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PARÂMETROS PRODUTIVOS DO MILHO SOB DÉFICIT HÍDRICO EM DIFERENTES FASES FENOLÓGICAS NO SEMIÁRIDO BRASILEIRO

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1 RESUMO

O objetivo deste trabalho foi avaliar o efeito do déficit hídrico em diferentes fases fenológicas do milho na região semiárida de Alagoas. O experimento foi conduzido no Instituto Federal de Alagoas, Campus Piranhas, durante os meses de fevereiro a junho de 2019. A partir dos dados coletados nas plantas durante a condução do experimento, foram realizadas as seguintes etapas: análise do efeito dos elementos climáticos sobre a cultura, determinação da produtividade em cada tratamento, avaliação de variáveis da espiga sob o efeito do déficit hídrico e estimativa da evapotranspiração da cultura (ETc). As plantas submetidas ao déficit hídrico nas fases de pendoamento e floração sofreram variação no número de grão por espiga e tiveram baixa produtividade quando comparadas às plantas submetidas na fase de grão farináceo. A temperatura e umidade do ar não influenciaram na limitação térmica para o desenvolvimento do milho durante todo o ciclo. Plantas submetidas ao déficit hídrico na fase de pendoamento e floração foram menos produtivas.

Palavras-chave: umidade do solo, estresse hídrico, produtividade agrícola.

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2 ABSTRACT

The objective of this work was to evaluate the effect of water deficit in different phenological phases of maize in the semiarid region of Alagoas, Brazil. The experiment was conducted at the Federal Institute of Alagoas, Campus Piranhas, from February to June 2019. From the data collected from the plants during the conduct of the experiment, the following steps were performed: analysis of the effect of climatic elements on the crop, determination of productivity in each treatment, evaluation of growth data and ear variables under the effect of the deficit water, estimation of crop evapotranspiration (ETc) and verification of the level of impact of water stress caused in each phonological phase of the culture. The plants subjected to water deficit in the tasseling and flowering phases suffered variation in the number of grains per ear and had low yield compared to the plants submitted to the farinaceous grain phase. The evapotranspiration of the crop, temperature and humidity did not influence the thermal limitation for developing maize throughout the cycle. Plants submitted to water deficit during the planting and flowering phase were less productive.

Keywords:soil moisture, hydric stress, yield.

3 INTRODUCTION

Corn (*Zea mays* L.) is a crop of global importance that is cultivated in almost all countries under different climates and management practices (ALMEIDA et al., 2017). As one of the main cereals in the world, corn provides several products that are widely used for human and animal feed. It is also widely used to supply raw materials for industry, mainly because of the quantity and quality of the accumulated reserves that it has in its grains (ALVES et al., 2015).

The semiarid region of Alagoas experiences low rainfall with prolonged periods of drought, resulting in low water reserves in arable land. This condition affects the development of many cultivated plant species, including corn, which directly impacts the family income of farmers, as corn is the main crop for livestock production in the region (SANTOS et al., 2020) and for subsistence farming by smallholders.

Corn crops have a high demand for water, require 250--500 mm of water per cycle, and are sensitive to water stress caused by low water availability in the soil, especially during the critical period, which begins at flowering and continues until grain filling (HERNÁNDEZ et al., 2015).

The occurrence of water stress causes considerable damage to corn crops, such as reduced productivity, plant height and stem diameter, in addition to reduced photosynthesis caused by decreased cell expansion and damage to the photosynthetic apparatus (GUIMARÃES; ROCHA; PATERNIAN, 2019).

Thus, this work aimed to evaluate the effects of water deficit on different phenological phases of corn in semiarid regions.

4 MATERIALS AND METHODS

The experiment was conducted at the Federal Institute of Alagoas, Piranhas Campus, between February 28 and June 3, 2019 (95 days). The corn cultivar used was the M274 hybrid, which is considered to have high production potential. According to the Köppen climate classification, the region has a Bsh climate, characterized as a very hot, semiarid climate, with a rainy season centered in the months of April, May, and June (ALVARES et al., 2013). The average annual rainfall in the region is 483 mm.

