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Production and yield response factor of sunflower under different irrigation depths

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Helianthus annuus
water requirement
drip irrigation

ABSTRACT
Local information about irrigation depths for sunflower can be used in the design of projects and irrigation management to increase crop yield and to reduce costs. This study aimed to evaluate the effects of irrigation depths on sunflower and calculate its yield response factor. The experiment was conducted in Fortaleza-CE, Brazil, in a randomized block design, with six treatments, four replicates and ten evaluated plants per plot. The treatments were applied in the phenological stages II, III and IV with irrigation depths equivalent to 25, 50, 75, 100, 125 and 150% of crop evapotranspiration. The yield response factor was calculated according to FAO Bulletin nº 33. The water supply, equivalent to 79.7 and 91.1% of crop evapotranspiration, increased capitulum mass (43.8 g) and commercial yield of seeds (3,360.2 kg ha^{-1}). Additionally, the yield response factor indicated that sunflower is tolerant to daily irrigation under controlled water deficit.

Palavras-chave:
Helianthus annuus
necessidade hídrica
gotejamento

Produção e fator de resposta do girassol a distintas lâminas de irrigação

RESUMO
Informações localizadas sobre lâminas de irrigação na cultura do girassol podem ser utilizadas na elaboração de projetos e no manejo de irrigação para aumentar o rendimento e reduzir custos. Neste contexto a finalidade do trabalho foi avaliar o efeito de lâminas de rega sobre a produção do girassol e sobre o fator de resposta da cultura ao déficit de água. O experimento foi realizado em Fortaleza, Ceará, seguindo o delineamento em blocos casualizados, com seis tratamentos, quatro repetições e parcelas com dez plantas úteis. Os tratamentos foram diferenciados nos estádios fenológicos II, III e IV com lâminas diárias correspondentes a 25, 50, 75, 100, 125 e 150% da evapotranspiração da cultura. O fator de resposta foi estimado pela metodologia do Boletim 33 da FAO. Neste período fenológico o suprimento hídrico, equivalente a 79,7 e 91,1% da evapotranspiração da cultura, maximizou a massa do capítulo (43,8 g) e a produtividade comercial das sementes (3.360,2 kg ha^{-1}). Ademais, o fator de resposta indicou que o girassol é tolerante à irrigação diária com déficit hídrico controlado.

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Introduction

Water availability is one of the main production factors for sunflower, and its production is influenced by irrigation depths (Gomes et al., 2012). The applied irrigation depths must be adequately quantified; otherwise, they may negatively affect the crop through water deficit or excess. Water deficit compromises photosynthesis, stomatal conductance and transpiration, reducing plant biomass (Duarte et al., 2012). The reduction in phytomass (Silva et al., 2012) and leaf area (Alahdadi et al., 2014) consequently decrease crop yield. Water excess reduces the oxygen for the roots (Bassegio et al., 2012), affects the absorption of nutrients and water through the lack of energy (Dutra et al., 2012) and leaches the salts of the soil (Wan et al., 2013).

Sunflower has great variability of water depth to maximize its yield. Such variability occurs even within the same state. In Pentecoste (Silva et al., 2011), Baixo Jaguaribe Valley (Viana et al., 2012) and Aquiraz (Bezerra et al., 2014), in the state of Ceará, 533.7, 807.1 and 296.6 mm were respectively, necessary to maximize the yield of seeds. This variation in the results, for suffering the influence from various factors (e.g. soil, climate, irrigation, fertilization), reinforces the importance of local experiments, which can provide general information for a certain region when analyzed together.

In regions with scarcity of water resources, the deficient water supply for sunflower has been studied in order to know its sensitivity and plan a specific irrigation strategy (Silva et al., 2014). The response factor Ky is the coefficient that indicates such sensitivity. This coefficient, for suffering the influence from various production factors (e.g. genotype and irrigation) also requires local adjustments (Steduto et al., 2012).

Considering the importance of irrigation for the sunflower cultivated in the coastal region of Ceará, this study aimed to differentiate water depths in the phenological stages II, III and IV in order to evaluate their effects on its production and on the response factor to water deficit.

