order exponential model well, with coefficients of determination ($R^2$) of 0.97, 0.95, 0.98, and 0.98 for treatments $E_1$, $E_2$, $E_3$, and $E_4$, respectively (Figure 3A). At 75 days after planting (DAP), the maximum canopy height values were 2.28, 2.27, 2.18, and 1.91 m in treatments E1, E2, E3, and E4, respectively, and the canopy height was 16.2% (37 cm) lower in E4 than in E1. The reason for this reduction in growth in season 4 in relation to that in season 1 is that the rainfall in E4 was poorly distributed, which resulted in long periods of water deficiency in the corn crop. In addition, at some times, there was percolation of rainwater in this planting season because the precipitation volume was greater than the soil storage capacity, which resulted in lower effective rainfall in E4 than in E1, 225.0 and 310.0 mm, respectively. According to Taiz and Zeiger (2013), plants under water stress close their stomata, consequently reducing $CO_2$ fixation, the photosynthetic rate, water and nutrient absorption, and growth. Soares et al. (2020) obtained similar results regarding the occurrence of maximum canopy height in corn. The authors observed a greater canopy height of 2.47 m at 73 DAP and reported that from that moment on, vegetative growth stabilized due to photoassimilates directed to the production and accumulation of starch in the grains. In the same region as in the present study, Barbosa (2017) reported a greater canopy height of 2.44 m at 75 DAP, a value similar to that reported in this study.

**Figure 3.** Vegetative canopy height (A) and leaf area index (LAI) (B) of the corn crop for four sowing seasons, from 05/28/2014 to 07/23/2014, in the region of Rio Largo, AL.




**Source:** Authors (2020)

Almeida (2016), evaluating water deficit and excess in corn (*Zea mays* L.) crops in a protected environment, reported that plants subjected to a water deficit of 50 and 70% of crop evapotranspiration (ETc) presented lower canopy heights of 1.98 and 2.07 m, respectively. Soares et al. (2020), evaluating corn growth at irrigation depths in Rio Largo, Alagoas, reported lower canopy heights of 2.12 and 2.30 m in treatments subjected to irrigation at 40 and 80% of ETc, respectively. According to the aforementioned authors, canopy height is a variable that is strongly linked to grain yield and should therefore be considered in production estimates.

Figure 3B shows that the leaf area index (LAI) in relation to the number of plants was a good fit for the quadratic regression mathematical model, with R2 values of 0.86, 0.73, 0.73 and 0.77 for treatments $E_1$, $E_2$, $E_3$ and $E_4$, respectively. The maximum LAI value occurred at all planting times at 60 days after planting, with the highest value (4.5) observed at E1 and the lowest at E4 (3.6), representing a difference of 20% in the LAI value. The first planting time was favored by the largest volume of effective rainfall during the growing cycle, which was 310 mm, whereas at the fourth planting time, a volume of only 225 mm was observed. According to Soares et al. (2020), plants subjected to water deficiency have the immediate effect of reduced cell expansion, which consequently results in a lower leaf area and leaf area index. From 60 to 105 DAP, the LAI decreased at all sowing dates, reaching the end of the cycle, with an average of 2.3. This occurred because after the LAI peak, the plants begin the process of allocating photoassimilates to the grains, with the natural senescence of older leaves occurring concomitantly.

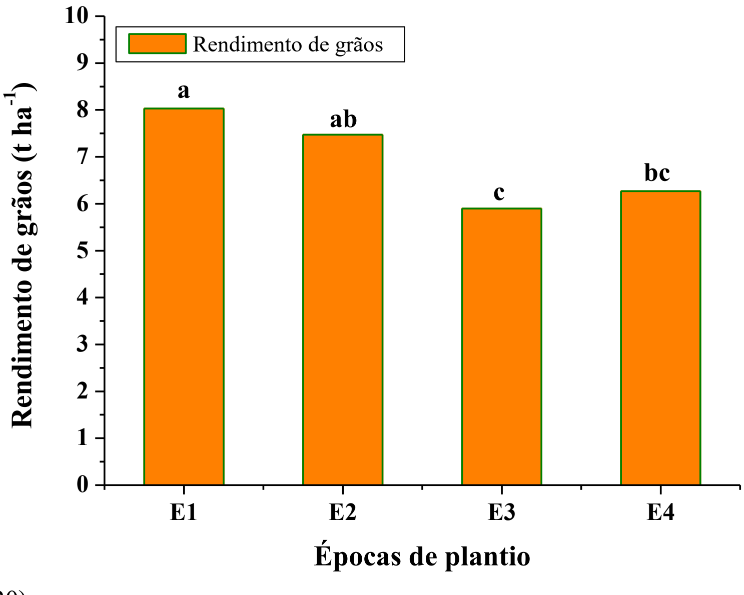
The planting date had a significant effect on the grain yield at a 1% probability according to the F test (Table 3). The highest grain yield was observed in the first planting season (E1), with a value of 8.03 t ha $^{-1}$ (Figure 4). This is explained by the fact that the crop did not experience water deficits at any stage of development, considering the critical stage of water shortage, which corresponds to flowering and grain filling (Figure 2). Water deficits were mild in the initial phase and during the vegetative growth phase. However, corn is not as sensitive to water shortages, which does not result in a significant reduction in agricultural productivity. According to Maldaner et al. (2014), corn plants have relative tolerance to water shortages during the vegetative phase. Mendoza-Pérez et al. (2016) evaluated the productive performance of corn subjected to water deficits outside the flowering period, and the authors reported no significant differences in grain yield.