The experimental design used was a strip plot with four replicates. The treatments were periods to initiate crop water deficit stress, starting at the following stages: tasseling (VT), pollination (R1), milky grain (R3), pasty grain (R4), and floury grain (R5) (without stress), corresponding to 45, 55, 65, 75, and 85 days after planting, respectively. The plots consisted of four 5.0 m long rows spaced 0.80 m apart, resulting in a total area of 16 ^{m2}, with the useful area comprising the central 3 m of the two middle rows.

Soil preparation was carried out by harrowing. The plants were planted in manually opened furrows, with two seeds placed every 0.20 m. When the plants reached four fully expanded leaves, thinning was carried out on one plant, resulting in 62,500 plants per hectare. Foundation fertilization was applied on the basis of the expected productivity of 10 t ha $^{-1}$, according to Coelho (2007), in which 96.2 kg ha $^{-1}$ of phosphorus was applied, with simple superphosphate as the source, plus half of the potassium (182.4 kg ha $^{-1}$) in the form of potassium chloride. The second half of the potassium plus nitrogen mixture (200 kg ha $^{-1}$) in the form of ammonium sulfate was applied as a top dressing 15 days after planting (DAP). At 22 DAP, foliar mixtures containing 0.35, 0.88, 0.88, 3.49, and 4.50 mg of potassium were also applied. 0.88, 0.17 and 0.16 kg ha -1 correspond to Zn, Cu, Fe, Mn, Mo, and Ni, respectively. Pest and disease control was achieved through integrated pest and disease management (IPDM), which uses manual control and the insecticide methomyl to control *Spodoptera frugiperda*. Weed control was achieved through manual weeding. Irrigation was provided via a drip system with a nominal flow rate of 7.5 L h $^{-1}$ m $^{-1}$, a nominal pressure of 10 mca and a spacing between drippers of 0.4 m. Irrigation was managed with daily irrigation shifts and maintenance of soil moisture close to field capacity, which was monitored with tensiometers at a depth of 20 cm, with readings taken with a digital tensiometer. For the purpose of determining water stress, the stresses equivalent to -8 kPa and -50 kPa were considered as the moisture point at field capacity and the critical moisture point, respectively.

Meteorological data were obtained from the automatic data acquisition station of the National Institute of Meteorology (INMET), which is located near the experimental area. Reference evapotranspiration (ETo), which represents the reference water consumption for the region, was calculated via the Penman–Monteith method (ALLEN et al., 1998) according to Equation (1):

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

where ETo is the reference evapotranspiration (mm); Δ is the slope of the saturated water vapor pressure versus air temperature curve (kPa °C $^{-1}$); Rn is the estimated net radiation (MJ m $^{-1}$ day $^{-1}$) calculated via the Penman–Monteith method; G is the ground heat flux (MJ m $^{-2}$ day $^{-1}$); γ is the psychrometric coefficient (°C $^{-1}$); T is the mean air temperature (°C); u2 is the mean wind speed at 2 m height (ms $^{-1}$); es is the saturation water vapor pressure of the air (kPa); and ee is the water vapor pressure of the air (kPa).

