Sunflower performance influenced by water suppression management

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Abstract: Sunflower (*Helianthus annuus* L.) stands out as the oilseed crop with the largest expansion in the world. Thus, the objective of this study was to evaluate the most appropriate moment to suppress irrigation, without hampering the productive and quality aspects of sunflower culture. A randomized experimental design was used with six treatments and four replicates. The treatments consisted on full irrigation of the crop until different days after sowing. Thus, the different times and irrigation doses applied were 45 days and 225.05 mm; 52 days and 290.78 mm; 59 days and 354.83 mm; 66 days and 417.04 mm; 73 days and 480.96 mm; and 80 days and 528.87 mm. At 90 days after sowing, mass of 1000 seeds, productivity, dry mass of the chapter and stem, oil content of the seed and water use efficiency (*WUE*) in the production of seed and oil were analyzed. For the 1000 seed mass variable, a significant effect (p <0.05) of suppression irrigation time was observed according the ANOVA, in which the linear model stood out with the highest R^2. The sunflower productivity was 2,370.30 kg ha^{-1} after 80 days after sowing of suppression of irrigation. The minimum *WUE* was estimated at 3.57 kg ha^{-1} mm^{-1}, which is related to the 71.92-day irrigation suppression, with an accumulated irrigation depth of 475.45 mm, estimated by regression. The maximum *WUE* observed value was 8.46 kg ha^{-1} mm^{-1}. From the results obtained in the experiment, it was possible to conclude that, when irrigation suppression occurs at any stage of the sunflower cycle, all components of crop production tend to be inhibited. The crop has the maximum *WUE* at irrigation suppression on day 45 after sowing, therefore, contributing to a lower water consumption.

Keywords: *Helianthus annus* L., irrigation depth, water use efficiency, productivity

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1 Introduction

The sunflower (*Helianthus annus* L.) has several applications, being a good option for crop rotation as it presents desirable agronomic characteristics, such as a short cycle, adaptability to different edaphoclimatic conditions, wide range of latitude, longitude and photoperiod, resistance to attack by pests and diseases (Silva et al., 2011; Viana et al., 2012). In addition, recent studies on the use of biofuels highlight that sunflower can also be even more useful than is already considered (Lustri et al., 2017). Sunflower oil is considered one of the best in terms of nutritional and organoleptic quality (Embrapa, 2012).

Sunflower is cultivated in almost all the world, as it is a crop that is resistant to weather conditions (dry

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conditions, low temperatures and also to heat), which is why it is highly adaptable to different regions of the world.

The evolution of sunflower crop at global scale and over a long period is quite remarkable, going from 10 Mt for 9.6 Mha in 1975 to 52 Mt for 27 Mha in 2018 (Freitas et al., 2020). Thus, sunflower production grew twice as fast as area, reflecting both a dynamic market and sustained technical progress. On the period 1975 – 2019, the global oilseeds production doubled every 20 years, and sunflower maintained a relatively constant share in the global oilseeds production, between 7% and 10% of the total, presently 9%. (Pilorgé, 2020).

According to Embrapa (2021) the world average of the average crop productivity is 1,300 kg ha^{-1}, being the highest in Switzerland and France 2,700 and 2,500 kg ha^{-1}, respectively, and the lowest in Morocco with 300 kg ha^{-1}.

In relation to the wide use of *Helianthus annus*, Brazil lacks incentive to increase the cropped area, as it still has low expression in the production of sunflower throughout the country, considering that the 2014/2015 crop was estimated at 0.21 kg ha^{-1}, which represented only 0.52% of the world production (Conab, 2015).

The Brazilian Northeast semi-arid region is frequently affected by a low and irregular rainfall regime throughout the year, which considerably affects crop productivity, and therefore irrigation is needed although there are some problems in water supply (Garcia et al., 2007; Silva et al., 2011).

Thus, the suppression of irrigation may be an option for saving water and for planting in arid and semi-arid regions where there are frequent periods of unseasonably warm and dry weather.