Material and Methods

The study was carried out from August 24 to December 17, 2007, in the experimental area of the Federal University of Ceará, in Fortaleza-CE, Brazil (3° 44' S; 38° 33' W; 19.50 m), under a tropical rainy climate ('Aw'), tropical savanna, with the driest period in the winter and maximum of rains in the summer-autumn (Köppen, 1931).

The agrometeorological data recorded during this period are shown in Figure 1.

The physical chemical characteristics of the Red Yellow Argisol (EMBRAPA, 2006) in the layer of 0-0.20 m were: fine sand (360 g kg^{-1}); coarse sand (480 g kg^{-1}); silt (90 g kg^{-1}); clay (70 g kg^{-1}); natural clay (30 g kg^{-1}); specific mass (1.42 g cm^{-3}); flocculation (57 g 100 g^{-1}); textural class (loamy sand); K^+ (1.0 cmolc dm^{-3}); Na^- (0.43 cmolc dm^{-3}); Ca^{2+} (17.0 cmolc dm^{-3}); Mg^{2+} (7.0 cmolc dm^{-3}); Al^{3+} (0.05 cmolc dm^{-3}); $pH_{1:0.25}$ in water (7.20); EC (0.27 dS m^{-1}). P, K and Na were extracted using Mehlich 1 and Al, Ca and Mg, using KCl.