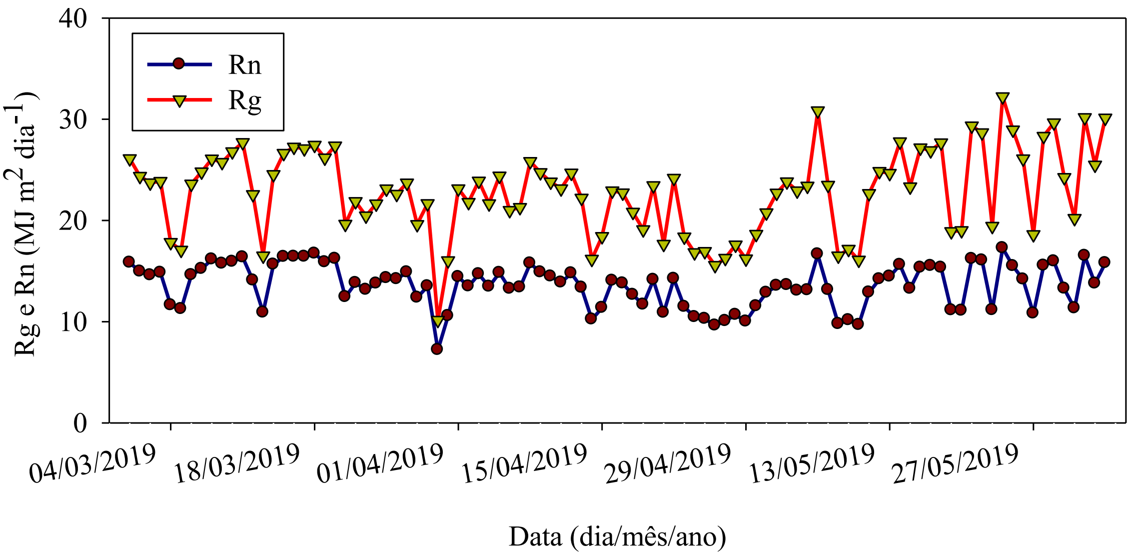
For the crop evapotranspiration (ETc) estimates, plant development was divided into four stages (initial with 20 days, growth with 32 days, intermediate with 40 days and final with 33 days), which are listed in the FAO-56 bulletin (ALLEN et al., 1998), which describes the detailed procedures for calculating ETc via the single crop coefficient (Kc) method. The initial Kc value adjusted via the graphical method was 0.65, and the intermediate and final Kc values adjusted via the equation method were 1.12 and 0.53, respectively, according to Allen et al. (1998).

At harvest, ears were collected at the physiological maturity stage (R6) to measure ear length and diameter, number of grain rows, number of grains per row, thousand-grain weight, and total grain weight in the plot area. After the grain weight was determined, the samples were placed in a drying oven at 65°C for 48 hours to determine the moisture content and agricultural productivity in each treatment, the latter of which was determined by dividing the grain weight at 12% moisture by the plot area. The results were subjected to analysis of variance (F test) and Tukey's test to assess the degree of significant difference between treatments. Spreadsheets were created in Microsoft Excel, and graphs were created via SigmaPlot and Origin.

5 RESULTS AND DISCUSSION

radiation (Rg) ranged from 10 MJ m $^{-2}$ day $^{-1}$ (2019-03-30) to 32 MJ m$^{\cdot -2}$ d $^{-1}$ (2019-05-24), with an average of 22.8 MJ m $^{-2}$ d $^{-1}$ (Figure 1). During the months from March to April, there were days with low Rg values due to the occurrence of rain, since cloudiness interferes with irradiance at the surface. The net radiation (Rn) ranged from 7.2 MJ m $^{-2}$ d $^{-1}$ (2019-03-30) to 17.3 MJ m $^{-2}$ d $^{-1}$ (2019-05-24), with an average of 13.6 MJ m $^{-2}$ d $^{-1}$. This energy is used in the processes of evapotranspiration; the heating of air, soil and plants; and photosynthesis (SANTOS et al., 2018).