**Table 3.** Analysis of variance and mean square values of corn grain yield (t ha $^{-1}$) according to the planting season in the region of Rio Largo, AL, from May 28, 2014, to July 23, 2014.

| Sources of Variation | [1] GL | Mean Squares Values<br>Grain yield |
|---|---|---|
| Block | 4 | 1.03 $^{ns}$ |
| Planting season | 3 | 13.08** |
| Error | 12 | 1.44 |
| [2] CV (%) | -- | 17.34 |

[1] Degrees of freedom; [2] Coefficient of variation; **significant at the 1% probability level; ns not significant according to the F test.
**Source:** Authors (2020)

**Figure 3.** Agricultural productivity (t ha $^{-1}$) of corn in four different planting seasons (E1, E2, E3 and E4), from 05/28/2014 to 07/23/2014, in the region of Rio Largo - AL.




**Source:** Authors (2020)

The second planting season ($E_2$) was the second most productive, with 7.5 t ha $^{-1}$, and did not differ statistically from that of $E_1$. However, the agricultural yield was reduced by 6.6% in E2 in relation to the most productive season (E1). The justification for such a reduction lies in the observation of a long period of water deficit (14 days without rain) during the reproductive stage of milky grains (R2) (Table 2).

The third planting season (E3) presented the lowest grain yield, at 5.9 t ha$^{-1}$, a difference of 26.5% compared with that of E1. This reduction was due to the 14-day period without rain during the tasseling and grain-filling phases, which resulted in a water deficit of 27.5 mm. According to Silva et al. (2016), the occurrence of a water deficit during the flowering and grain-filling phase can lead to a 50% reduction in corn agricultural productivity. According to Soares et al. (2020), the most critical period of water deficiency for corn crops is from tasseling to flowering, as during these phases, water stress can prevent stigma fertilization, which reduces the number of grains per ear and, consequently, agricultural yield. The same authors reported that if the deficit extends into the grain-filling phase, there will be a reduction in grain mass per ear, resulting in a decrease in productivity. Almeida (2016), who analyzed water deficits and excesses in corn, reported a 22.6% reduction in grain yield when the crop was subjected to 50% water restriction during the tasseling phase and a 26.1% reduction when the 50% restriction occurred during the flowering phase.

The fourth planting season (E4) had the second lowest grain yield, with a value of 6.3 t $ha^{-1}$, but did not differ statistically from that of E3. This low yield can be explained by the poor distribution of rainfall during the growing season, as even though this season had the highest rainfall volume (584 mm), it only totaled 225 mm of effective rainfall. From 73 to 77 days after planting, during the grain-filling phase, 178 mm of rainfall was observed (Figure 1), a value well above the soil water storage capacity, which caused a water excess of 148 mm. According to Magalhães and Durães (2006), soils with high moisture contents resulting from water excess at the beginning of the reproductive phase can lead to the unviability of corn pollen grains and to the death of the plants. Another explanation for this reduction in grain yield in E4 is that there were thirteen days of water deficit, totaling 15.1 mm, in the critical phase of the crop (tasseling and flowering). Soares et al. (2020), evaluating the effects of five irrigation depths (40, 80, 120, 160, and 200% of crop evapotranspiration (ETc)) on corn phenology, production components, and agricultural yield, reported that the treatments that met only 40 and 80% of the crop water demand were the least productive, with values of 6.6 t $ha^{-1}$ and 7.6 t $ha^{-1}$, respectively. The same authors explained that the reduction in grain yield in the irrigated treatment with 40% ETc was due to the 80 mm water deficiency recorded in the tasseling and grain-filling phases, whereas in the irrigated treatment with 80% ETc, the reduction occurred because of the 40 mm water deficit observed in the grain-filling phase.

## 6 CONCLUSIONS

Corn growth and grain yield are affected by the planting season because they are influenced by the rainfall distribution during the growing season;

Corn, in the Rio Largo region, reaches the greatest canopy height when sown between the third ten days of May and the first ten days of June;

The highest grain yield is obtained when corn is planted before the first ten days of June.

## 7 ACKNOWLEDGMENTS

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