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Evapotranspiration, crop coefficient and water use efficiency of onion cultivated under different irrigation depths[1]

Evapotranspiração, coeficiente de cultivo e eficiência do uso da água da cebola sob diferentes lâminas de irrigação

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HIGHLIGHTS:

Irrigation with 75 and 50% of water replacements are efficient alternatives for onion crops in the Brazilian semiarid region.
Irrigation with 50% of water replacements was the one with the highest water use efficiency.
Onion crops under high water stress have unregulated crop evapotranspiration during the growth phases.

ABSTRACT: This study aimed to determine crop evapotranspiration through the soil water balance, the crop coefficient and water use efficiency of the onion (*Allium cepa* L.) in a system with four irrigation regimes, cultivated in the semiarid region of northeastern Brazil. Two field experiments were carried out during the rainy and dry periods of the region in 2018, using the treatments of 100% (T1), 75% (T2), 50% (T3) and 25% (T4) of the reference evapotranspiration for daily water replacement and five replicates for each treatment. It was verified that crop evapotranspiration varies according to the water availability in the soil; however, the highest water use efficiency occurred for the T3 treatment. The T1 treatment obtained the highest estimated yield, 43.86 tons ha^{-1}, while T4 obtained 13.47 tons ha^{-1}, the lowest estimated yield among the treatments, and this difference was statistically significant ($p \leq 0.05$) by F test. The crop coefficients obtained were 0.68, 0.89, 0.99 and 0.73 for the initial, vegetative, bulbing and maturation stages, respectively.

Key words: *Allium cepa* L., soil water balance, water need

RESUMO: Este estudo objetivou determinar a evapotranspiração da cultura através do balanço de água no solo, o coeficiente de cultivo e a eficiência do uso da água da cebola (*Allium cepa* L.) em um sistema com quatro regimes de irrigação, cultivada no semiárido nordestino. Foram realizados dois experimentos de campo durante os períodos chuvoso e seco da região no ano de 2018, utilizando-se os tratamentos de 100% (T1), 75% (T2), 50% (T3) e 25% (T4) da evapotranspiração de referência para reposição hídrica diária e cinco repetições para cada tratamento. Verificou-se que a evapotranspiração da cultura varia de acordo com a disponibilidade hídrica no solo, entretanto, a maior eficiência do uso da água ocorreu para o tratamento T3. O tratamento T1 obteve a maior produtividade estimada em 43.86 tons ha^{-1} e T4 com 13.47 tons ha^{-1}, a menor produtividade estimada entre os tratamentos. Essa diferença foi estatisticamente significativa ($p \leq 0,05$) pelo teste F. Os valores do coeficiente de cultivo obtidos foram de 0,68; 0,89; 0,99 e 0,73 para as fases inicial, vegetativo, bulbificação e maturação, respectivamente.

Palavras-chave: *Allium cepa* L., balanço hídrico do solo, necessidade hídrica

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Introduction

The use of water resources is mostly directed to agricultural activity, since in recent decades irrigated agriculture is used worldwide, especially in areas with dry climate and water scarcity. Therefore, placing sustainability and water saving as protagonists in agriculture has become a challenge, as it is necessary to adopt strategic measures for the management and preservation of this resource, in addition to compatibility with food production and demand (Nurga et al., 2020; Rodrigues, 2020).

The Brazilian semiarid region fits in characteristics such as low agricultural productivity and low agricultural land suitability, and these conditions are mainly explained by the predominant climate of the region, with historical series of prolonged droughts, in addition to irregular spatial distribution of rainfall, bringing water restriction as the biggest limiting factor for agriculture in the region (IPEA, 2018).

Currently, several irrigation methods for onion (*Allium cepa* L.) crops can be used, such as conventional sprinkler, furrow irrigation, center pivot, micro sprinkler and drip irrigation, the latter being one of the most efficient, due to its ease of operation, saving labor, energy and water, in addition to the important positive points: good control of soil moisture and aeration and greater phytosanitary control (Vilas Boas et al., 2011).

In this context, the present study aimed to determine the crop evapotranspiration through the water balance method, used by several authors (Silva et al., 2015; Ferreira et al., 2015; Santana et al., 2016; Alves et al., 2019); the crop coefficient and the water use efficiency of onions cultivated in a system with different irrigation regimes, in the semiarid region of northeastern Brazil, in order to analyze the limits of the onion crop water demand with the respective productivity levels.