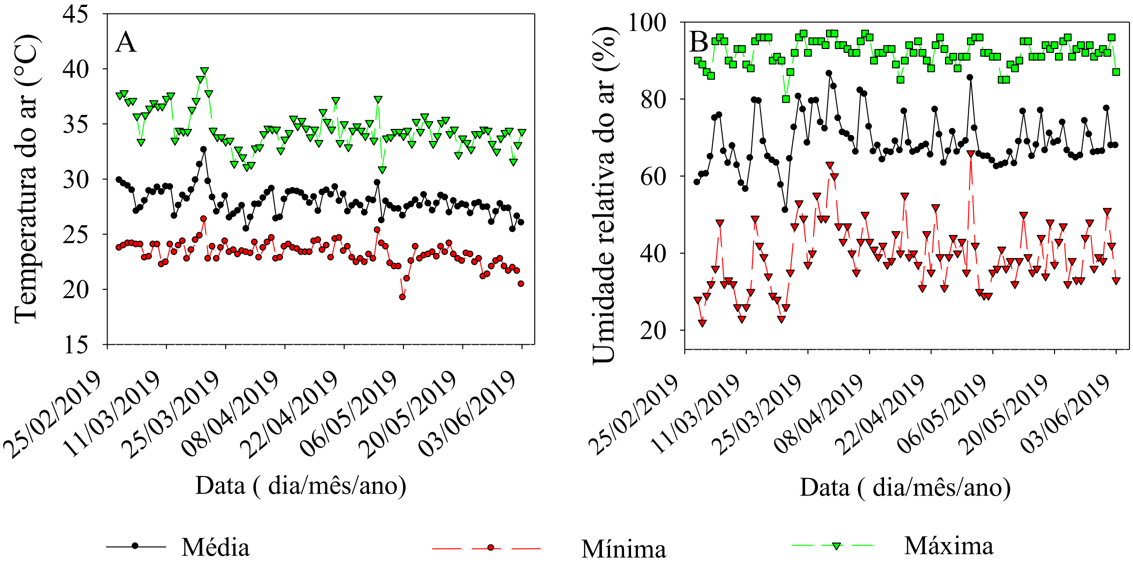
Figure 1. Daily Rn and Rg values from February to June 2019 during the corn cycle in Piranhas, AL.



According to Santos et al. (2018), solar radiation directly affects plant development and growth and indirectly affects the thermal regime of any terrestrial system. Light is essential for corn crops, as this plant requires light to express its high efficiency in converting radiant energy into chemical energy. The use of solar radiation by this crop indicates the potential for photosynthetic activity, which directly impacts agricultural productivity. As a C4 tropical grass, it has high photosynthetic efficiency and yields high yields when it is grown in favorable environments.

Figure 2 shows the variations in relative humidity (RH%) and air temperature during the crop cycle. The relative humidity ranged from 39 to 92% (03/01/2019 and 05/18/2019, respectively), with an average of 69%, whereas the average temperature ranged from 23 to 35°C (03/28/2019 and 05/18/2019, respectively), with an overall average of 28°C. A decrease in air temperature and an increase in RH% were observed on rainy days. However, no thermal limitation was observed for corn development, whose ideal range for growth and development is between 24 and 30°C (CARON et al., 2017).

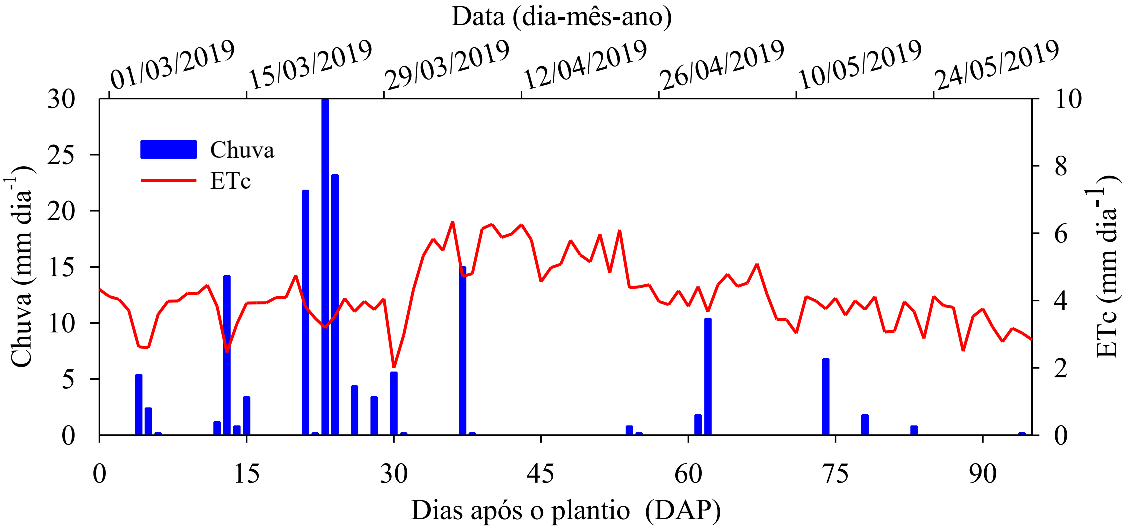
Figure 2. Average daily values of temperature and relative humidity from February to June 2019 during the corn crop cycle in Piranhas, AL.