Irrigation was performed using a surface drip system,

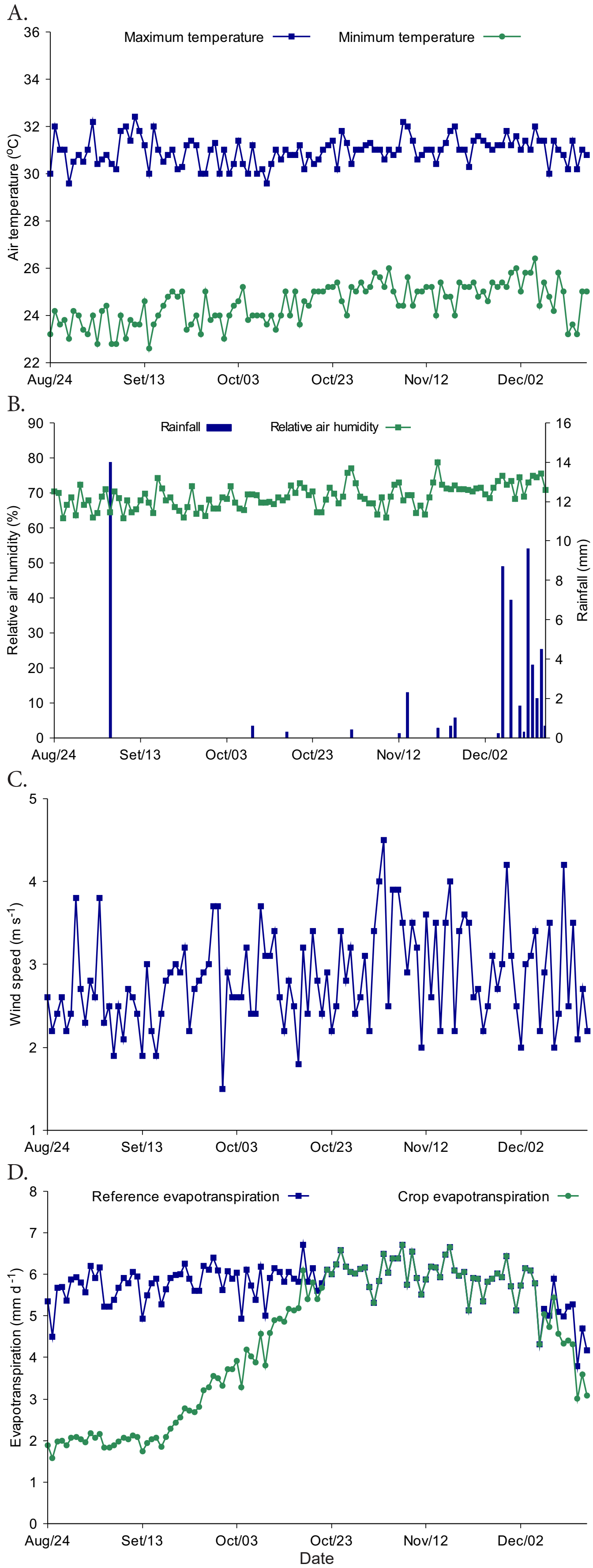


Figure 1. Daily mean values of maximum and minimum air temperature (A), rainfall and relative air humidity (B), wind speed (C) and reference (Penman-Monteith) and crop (estimated with Kc of Allen et al., 2006), evapotranspiration, during the cycle of sunflower cv. 'Catissol 01'

with 4-m-long lateral lines (LDPE DN16), spaced by 1.0 m. Pressure-compensating drippers with flow rate of 2.0 L h^{-1} at 100 kPa were placed every 0.50 m.

'Catissol 01' sunflower was sown directly in the field on August 18, 2007, in 0.05-m-deep holes spaced by 0.20 m. Planting followed a randomized block design, with six treatments per block, four blocks and 2.0-m^2 plots containing 10 plants for evaluation. The treatments consisted of irrigation depths based on 25, 50, 75, 100, 125 and 150% of crop evapotranspiration, differentiated during the phenological stages II, III and IV.

Irrigations were daily managed according to the sequential climatological water balance, simplified in Eq. 1.

$$LL = ETc - Pe \tag{1}$$

where:

LL - net irrigation depth, mm;
ETc - crop evapotranspiration (Eq. 2), mm; and,
Pe - effective rainfall, mm.

$$ETC = EToPM \times Kc \times Kr \tag{2}$$

where:

EToPM - reference evapotranspiration of Penman-Monteith, mm;
Kc - crop coefficient, dimensionless; and,
Kr - reduction coefficient (Keller & Karmeli, 1974), dimensionless.

Pe, calculated through the method of the Soil Conservation Service of the United States (Smith, 1992), was not accumulated for the irrigation on the next day (Pe ≤ ETc). EToPM was estimated using daily data of an automatic weather station (Allen et al., 2006). Kc was equal to 0.35 in stage I, 0.35-1.0 (interpolated) in stage II, 1.0 in stage III and 1.0-0.35 (interpolated) in stage IV (Allen et al., 2006). The cover factor in the reduction coefficient was considered as 1.

The gross irrigation depth was estimated according to Eq. 3.

$$LB = LL\left(\frac{TR}{EF}\right) \tag{3}$$

where:

LB - gross irrigation depth, mm;
LL - net irrigation depth, mm;
TR - irrigation interval, day; and,
EF - water application efficiency, %.

EF was estimated through the product between the coefficients of uniformity (Christiansen's) (90%) and soil transmissivity (tabulated, equal to 0.95) for arid climate, sandy soil and root depth from 0.7 to 1.5 m. Both coefficients were obtained according to the methodology of Keller & Karmeli (1974).

The total water depth used to meet sunflower water requirements was calculated based on the sum of effective rainfall and net irrigation depth, because, in this case, the gross irrigation depth only guaranteed its adequate application.

Thus, until 25 days after germination (September 17, 2007), in the phenological stage I, plants of all the treatments were subjected to a total water depth corresponding to 100% ETc (57.2 mm). After this period (September 18 to December 17, 2007) in the phenological stages II, III and IV, the treatments were differentiated with total depths equivalent to 25% ETc (131.0 mm), 50% ETc (236.9 mm), 75% ETc (344.2 mm), 100% ETc (452.7 mm), 125% ETc (561.6 mm) and 150% ETc (671.6 mm).

Fertilization was performed based on soil analysis, using the macronutrients N-P-K in the formulation 60-70-50 kg ha^{-1}. The following fertilizers were used: urea, single superphosphate and white potassium chloride. All the phosphorus was supplied in basal application and the other nutrients were fertigated in eight weekly applications, from planting.