Despite irrigation is stopped earlier, there is enough water stored in the soil to attend crop water requirements without reducing its productive potential and the quality of the final product (Duarte et al., 2012). In addition, it reduces pumping costs and improves the crop profitability.

In view of these considerations, the objective of this study was to evaluate the effects of suppression of irrigation on sunflower performance, for the edaphoclimatic conditions of the Ceará (Brazil) coastal region.

2 Material and methods

The experiment was carried out from August to November 2017 in the experimental area of the Agrometereological Station of the Department of Agricultural Engineering (DENA), Federal University of Ceará (UFC), in the city of Fortaleza (State of Ceará, Brazil), located within the geographical coordinates 3º 44’ 45” S and 38º 34’ 55” W at 19.5 m of altitude. According to the Köppen’s climatological classification, the climate of the region is of the Aw’-type, characterized as a rainy tropical, very hot, with predominant rainfall in the summer and fall.

Before the implementation of the experiment, soil samples were collected in the 0.00 - 0.20 m layer, to determine the physical-hydraulic and chemical characteristics (Table 1).

Table 1 Physical-hydric characteristics of the soil in the experimental area, Fortaleza, CE, Brazil, 2017

Physical-hydraulic attributes	Layer (0.00 – 0.20 m)
Coarse sand (%)	41.2
Fine sand (%)	38.2
Silt (%)	11.6
Clay (%)	9.0
Natural clay (%)	7.9
Soil bulk density (g cm^{-3})	1.52
Particle density (g cm^{-3})	2.58
Texture class	Loam-sand
Soil moisture for the matric potential of -0.033 Mpa	6.30
Soil moisture for the matric potential of -1.5 Mpa	4.94
Chemical attributes	**Layer (0.00 – 0.20 m)**
pH (in water)	6.30
OM (g kg^{-1})	7.34
P (mg dm^{-3})	33.0
K (cmol$_c$ dm^{-3})	0.25
Ca (cmol$_c$ dm^{-3})	1.00
Mg (cmol$_c$ dm^{-3})	0.80
Na (cmol$_c$ dm^{-3})	0.12
Al (cmol$_c$ dm^{-3})	0.15
Sum of Bases (cmol$_c$ dm^{-3})	2.20
Cation exchange capacity – CEC (cmol$_c$ dm^{-3})	3.80
Base saturation (%)	58.0
Electric conductivity (dS m^{-1})	0.26

The average weather values collected during the experiment are exposed in Table 2.

Table 2 Monthly average values of average temperature, air relative humidity, wind speed and total monthly rainfall of the experimental period, Fortaleza, CE, Brazil, 2017

Month	Air temperature (ºC)	Relative humidity (%)	Wind Speed (m s^{-1})	Rainfall (mm)
August	26.5	73.0	4.1	16.8
September	26.7	71.0	4.1	12.4
October	27.1	80.0	4.1	3.7
November	27.4	70.0	4.1	1.9
Average	26.9	73.5	4.1	8.7

The sunflower (*Helianthus annuus* L.) cultivated was a simple hybrid BRS 323, produced by EMBRAPA SOY, in Brazil. The seeds were sown manually in planting furrows following the spacing of 1.0 m between rows and 0.2 m between plants, which is equivalent to a stand of 50,000 plants ha^{-1}. The experimental area was 60 m² (25 × 2.4 m), split into four replications of 15 m^2, (6.25 × 2.4 m) as shown in Figure 1. Thinning was carried out manually, leaving only one plant per hole. Water suppression treatments were started on the 45^{th} and ended on the 80^{th} day after sowing (DAS).

The experimental design used was the randomized complete replication, with six treatments and four replications. Treatments in Figure 1 were S45 = 225.05 mm (irrigation up to 45 days after sowing (DAS), S52 = 290.78 mm (irrigation unit 52 DAS), S59 = 354.83 mm (irrigation until 59 DAS), S66 = 417.04 mm (irrigation until 66 DAS), S73 = 480. 96 mm (irrigation until 73 DAS) and S80 = 528.87 mm (irrigation until 80 DAS). The colors indicate the irrigation lines corresponding to the irrigation suppression treatments.