Material and Methods

The study was carried out at Experimental Agrometeorological Station - EstAgro/DCA of the Universidade Federal de Campina Grande - UFCG, located in the municipality of Campina Grande, State of Paraíba, Brazil. The local vegetation belongs to the semiarid region, specifically in the eastern part of the Borborema Plateau, with latitude of 07° 13’ 50” S, longitude of 35° 52’ 52” W, and altitude of 546 m above sea level.

The accumulated precipitation during the experimental period was 86.4 mm in the first cycle, between April and July, decreasing considerably to 8.6 mm during the second cycle, between August and November, according to Table 1. This marked difference was caused by the distribution of rain in the region that characterizes the rainy season during autumn and winter and the dry period in spring and summer, respectively.

The study was conducted through two cycles of ‘Vale Ouro IPA 11’ onion, the first cycle lasted 90 days (from 04/27/2018 to 07/25/2018) and the second cycle lasted 83 days (from 08/29/2018 to 11/19/2018). The field experiment with onion was carried out in four plots with dimensions of 1 m wide and 7.6 m long, for the four irrigation treatments: 100% (T1), 75% (T2), 50% (T3) and 25% (T4) of reference evapotranspiration (ET_o) in a completely randomized design. There were nine plants per experimental unit, totalizing five replicates distributed in four drip lines, and spacing of 0.26 m between rows and 0.20 m between plants. In addition, two PVC pipe access tubes with length of 1 m, external diameter of 56.5 mm and internal diameter of 51 mm, properly sealed at the bottom, were installed to monitor the variation of soil moisture with a Diviner 2000 probe during the two periods studied.

For germination of the crop, trays were used in a greenhouse and, after two weeks, thinning was performed so that only the most vigorous plant continued in the tray. The transplantation to the field was performed on the 45th day after sowing (DAS) to reduce possible planting failures such as attack by insects and non-germinated seeds, when the crop measurements were between 18 and 20 cm in height and 0.75 mm in diameter and developed enough to tolerate transport and change to the external environment. The seedlings were transplanted to the nearest available dripper. After transplantation, the daily irrigation was done during the morning, replacing the water depths for each treatment.

The application of agricultural pesticides was carried out with a contact insecticide and a defensive systemic fungicide registered for the crop according to demand in the initial period of the two cycles.

The soil of the cultivated area was classified as Alfisols, which the physical (Table 2) and chemical analyses (Table 3) were performed at the Irrigation and Salinity Laboratory of UFCG to know the fertility deficiencies in the soil of the experimental area. Thus, the replacement of the amount of nutrients needed in chemical fertilization was evaluated.

Following the recommendation of fertilization for onion proposed by EMBRAPA (2015) and based on the

Table 2. Summary of soil physical properties in the experimental area

Depth (cm)	Granulometric composition (%)			Textural classification	Soil bulk density	Particle density
	Sand	Silt	Clay		(g cm^{-3})	
10	79.9	14.0	6.0	Loamy Sandy	1.29	2.73
20	81.9	11.0	7.0	Loamy Sandy	1.26	2.71
30	83.4	10.5	6.0	Loamy Sandy	1.34	2.73
40	82.0	10.5	7.5	Loamy Sandy	1.33	2.73
50	82.9	10.5	6.5	Loamy Sandy	1.36	2.71
60	82.9	10.5	6.5	Loamy Sandy	1.43	2.69
70	84.9	10.0	5.0	Loamy Sandy	1.49	2.71

Table 1. Maximum values of air temperature (Tmax) and maximum relative air humidity (RHmax), wind speed (WS), solar radiation (SR) and reference evapotranspiration (ETo); minimum air temperature (Tmin) and minimum relative air humidity (RHmin) and total precipitation (PRP) recorded in the two cycles of the experiment

Cycle	Tmax	Tmin	RHmax	RHmin	WS	SR	PRP	ET_o
	(°C)		(%)		(m s^{-1})	(W m^{-2})	(mm)	
1st	28.9	16.4	98.0	36.0	3.5	250.7	86.4	4.6
2nd	33.0	17.0	97.0	29.0	5.4	327.5	8.6	7.2