Sunflower harvest occurred on December 17, 2007, when the back of the capitula was yellow and the bract was brownish.

The following variables were analyzed: capitulum diameter (CD), capitulum mass (CM) and commercial yield (CY). CD, measured with a digital caliper (0.01-mm resolution), was estimated by the arithmetic mean for each plot. CM, determined on a precision scale (0.01-g resolution), was calculated by the arithmetic mean of each plot. CY was estimated by extrapolating the mass of the capitula of the plots.

The mean values of the variables were subjected to analysis of variance of the regression (p-value ≤ 0.05), testing linear and quadratic polynomial models.

Sunflower water use efficiency was estimated based on Eq. 4.

$$WUE = \frac{Y}{W} \tag{4}$$

where:

WUE - water use efficiency, kg ha^{-1} mm^{-1};
Y - commercial yield, kg ha^{-1}; and,
W - total water depth in the phenological stages II, III and IV, mm.

The crop yield response factor was estimated according to Doorenbos & Kassam (1979) (Eq. 5).

$$\left(1-\frac{Yr}{Ym}\right) = Ky\left(1-\frac{ETr}{ETm}\right) \tag{5}$$

where:

Ky - crop yield response factor to water deficit, dimensionless;
Yr - real yield, kg ha^{-1};
Ym - maximum yield, kg ha^{-1};
ETr - real evapotranspiration, mm; and,
ETm - maximum evapotranspiration, mm.

The maximum values of yield and evapotranspiration were obtained with total water depths equivalent to 100% ETc, while the real values with total water depths equivalent to 25, 50 and 75% ETc. After calculating Ky for the deficit interval selected in the present study (25 to 75% ETc), it was estimated for the interval of 50 to 100% ETc, proposed in the FAO Bulletin nº 33.

In order to form this interval, the following deficits were selected: 50, 60, 70, 80 and 90% ETc. The values of irrigation depth and yield of these deficits were calculated by the relationship 'total water depth vs ETc' ($\hat{y} = 4.3264 + 21.1066\ x$) and 'commercial yield vs % ETc' ($\hat{y} = 239.19 + 68.549\ x - 0.3764\ x^2$). Maximum values were considered as those at the optimal water depth of 91.1% ETc and the real ones, those estimated in the other treatments.

The Ky for the entire deficit interval was obtained through linear regression, adjusted through the origin, between the reduction in relative yield and deficit of relative evapotranspiration. Ky was considered as the angular coefficient of the regression equation, as recommended by Bilibio et al. (2010).

Sunflower sensitivity to water deficit was classified by the FAO Bulletin nº 66 as: 'very sensitive' (Ky > 1) 'proportionally sensitive' (Ky = 1) and 'little sensitive' (Ky < 1) (Steduto et al., 2012).

Results and Discussion

The summary of the analysis of variance shows that the capitulum diameter was not significantly influenced by the treatments, contrary to the variables capitulum mass and commercial yield, which showed a quadratic variation pattern validated by the coefficient of determination and Student's t-test (Table 1 and Figure 2).

At the inflection point of the regression curve, the maximum value of capitulum mass (43.8 g) was estimated with 79.7% ETc or 365.9 mm of water (Figure 2A). The other treatments, 25, 50, 75, 100, 125 and 150% ETc, reduced this variable by 20.4, 6.0, 0.15, 2.8, 14.0 and 33.8%, respectively. The highest reductions, with 25 and 100% ETc, must have damaged the crop through the more pronounced negative effect of water deficit and excess.