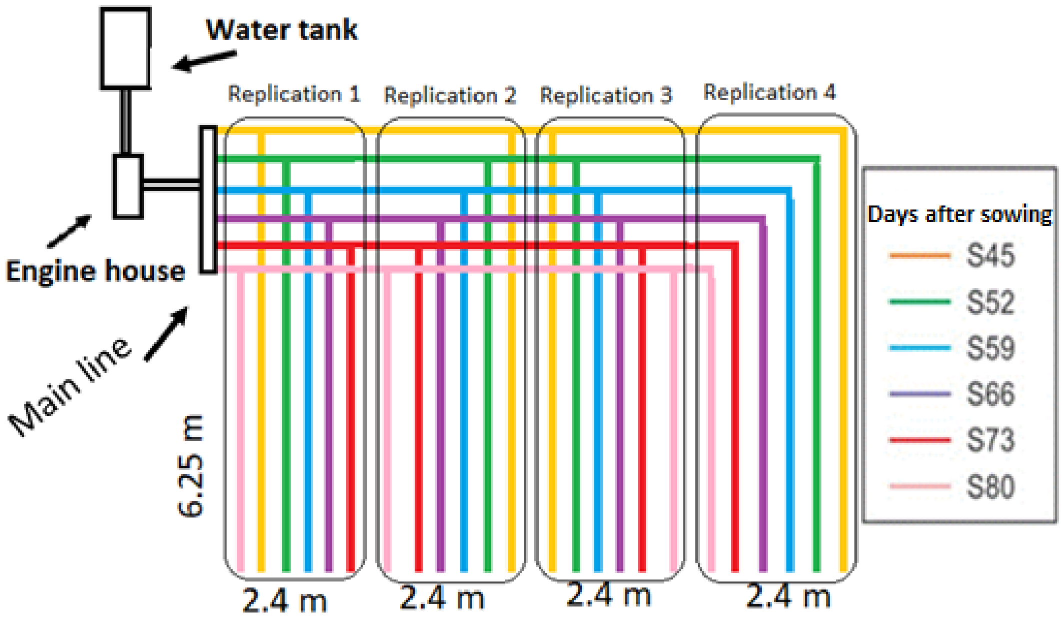


Figure 1 Scheme of the experiment with suppression of irrigation, with six treatments of full irrigation until different days after sowing and four replications

Irrigation was carried out to replace 100% of the crop evapotranspiration. The reference evapotranspiration (*ETo*) was estimated through the "Class A" evaporation pan, according to Doorenbos and Pruitt (1997). The values of the crop coefficients by the growth phases were: initial phase (I) 0.52; vegetative development (II) 0.74; flowering (III) 0.98 and physiological maturation (IV) 0.81, respectively, according to Cavalcante et al. (2013). It was used the drip-irrigation system over the entire cycle of the culture, which was 90 days, using a self-compensating drip tape spaced 0.3 m apart, with a flow rate of 2.5 L h^{-1} and an average service pressure of 147.1 kPa.

Establishment fertilization was carried out with the following quantities of nutrients and commercial sources used at the following proportions: 100 kg ha^{-1} N (Urea - 45% N); 300 kg ha^{-1} P (Simple superphosphate - 18% P_2O_5) and 90 kg ha^{-1} P (Potassium chloride - 60% K_2O).

At sowing, the amount of 30 kg ha^{-1} of a cocktail of micronutrients (FTE BR-12) for soil composed of sulfate oxides was also used, as a source of nutrients (3.9% S, 1.8% B, 2.0% Mn and 9.0% Zz). It should be observed that prior to the fertilization, an irrigation (8.5 mm) was carried out in order to raise the soil moisture to the field capacity.