Table 3. Soil chemical properties in the experimental area for the 1st and 2nd cycles

Chemical characteristics	Cycle	
	1st	2nd
Calcium (cmol dm^{-3})	3.26	2.11
Magnesium (cmol dm^{-3})	2	2.72
Sodium (cmol dm^{-3})	0.07	0.13
Potassium (cmol dm^{-3})	0.3	0.27
Hydrogen (cmol dm^{-3})	1.93	0.5
Aluminum (cmol dm^{-3})	0	0
Qualitative calcium carbonate	Absent	Presence
Organic carbon (g kg^{-1})	14.6	9.5
Organic matter (g kg^{-1})	25.1	16.4
Assimilable phosphorus (mg dm^{-3})	34.7	122.6
pH H_2O (1;2,5)	5.76	6.15
Electrical conductivity (mmhos cm^{-1})	0.11	0.35

data interpreted in the soil fertility analysis (Table 3), the following doses of inputs were applied of the macronutrients supplied by ammonium sulfate (AS) with 20% N and 22% S, monoammonium phosphate (MAP) with 11% N and 52% P_2O_5 and potassium chloride (Kcl) with 60% K_2O, and the micronutrient B was supplied by boric acid (H_3BO_3), performed directly on the soil. Onion is relatively sensitive to acidity, developing better in soils with base saturation (V%) of 70%. According to the results of soil fertility analyses, the study area did not required corrective in any of the cycles due to the calculated base saturation values of 74.5 and 91.3% to 1st and 2nd cycle, respectively.

Reference evapotranspiration was calculated through ET_o calculator software (version 3.20, FAO), which uses the Penman-Monteith method (Allen et al., 1998):

$$ET_o = \frac{0.408\Delta\left(Rn - G\right) + \gamma\frac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \qquad (1)$$

where:

ETo - reference evapotranspiration [mm per day];
Rn - net radiation at the crop surface [MJ m^{-2} per day];
G - soil heat flux density [MJ m^{-2} per day];
T - mean daily air temperature at 2 m height [°C];
u_2 - wind speed at 2 m height [m s^{-1}];
e_s - saturation vapour pressure [kPa];
e_a - actual vapour pressure [kPa];
e_s-e_a - saturation vapour pressure deficit [kPa];
Δ - slope vapour pressure curve [kPa °C^{-1}]; and,
γ - psychrometric constant [kPa °C^{-1}].

The data needed to calculate ET_o were obtained from the website of the Instituto Nacional de Meteorologia (INMET) through the Automatic Meteorological Station of Campina Grande, located at Embrapa Algodão. The variables used are daily data of maximum and minimum temperature, maximum and minimum relative air humidity, precipitation, wind speed and global solar radiation.

Soil water balance (BH) was calculated based on the following equation (Libardi, 1995):

$$P + I \pm \frac{D}{A} \pm \Delta h \pm R - ET_c = 0 \qquad (2)$$

where:

ET_c - crop evapotranspiration (mm per day);
P - precipitation (mm per day);
I - irrigation depth (mm);
Δh - water storage variation in soil profile (mm);
R - surface runoff (mm); and,
D/A - deep drainage or capillary rise (mm).

In the calculation, soil moisture variation (Δh) was monitored by the Diviner capacitance probe, composed of a display with keyboards; the datalogger has a cable with rod and a sensor that automatically reads every 0.10 m deep in the soil up to the maximum depth of 0.75 m. Surface runoff was considered null because the area of the raised bed was relatively small and flat, and D/A was also disregarded because the water table of the site is deep and onion roots are tender, so their influence is null. Therefore, crop coefficient was calculated by the relationship between crop evapotranspiration (mm per day) and reference evapotranspiration.

The plant height variable (cm) and the bulb diameter (mm) were measured using a tapeline and a digital pachymeter, respectively, the productivity (tons ha^{-1}) was calculated from the bulb weight and a refractometer was used to measure soluble solids (°brix).