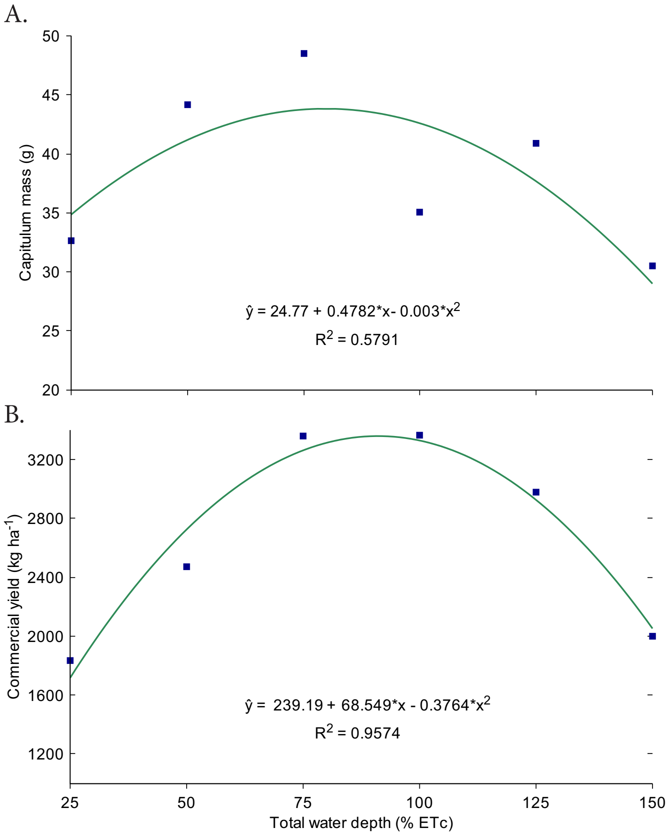
Studies with irrigation depths in sunflower show that water levels above (Silva et al., 2011) and below (Nobre et al., 2010) that required by the crop significantly harm the mass of capitulum.

The value of maximum technical efficiency of the commercial yield (3,360.2 kg ha^{-1}) was estimated at the inflection point of the regression curve with 91.1% ETc or 415.2 mm of water (Figure 2B). The percent yield reductions promoted by the treatments 25, 50, 75, 100, 125 and 150% ETc were respectively of 48.8, 18.8, 2.8, 0.9, 12.9 and 38.9%.

Table 1. Summary of the analysis of variance for the variables of production of seeds of sunflower cv. 'Catissol 01'

Source of variation	DF	Mean square		
		Capitulum diameter (cm)	Capitulum mass (g)	Commercial yield (kg ha^{-1})
Treatment	5	2.04$^{(ns)}$	198.19*	1,792,069*
Block	3	0.24$^{(ns)}$	52.27$^{(ns)}$	149,881$^{(ns)}$
Residue	15	0.89	23.68	67,539
Total	23	-	-	-
CV (%)	-	11.34	12.60	9.74
Mean	-	8.3	38.6	2,669.0
Linear model	1	-	169.41$^{(ns)}$	453,062$^{(ns)}$
Quadratic model	1	-	688.15*	2,824,470*

* significant at 0.05 by F test; $^{(ns)}$ not significant at 0.05 by F test



*Significant at 0.05 by Student's t-test

Figure 2. Capitulum mass (A) and commercial yield (B) of seeds of sunflower cv. 'Catissol 01' as a function of the total water depth in the phenological stages II, III and IV, obtained with 25, 50, 75, 100, 125 and 150% of crop evapotranspiration (ETc)

As observed for the capitulum mass, the treatments with extreme total water depths, 25 and 150% ETc, for intensifying the harmful effects of water deficit and excess on the crop, were responsible for the worst results.

In other experiments with irrigation depths, yield reduction is normally more pronounced in treatments with higher water scarcity for the crop (Silva et al., 2011). Its harmful effects, for morphologically affecting sunflower (Soares et al., 2015) in any development stage (Silva et al., 2012), ultimately have a negative effect on yield (Viana et al., 2012). Water excess is another factor to be avoided, because it also has deleterious effects on crop production (Loose, 2013).

The water supply, when there is no restriction to the use of water, must replenish crop requirements completely to maximize the production (91.1% ETc). Otherwise (occurrence of drought, dry spell, high water cost etc.), it must be provided to maximize water use efficiency.

In sunflower, this efficiency had a decreasing linear pattern with the increment in water supply, which indicates the tolerance of the crop to water stress (Figure 3).

The maximum value of efficiency was promoted by the extreme deficit of water depth (25% ETc). This value, although high, is not interesting for sunflower, because it reduced 48.8% of the maximum commercial yield.