The topdressing fertilizations were carried out via fertigation, using a 20-L spray volume, necessary for the injection of the nutrient solution and for a better distribution of the fertilizers over the planting area. The injection rate in the irrigation system was 80 L h^{-1}.

At 90 days after sowing, harvest was carried out by randomly removing three plants from the central line of each experimental unit. The evaluated agronomic characteristics of the sunflower were: mass of 1000 seeds (M1000S) according to the rules prescribed in the Rules for Seed Analysis – RAS (Brasil et al., 2009), by means of direct counting and measurement of seed mass, according to Equation 1;

$$M1000S = \frac{SM}{TNS} \quad (1)$$

Where:

M1000S - mass of 1000 seeds (g)

SM - sample mass of seeds (g)

TNS - total number of seeds

The productivity (PROD) was estimated by the product of the average seed mass of three tested plants with the number of plants per hectare, calculated according to the adopted spacing, expressed in kg ha^{-1}.

Head dry mass (DM Head) and stem dry mass (DM STEM), were measured after drying the plant material in a forced air ventilation oven for a period of 72 h at a temperature of 60ºC, until reaching weight constant (Benincasa, 2003).

For measuring the seed oil content (SOC), hexane solvent was used through the Soxhlet method, according to the method suggested by the Brazilian Association of Technical Standards (ABNT) based on NBR 13,348 (ABNT, 1995).

Water use efficiency in seed production (*WUE*) was measured for each treatment using the relationship between the productive potential of seeds in kg ha^{-1} (PPS) and the total water depth applied in irrigation (mm) over the crop cycle, according to Equation 2 proposed by Doorenbos and Kassam (1994), considering the occurrence of rains.

The water use efficiency in oil production (*WUEo*) was measured for each treatment using the relationship between the oil production potential (OPP) for each treatment, expressed in kg ha^{-1} and the total water depth applied to irrigation (mm), over the crop cycle, according to Equation 3 proposed by Doorenbos and Kassam (1994).

$$WUE = \frac{SPP}{W} \quad (2)$$

Where:

WUE – water use efficiency in seed production (kg ha^{-1} mm^{-1})

SPP – seed productive potential (kg ha^{-1})

W – total depth of the water applied over the crop cycle (mm).

$$WUEo = \frac{OPP}{W} \quad (3)$$

Where:

WUEo - water use efficiency in oil production (kg ha^{-1} mm^{-1})

OPP - oil potential production (kg ha^{-1})

Initially an analysis of variance (ANOVA) was performed and, then, for significant data, a regression analysis was carried out at 5% and 1% probability for variables of a quantitative nature, using the computer software ASSISTAT 7.7 (Silva and Azevedo, 2016). The regression study sought to adjust equations with significances and separating the mathematical model that presented the best level of significance and or the highest value for the coefficient of determination (R^2).

3 Results and Discussion

In order to evaluate the behavior of the BRS 323 sunflower hybrid, according to the different periods of irrigation suppression, a regression analysis was applied as the data are shown in Table 3, in which the results of the following variables can be seen: mass of thousand seeds (M1000S), seed oil content (SOC) significant at 5% (p <0.05). On the other hand, productivity (PROD), dry mass of the head (DM Head), dry mass of the stem

(DM Stem), water use efficiency in seed production (*WUE*) and in oil production (*WUEo*) were significant at 1% (p <0.01).