A rising air temperature increases the amount of water vapor that the atmosphere can retain. Therefore, with increasing temperature, the atmospheric water potential decreases, increasing the gradient between the leaf and the air potential, which can significantly affect plant growth and development (SILVA et al., 2016). It is clear that the study region did not experience extreme air temperature values, which were equivalent to the basal temperatures (lower and upper), which allows us to infer that the crop was in full development with respect to air temperature and was not suffering thermal stress, as temperatures below the lower base and above the upper base negatively interfered with the plant's photosynthesis rate.

Rainfall during the corn production cycle totaled 156 mm, with 75% (118 mm) of this precipitation occurring during the month of March (March 4, 2019, to March 31, 2019), characterizing the irregular distribution of rainfall during the growing season (Figure 3). This period corresponds to the region's rainy season, but this water availability is insufficient to meet the crop's water demand, which, according to Machado (2016), requires 400 to 600 mm of water during the cycle for good production. Corn is considered a highly water-demand crop, but it is also one of the most efficient in its use; that is, it produces a large amount of dry matter per unit of water absorbed (CAVALCANTE JUNIOR et al., 2018).

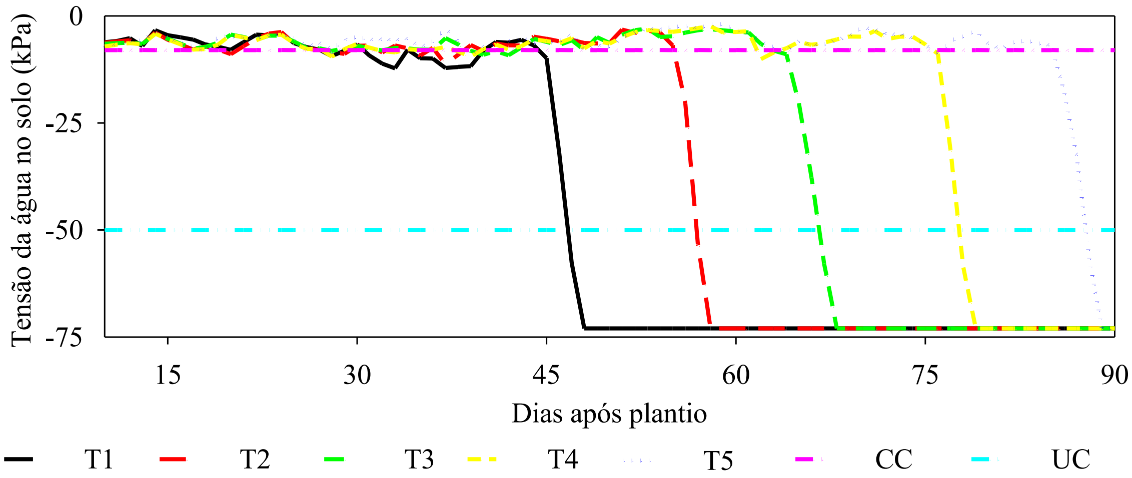
Figure 3. Daily rainfall and ETc values from February 2019 to June 2019 during corn cultivation in Piranhas, AL.



The total crop evapotranspiration (ETc) in the cultivation cycle was 399 mm, with partial values of 32.9, 212.4, 51.1, 48.6, 53.5, 56.1 and 57.9 mm for the respective development phases shown in Figure 3. Lower ETc values are observed during the rainy season, when there is high cloud cover and a decrease in the intensity of solar radiation, atmospheric heating and, consequently, atmospheric water demand. Throughout the entire crop cycle, average, minimum and maximum ETc values of 4.2.2 and 6.4 mm day $^{-1,}$ respectively, were observed (Figure 3).