Less severe deficits, such as 50 and 75% ETc, also caused high efficiency; however, with less intense harmful effects. The least harmful effect was caused by the treatment of 75% ETc,

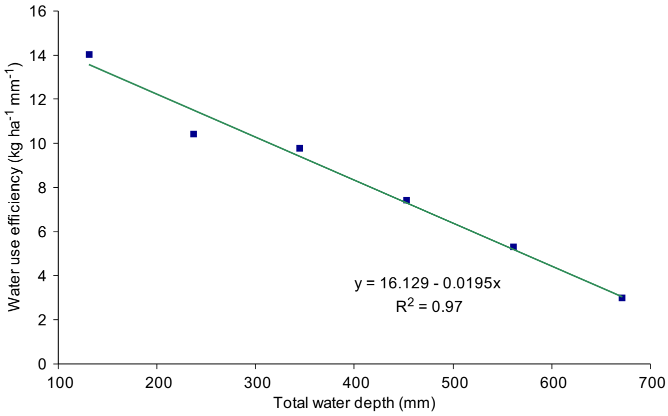


Figure 3. Water use efficiency of sunflower cv. 'Catissol 01' as a function of the total water depth in the phenological stages II, III and IV, obtained with 25, 50, 75, 100, 125 and 150% of crop evapotranspiration

since its commercial yield was only 2.8% lower than that in the optimal treatment (91.1% ETc). This fact indicates that the strategy of deficit irrigation with up to 75% ETc could be used daily in sunflower, with minimum impacts on production.

Sezen et al. (2011) claim that weekly sprinkler and drip irrigations, replenishing only 50% of the water available in the soil, may be appropriate for the conditions of Tarsus, Turkey. Silva et al. (2013) highlights that, in Pentecoste-CE, the gas exchanges of sunflower tolerate irrigations with 50% ETo without damages to the photosynthetic process. In the present experiment, 50% ETc could be used in deficit irrigations; however, it must be considered the reduction of 18.8% in the optimal yield.

The water use efficiency in the treatments 100, 125 and 150% ETc was more reduced. In these treatments, part of the water supplied to the crop was not converted into production of seeds.

The reduction in sunflower yield was less than proportional to the decrease in water use, since all the Ky values were lower than 1 (Table 2).

The 75% ETc treatment, with maximum yield close to that in the 100% ETc treatment, almost did not suffer negative influence of water deficit (Ky = 0). However, the treatments of 50 and 25% ETc showed Ky 44 and 36% lower than the limit that indicates sensitivity. In the regression equation, the Ky of 0.59 was 41% lower than the unit value (Figure 4A). These results show the low sensitivity of the crop to the daily water deficit.

In the range from 50 to 100% ETc, Ky values remained low (Table 3). The decrease in Ky in Figure 4B was 37.2% higher than in Figure 4A, because the treatment that most affected the crop negatively (25% ETc) was disregarded.