Table 3 Summary of regression analysis for the variables analyzed as a function of irrigation suppression times, Fortaleza, Ceará, Brazil, 2017

SV	DF	MEAN SQUARE						
		M1000S	PROD	DM Head	DM Stem	SOC	*WUE*	*WUEo*
Replication	3	24.16^{ns}	113,411.39^{ns}	58.07^{ns}	74.73^{ns}	243.80^{ns}	3.85^{ns}	0.70^{ns}
Linear regression	1	243.88*	3,973,404.84**	2,588.56**	836.51**	12.77*	28.81^{ns}	38.95*
Quadratic regression	1	30.49^{ns}	25,611.90^{ns}	6.03^{ns}	645.64**	709.84^{ns}	13.27**	11.41**
Residue	15	35.93^{ns}	103,493.28	120.34	59.56	57.81	2.39	1.21
Total	23	-	-	-	-	-	-	-
CV%	-	10.70	18.86	21.11	22.91	16.36	30.00	29.94
SV		*p*-VALUES						
Replication		0.582	0.3814	0.6993	0.3253	0.0238	0.6375	0.2281
Linear regression		0.0153	<0.0001	<0.0001	0.0017	0.7226	0.5987	0.0451
Quadratic regression		0.3558	0.6259	0.7821	0.0047	0.0151	0.0341	0.001

Note: * significant at 5% ($0.01 \leq p < 0.05$) by the F test; ** significant at 1% (p <0.01) by the F test; (ns) non-significant ($p \geq 0.05$) by the F test. SV – Source of variation; DF – Degrees of freedom.

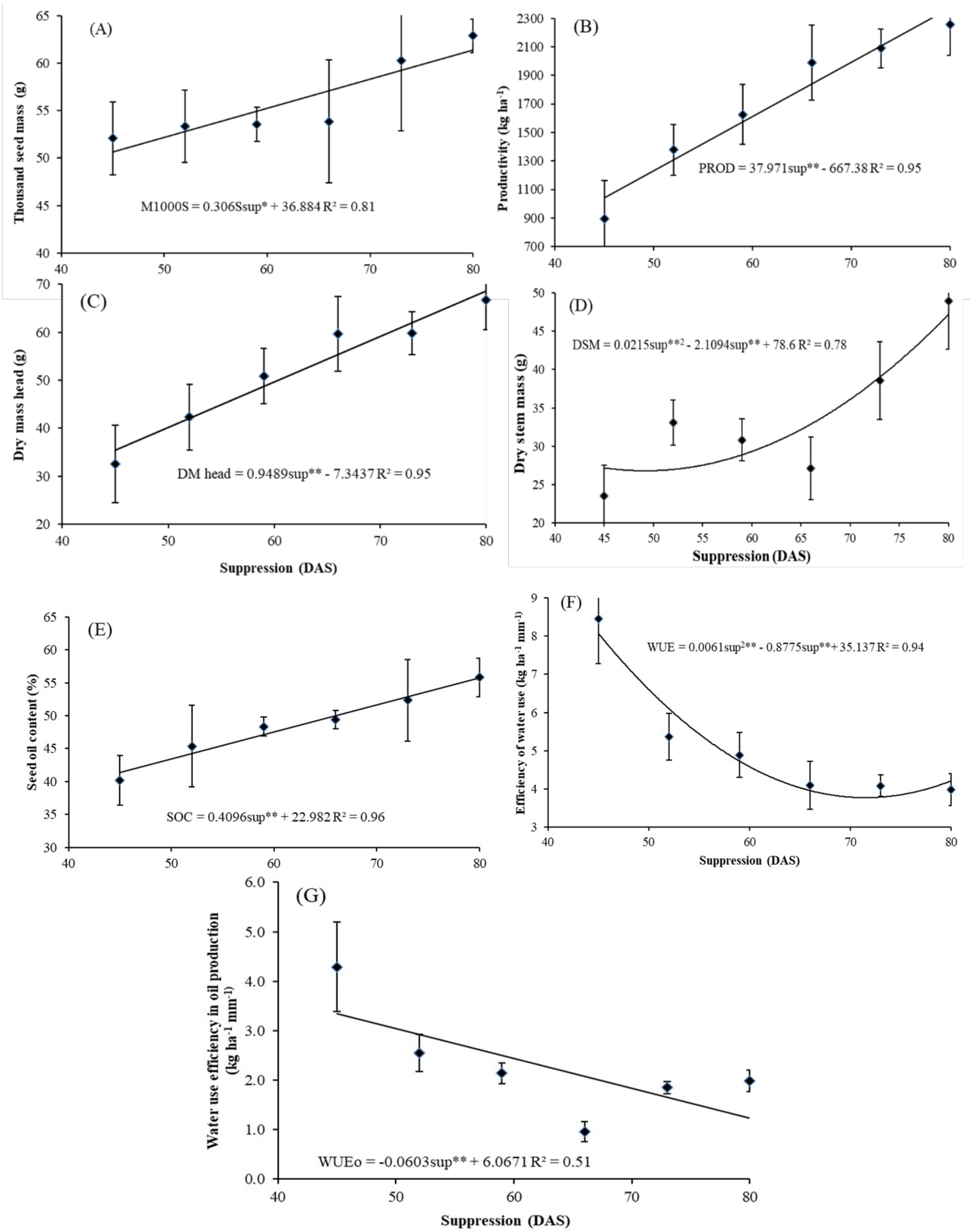
For M1000S, a significant effect (p <0.05) of suppression irrigation time was observed according the ANOVA, in which the linear model stood out with the highest R^2 (Table 3). Therefore, the greatest mass of a thousand seeds reached in the experiment was 61.36 g for the 80 DAS, referring to an accumulated irrigation depth of 528.87 mm corresponding to 100% of ETc, as shown in Figure 2A. However, Bastos et al. (2016) found a quadratic response and a reduction in the weight of 100 seeds (100GW) with the 5.4-day irrigation suppression, whose maximum value was 26.24 g. A similar behavior trend was observed with the weight of one hundred seeds by Azevedo et al. (2014) with the peanut crop, in Fortaleza, Ceará. Other authors such as Schwerz et al. (2015), when analyzing the production of sunflower with or without water supplementation found that when grown in soils without water limitation, the seed mass was not influenced when the crop was established over soybean, corn and grass plant residues. Other tests under water stress in the field were carried out by Freitas et al. (2010) and Viana et al. (2010) with castor bean crop, in which significant effects were observed on the weight of one hundred seeds.