The irrigation applied to the crop meant that from planting until the end of the crop growth phase (0--45 DAP), all the treatments had moisture levels close to field capacity (FC), which was equivalent to -8 kPa (Figure 4). From the tasseling stage onward, the soil water tension at T1 was below the critical moisture point (-50 kPa) because of the suspension of irrigation. In treatments T2, T3, T4, and T5, the soil water tension remained close to that of the FC until 55, 65, 75, and 85 DAP, which corresponded, respectively, to the pollination, milky grain, pasty grain, and floury grain stages reached by the crop. After these periods of irrigation in all the treatments (tassing to floury grain), the soil water tension decreased dramatically, exceeding the critical moisture point for the crop. This negatively affected the growth, dry matter and productivity variables of the crop, except for T5, which had the water supply suspended when there was no longer any effect of soil moisture on grain filling.

Figure 4. Soil water tension during corn cultivation from February to June 2019 in Piranhas, AL.



Corn plants grown in the different treatments presented different performances. In T1, the plants did not flower, unlike those in T2, which, despite showing reduced growth, had flowering, although it was more uneven than that in T4 and T5. The observed aspects of corn flowering were similar to those of Melo et al. (2018), who evaluated corn genotypes and reported delayed flowering in treatments with low water availability. Storck et al. (2009) also reported late flowering in corn grown under water stress.

With respect to the evaluation of production parameters, only T1 did not produce an ear. Among the other treatments, there was no significant difference in the number of rows per ear, while the variables ear length and diameter and the number of grains per row differed statistically (Table 1). The number of grains per row ranged from 31.97 to 25.4 for treatments T5 and T2, respectively. Compared with T5, T2 also presented a shorter ear length and diameter. The highest thousand-grain mass was obtained by T5, which presented 136% more thousand-grain mass than did T2 (Table 1).

Table 1. Values of the productive parameters of the corn crop, ear length (CE), ear diameter (DE), number of grains per row (NGF), number of rows (NF) and dry mass of a thousand grains (Massa), cultivated from February to July 2019 in Piranhas, AL.

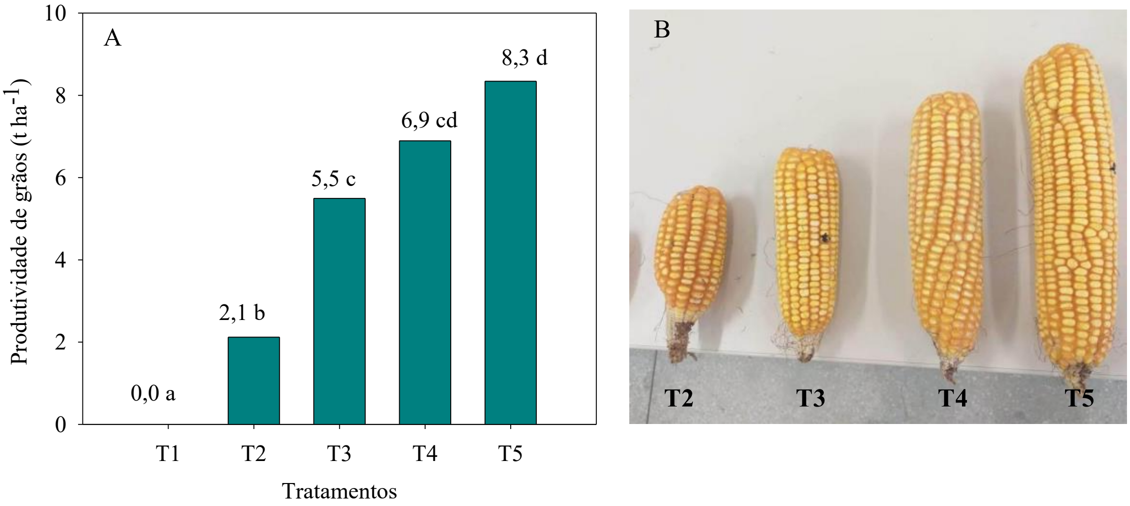
TREATMENTS	**CE**	**OF**	**NGF**	**NF**	**Mass**
	cm	**cm**	**plant unit $^{-1}$**	**plant unit $^{-1}$**	**g**
T1- Tasseling	-	-	-	-	-
T2- Pollination	13.3 c	3.31 b	25.40 b	14.40 a	11.0 c
T3- Milky grain	16.4 b	3.86 b	31.70ab	14.20 a	16.75 b
T4- Pasty grain	15.9 ab	4.26ab	29.12 a	14.70 a	23.25 a
T5- Flour grain	17.7 a	6.51a	31.97 a	14.55 a	26.00 the
Overall average	15.88**	4.48**	29.55**	14, 46 ^{ns}	19.25**
CV %	4.47	25.51	6.41	3.34	10.46