Water use efficiency (WUE), in kg ha^{-1} mm^{-1}, was obtained through the ratio between yield and crop evapotranspiration accumulated during the cycle, according to the equation proposed by Simsek et al. (2005):

$$WUE = \frac{Y}{ET_c} \qquad (3)$$

where:

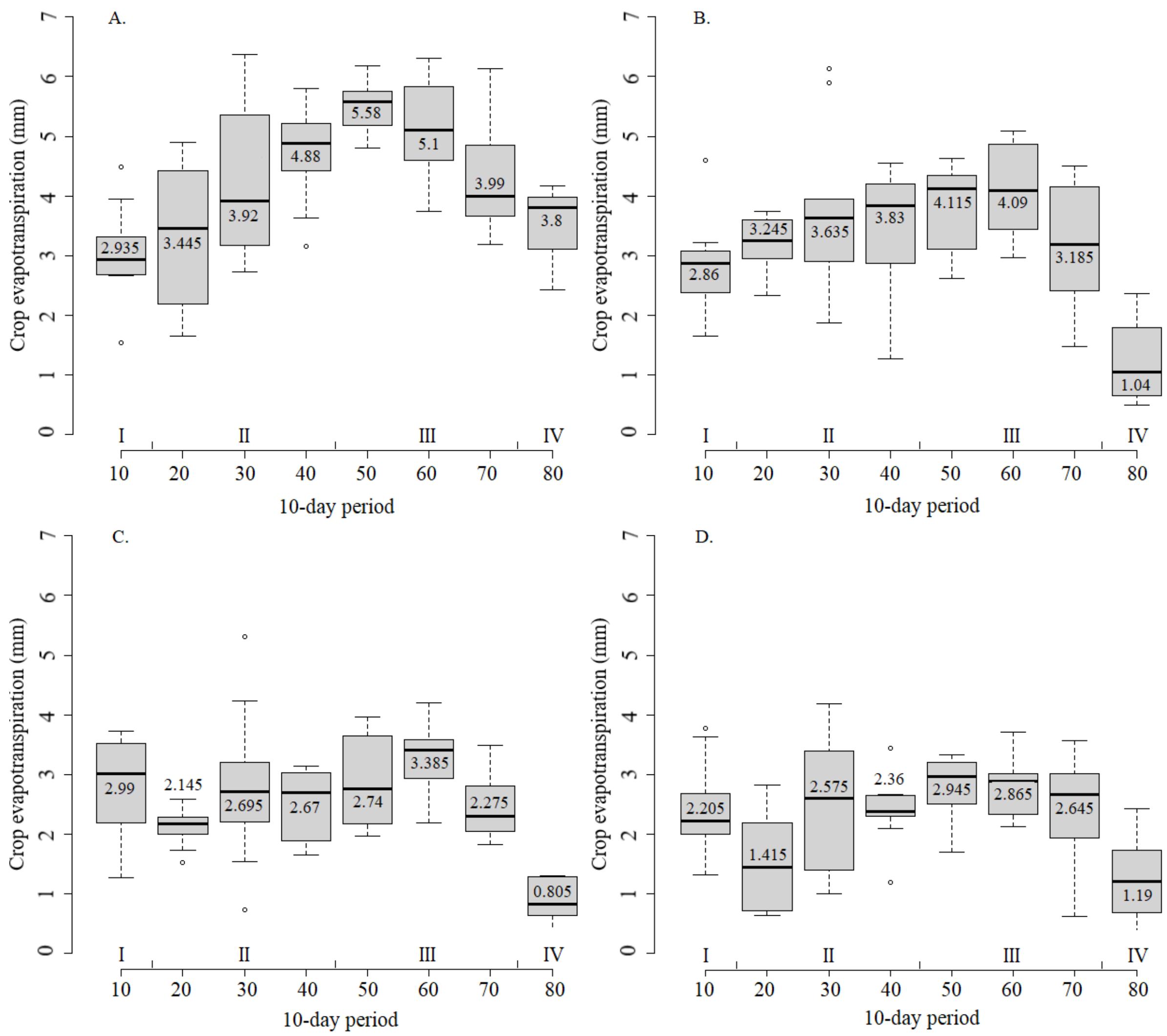
Y - yield (kg ha^{-1}); and,
ET_c - crop evapotranspiration (mm).

For the crop evapotranspiration graph, the median, maximum, minimum, first and third quartile were generated through R studio software. The linear regression made in the SISVAR software was used for statistical analysis of the crop according to treatments.