Grain productivity – PROD (Table 3) showed only a significant (p<0.01) linear regression (Figure 2b). There was a linear increase in productivity due to the delay on suppression of irrigation.

It was observed that at 80 days after sowing of suppression of irrigation, there was an increase in productivity, resulting in 2,370.30 kg ha^{-1}. For the suppression of irrigation at 45 days after sowing productivity reached 1,041.35 kg ha^{-1}, resulting in a reduction of 56.07% in relation to the suppression of 80 days. The values obtained in the 80 DAS treatment were well above the average productivity values for the State of Ceará and Brazil, which are 456 kg ha^{-1} and 1,590 kg ha^{-1}, respectively, according to Conab (2015).

When testing different irrigation-suppression periods in the peanut crop, Azevedo et al. (2014) obtained an increase in productivity in the treatment without suppression of irrigation at 90 days after sowing with a higher productivity (1,270 kg ha^{-1}), so that the suppression of irrigation at 45 DAS resulted in productivity of 320 kg ha^{-1}, causing a reduction of 74.43%, which in fact did not occur in this study. Bastos et al. (2016) also in works with beans, found that treatments with 7 and 14 days of irrigation suppression resulted in reductions of 0.10 and 3.07%, respectively, in relation to the maximum point. In addition, reduction increased up to 10.10% at 21 days of irrigation-suppression.

However, Azevedo et al. (2016), when evaluating the effect on the response factor of the sunflower crop to the water deficit, concluded that the water supply equivalent to 79.7% and 91.1% of the crop evapotranspiration (ETc), maximized the commercial productivity of the grain in 3,360 kg ha^{-1}. In addition, the response factor signaled that the sunflower supports daily irrigation with moderate water deficiency.