** Significant at the 1% probability level according to Tukey's test; * significant at the 5% probability level according to Tukey's test; ns - not significant.

Lower ear length values were observed in T2 (Table 1), a treatment subjected to water deficit during the pollination phase, a stage that determines grain yield. The same occurs for the number of grains produced in each row. Ear length and the number of grains per row are determined in the last weeks before tasseling (MAGALHÃES; DURÃES, 2006). Subjection to stress at this stage reduces the number of grains produced in each row, but the final grain number is determined during and after pollination. According to Cirilo and Andrade (1994), the number of grains per ear in corn depends on the physiological conditions of the plant at flowering. However, climatic conditions during the grain-filling period can affect the production and allocation of photoassimilates for grain formation. Investigations by New, Duthion and Turc (1994) demonstrated that when water deficit occurs together with or after flowering, it significantly affects the reduction in grain number and that the final grain mass is a function of the plant development rate and the duration of the grain-filling period.

The results of the Tukey test ($p \leq 0.05$) indicate that there was a significant difference in grain yield between the treatments subjected to water deficit (Figure 5). The T5 treatment, subjected to water stress at 85 DAP, was the most productive, totaling 8.3 t ha $^{-1}$, which was approximately four times greater than that of the T2 treatment, which had an agricultural productivity of only 2.1 t ha $^{-1}$ (Figure 5). The T1 treatment had no effect, as no ear formation occurred.

Figure 5. Productivity (A) and example of harvested ears (B) of corn grown under water deficit from February to July 2019 in the region of Piranhas, AL.



Treatments T1 and T2 were the most affected, as grain yield was affected by poor synchronization between male and female flowering, which, according to Santos et al. (2020), can lead to yield losses of between 35% and 50% under water stress, with the flowering stage being considered the critical phase for corn. In T2 (water deficit at 55 DAP), the water deficit affected pollination and caused low ear grain size, since, under drought, both the "hairs" and the pollen grains tended to desiccate (MAGALHÃES; DURÃES, 2006). For Durães et al. (2004), only two days of water stress during pollination can reduce yield by more than 20%, and four to eight days can cause losses of more than 50%, as when the grain yield is determined. In T3 (water deficit at 65 DAP), there was a 66% reduction. According to Adebayo et al. (2014), the grain-filling stage is also considered a critical phase for corn, and during this phase, water stress reduces grain yield, potentially resulting in losses of 80%. Unlike the other treatments, T5 produced the highest yield because it was not stressed during the critical phases and received full irrigation, resulting in no reduction in productivity. In a study by Bergamaschi et al. (2004), which evaluated corn yield in two different agricultural years in the Eldorado do Sul region, Rio Grande do Sul, the authors reported that adequate irrigation conditions during the critical period ensured yields close to 8.95 t ha $^{-1}$. Applying a water deficit during this period reduced productivity by more than 80%. Environmental stress at this stage can anticipate the onset of the black layer, an indicator of physiological maturity. The reduction in production, in this case, was related to the mass of the grains and not to the number of grains. At this stage, the grains have an approximately 55% moisture content (MAGALHÃES; DURÃES, 2006).

6 CONCLUSION

– The region's high levels of solar radiation and air temperature do not have much of a negative influence on corn grain production when it is already under severe water stress;

– The occurrence of water stress from the corn tasseling stage causes the plant to not form an ear;

– When water deficit occurs from the pollination phase onward, corn produces poorly formed ears and presents low yield, in addition to a reduction in leaf area and dry matter;

– The suspension of water in the floury grain phase does not compromise the development or productivity of corn.

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