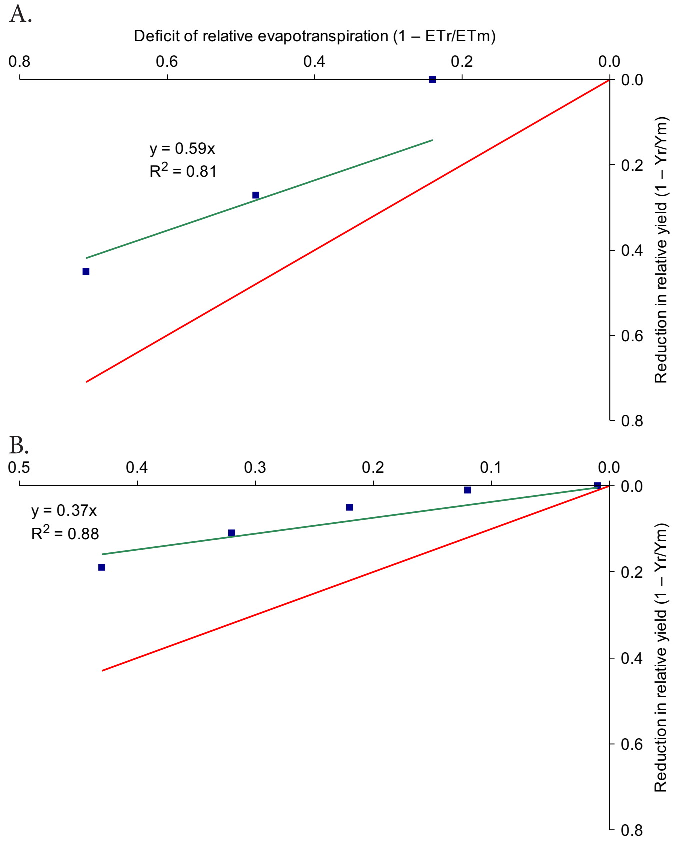


Figure 4. Response factor (Ky) in the phenological stages II, III and IV of sunflower cv 'Catissol 01' for the treatments obtained with 25, 50 and 75% ETc (A) and estimated with 50, 60, 70, 80 and 90% ETc (B)

Table 2. Real evapotranspiration (ETr), maximum evapotranspiration (ETm), deficit of relative evapotranspiration (1-ETr/ETm), real yield (Yr), maximum yield (Ym), reduction in relative yield (1-Yr/Ym) and crop yield response factor to water deficit (Ky) in the phenological stages II, III and IV of sunflower cv. 'Catissol 01'

Treatment	ETr (mm)	ETm (mm)	(1 - ETr/ETm)	Yr (kg ha^{-1})	Ym (kg ha^{-1})	(1 - Yr/Ym)	Ky
25% ETc	131.0	452.7	0.71	1,836.9	3,364.9	0.45	0.64
50% ETc	236.9	452.7	0.48	2,471.2	3,364.9	0.27	0.56
75% ETc	344.2	452.7	0.24	3,362.1	3,364.9	0.00	0.00

ETc: crop evapotranspiration

Table 3. Estimated values of real evapotranspiration (ETr), maximum evapotranspiration (ETm), deficit of relative evapotranspiration (1-ETr/ETm), real yield (Yr), maximum yield (Ym), reduction in relative yield (1-Yr/Ym) and response factor to water deficit (Ky) in the phenological stages II, III and IV of sunflower cv. 'Catissol 01'

Treatment	ETr (mm)	ETm (mm)	(1 - ETr/ETm)	Yr (Mg ha^{-1})	Ym (Mg ha^{-1})	(1 - Yr/Ym)	Ky
50% ETc	237.4	415.2	0.43	2,725.6	3,360.1	0.19	0.44
60% ETc	280.7	415.2	0.32	2,997.0	3,360.1	0.11	0.33
70% ETc	324.0	415.2	0.22	3,193.2	3,360.1	0.05	0.23
80% ETc	367.2	415.2	0.12	3,314.1	3,360.1	0.01	0.12
90% ETc	410.5	415.2	0.01	3,359.7	3,360.1	0.00	0.01

ETc: crop evapotranspiration

According to the FAO Bulletin nº 66, the crop is considered as ‘little sensitive’ to water deficit, since all the Ky values were lower than 1. The tolerance to drought of this crop is due to its great capacity to extract water from the subsoil, because it can regulate gas exchanges and adapt the development of leaf area to the scarcity of water (Steduto et al., 2012).

Regarding the present study, in the literature there are agreements (Ky < 1) (Silva et al., 2014) and divergences (Ky > 1) (Sezen et al., 2011), with respect to the tolerance of sunflower. However, Steduto et al. (2012) explain that these differences result from the particular conditions (climate, soil, irrigation, nutrition etc.) of each experiment.

Conclusions

1. The sunflower crop cultivated under the edaphoclimatic conditions of the coastal region of Ceará can be irrigated with 100% ETc until 25 days after germination and with 91.1% ETc until harvest, in order to maximize the commercial yield of seeds.

2. For being considered as tolerant to water deficit in the phenological stages II, III and IV (Ky < 1), sunflower can be included in strategies of controlled deficit irrigations.

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