(a) productivity – PROD (b) dry mass head – DM Head (c) dry stem mass – DSM (d) seed oil content – SOC (e) water use efficiency in seed production – *WUE* (f) water use efficiency in oil production – *WUEo* (g) according to irrigation suppression at different days after sowing (DAS)

Figure 2 Average and standard error bars of treatments for mass of one thousand seeds – M1000S

For the DM Head, the highest value obtained was 68.58 g referring to the 80-day after sowing irrigation suppression, which increased linearly during the time when the crop did not receive irrigation with an increase of 48.39%, between the treatments 80 and 45 DAS, respectively. Consequently, the BRS 323 sunflower hybrid, under the conditions in which the study was developed, performed better with treatments between 45 and 80 DAS, as it can be seen in Figure 2c.

Soares et al. (2015), when assessing the phytomass of sunflower plants grown under different levels of water replacement, found that increasing water depths resulted in an increase in the dry phytomass of the head, which was the best response obtained with 120% of the reference evapotranspiration (ETr). Similar to this result, Nobre et al. (2010) obtained a significant response (p <0.01), with an increase of 6.5% in the fresh phytomass of the head per a unit increase (%) of ETc, reaching a phytomass of 225.71 g with 120%.

Silva et al. (2012) in a study with the sunflower crop in field conditions, also found reductions in this variable when the irrigation deficits and evaluation periods interacted and affected the dry mass of the head. However, Azevedo et al. (2016) observed that in the phenological periods of the sunflower, the water supply maximized the mass of the head in 43.8 g.

It was observed that for minimum dry mass of the stem (DM Stem), a quadratic polynomial model was significant (Table 3), having a coefficient of determination (R^2) of 0.78 (Figure 2d). The DM Stem was estimated at 26.86 g, with an irrigation suppression at 49.05 days calculated and estimated according to the regression equation, relative to an accumulated depth equivalent to 245.32 mm, estimated by the equation of Figure 2d, demonstrating that this is not the most opportune time to suspend irrigation in the BRS 323 hybrid sunflower crop. This may be a critical stage of the plant, so, in this phase, the water supply must be maintained, to guarantee the crop production.

Corroborating these results, Dutra et al. (2012), when studying the growth of sunflower plants under different levels of water in the soil, observed that the DM Stem showed better performance when submitted to 80% to 100% of the water retention capacity (WRC) in the soil, so that the values at 60% of WRC caused a reduction of approximately 300% in relation to the WRC-80% treatment. When evaluating the interaction between water deficit and the evaluation periods in the sunflower crop, Silva et al. (2012) also found a significant effect for DM Stem.

The supply of water in a satisfactory and well distributed portion over the crop cycle is vital, and may be up to 90% of the fresh mass of the plants. This regularity is healthy and important in plant metabolism (Taiz and Zeiger, 2009). Moreover, it is important to emphasize that the excess of water is also harmful.

For the seed oil content (SOC), the increasing linear model was shown as the most appropriate and with significant by test linear regression (p <0.05) as it can be seen in Table 3. It was observed that for this variable in the period of water suppression in the 45 DAS treatment, the lowest value of 41.43% was obtained in oil content, while for 80 DAS treatment, it reached the highest value of 55.75% in oil content, as shown in Figure 2e.

The lower values of the oil content found in the 45 DAS treatment, may be certainly linked to the occurrence of water deficit in causing the stomata to close (guard cells), consequently affecting the gas exchange (O_2 emission and CO_2 absorption) in the performance of respiration and photosynthesis (assimilation of photosynthesis) with reduced seed filling and, on the other hand, granting a lower production of oil content.

These values were higher than those obtained by Sousa et al. (2011), where it was reached a lower oil content (20.52%) in the treatment of replacement of water consumption by the plant of 25%, a higher oil content (31.33%), referring to the treatment of water replacement of 1.25 in the jatropha treatment. However, Duarte et al. (2012) observed in the sunflower crop that the treatment with no water suspension provided a higher oil content of the seeds with a value of 37.70% and the suppression of irrigation at 65 DAS resulted in a lower value with 33.25 %, a trend that corroborates the present study as the lower the water suppression, the greater the amount of oil produced in the sunflower crop (Figure

2e).

Evangelista et al. (2013), in a study with jatropha with and without water replacement, found that SOC were 34% and 27%, respectively. These results differed from those of this experiment, which were 51.7% and 41.4% for treatments with 10 and 45 days of water suppression, respectively.

Regarding *WUE*, there was significant quadratic regression (Figure 2f), for the period of suppression of irrigation studied. Such observations are in accordance with the results obtained by Duarte et al. (2012) when demonstrating that the efficiency of water use in seed production was significantly affected by the different periods of irrigation suppression.

The BRS 323 hybrid sunflower presented an average daily water uptake during the experiment of 5.00; 5.59; 6.01; 6.31; 6.58 and 6.61 mm day^{-1} for the accumulated irrigation depths of 225.05; 290.78; 354.83; 417.04; 480.96 and 528.87 mm, corresponding to the suppression periods at 45, 52, 59, 66, 73 and 80 DAS, respectively.

The minimum *WUE* was estimated at 3.57 kg ha^{-1} mm^{-1}, which is related to the 71.92-day irrigation suppression estimated by the quadratic regression equation, with an accumulated irrigation depth of 475.45 mm. The maximum observed value was 8.46 kg ha^{-1} mm^{-1}.

Therefore, it is observed a reduction in the efficiency of water use in the production of seeds with the application of reductions in the irrigation-suppression periods in such a way that the highest values for the variable in question were obtained with the increase in the irrigation-suppression periods, which is similar to the data of Duarte et al. (2012) when they specify that in most cases, the increase in the efficiency of water use is achieved as a result of the decrease in the amount of water applied. These results also support those obtained by Silva et al. (2011).

The examination in the efficiency of water use in seed production (*WUE*) allows to clearly observe that the different periods of suppression of irrigation significantly influenced this variable at the level of 1% probability (Table 3), in agreement with the efficiency of the use of water in seed production.

These results corroborate those reported by Duarte et al. (2012) when examining the statistically significant difference due to the suspension of irrigation applied to the sunflower crop for the efficiency of water use in oil production.

The effect of different periods as a function of the suppression of irrigation on the WUEo was also better represented by a linear mathematical model for the BRS 323 sunflower hybrid, with significant effects (p <0.05) according to Table 3 and the determination coefficient of 0.51, this greater than that of the quadratic equation (Figure 2g).

According to this mathematical model, the minimum *WUEo* was estimated as 1.27 kg ha^{-1} mm^{-1}, referring to the suppression of irrigation at 68 DAS with an accumulated irrigation depth of 435.30 mm. The maximum observed value was 4.18 kg ha^{-1} mm^{-1} for the 45 DAS treatment.

Thus, similar to what occurred with *WUE*s, a reduction was also found in WUEo with the application of the decreasing periods of irrigation-suppression in such a way that the highest values for this variable were achieved with the applications of the shortest periods of irrigation-suppression, which also corroborates the results of Duarte et al. (2012) when they mentioned that almost always, the efficiency of the water use to produce oil increased as the sunflower crop was exposed to water restriction.

On the other hand, Silva et al. (2011) mentioned that the greatest efficiencies of the water use in the production of sunflower oil were achieved with the application of the lowest irrigation depth, confirming the results exposed in the present work. In studies carried out with other crops, (Marinho et al., 2009; Angeli et al., 2016) found higher values for water use efficiency from smaller water depths.

4 Conclusion

The components of sunflower production tend to be inhibited when irrigation is suppressed at any stage of the crop cycle.

The plants in the treatment with irrigation suppression at 80 days after sowing showed best results for the analyzed variables.

The maximum efficiency of water use in irrigation suppression is reached at 45 days after the sunflower sowing. The best response for the evaluated variables ranging from 528.87 to 480.96 mm, is obtained in the irrigation-suppression interval between 80 and 73 days after sowing.

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