Results and Discussion

It is important to highlight that the meteorological variables between the two cycles are distinct. The first experiment was marked by mild temperatures, radiation and wind, as well as high relative air humidity and high precipitation rates. The second cycle was marked by the trend of increasing maximum and minimum temperatures, wind, solar radiation and evapotranspiration, in addition to low minimum relative air humidity and low precipitation. Nevertheless, there was no difference in phytosanitary treatment between the two cycles, with the occurrence of caterpillars, ants and fungus in the initial stage of the plants in the two cycles of the experiment.

Figure 1 shows the mean crop evapotranspiration (ET_c) of the two cycles, grouped into 10-days period, where it is possible to note the behavior of onion water consumption according to



Values represent the means of the two cycles; Stage I – 10; Stage II – 20 to 40; Stage III – 50 to 70; Stage IV – 80

Figure 1. Evapotranspiration of onion crop under 100% of ETo (A), 75% of ETo (B), 50% of ETo (C) and 25% of ETo (D) replacement in the initial (I), development (II), bulbification (III) and maturation (IV) stages

each stage of plant development and its respective treatment. The results show that in the initial stage (I), the ET_c values almost do not differ between them.

Treatment 1 with 100% of ETo (Figure 1A), Treatment 2 with 75% of ETo (Figure 1B), Treatment 3 with 50% of ETo (Figure 1C) and Treatment 4 with 25% of ETo (Figure 1D). Despite the different irrigation treatments adopted, soil moisture was homogeneous in the experimental raised beds before and at the beginning of irrigation, which can be justified by Tanner & Jury (1976), who state that soil evaporation still comprises most of the total evapotranspiration, because the crop has a low leaf area index (LAI).

Throughout the cycle in the Treatment 1 and Treatment 2, ET_c increased according to plant growth and water availability, with the maximum value found during the beginning of the bulbing stage (III) of onion as shown in Figures 1A and B, in which the means were 5.58 and 4.11 mm per day in 10-days period 50, respectively. According to EPAGRI (2013), the need for irrigation of the onion crop increases with its growth and development, mainly in some periods of vegetative development and it reaches the peak of evapotranspiration in the bulbing stage, followed by a reduction in maturation; at the end of the cycle, the physiological maturation (IV) of the plant begins, which may be identified by Gonçalves et al. (2014) as the fall of the pseudostem, known as the "top collapse".

Carvalho et al. (2017) found values for the variety Alfa São Francisco close to those of the T1 treatment of this study with water consumption of onion crop, which ranged from 3.9 mm per day for the initial stage to 5.8 mm per day for the stage of maximum development and formation of bulbs, reaching daily maximum values of up to 7.2 mm per day. Still in Figure 1, it can be noted that ET_c in Treatment 2 is lower than in Treatment 1, suggesting that the reduction in the amount of water in soil leads to lower rates of crop evapotranspiration. For Treatments 3 and 4, different behaviors were observed; despite the gradual reduction of ET_c according to water reduction, as expected, the values became more dispersed in treatments with higher water stress mostly in the development and maturation stages.

According to Oliveira et al. (2014), for being a vegetable plant with superficial root system, the onion makes it less accessible to soil water reserves, about 90% of the roots are found in the first 40 cm of depth so that the sensitivity of the crop to dry spells and/or poorly distributed rains is great. When transpiration is affected, the development and production of bulbs are also hampered, as observed. The onion cultivated under the conditions of the Treatment 4 was more affected by water stress, which stimulated premature bulbing in comparison to the other treatments and less development of bulb diameter.

The coefficients in Table 4 integrate the effects of evapotranspiration throughout the cultivation period, showing the comparison between the values of the crop coefficient (Kc) found by Allen et al. (1998) and the one found in this experiment in the T1 treatment. The results found show the difference between the values caused by the climate and location of the respective studies. In addition, according to the authors, the crop coefficients for the initial and development stages are subject to great variation in the values due to the frequency of irrigation, so it needs to be improved whenever its use is necessary. Therefore, the experimental Kc is the most suitable for onion in that study region.

It is also noted that the coefficient curve is likely that described by Allen et al. (1998): at the beginning and at the end of the experiment the values are lower, and the maximum value is found in the period of highest water demand, in the bulbing period.

Figure 2 shows the maximum plant height and diameter, the concentration of soluble solids, yield and water use efficiency of onion in the studied treatments, with values representing the means of the two cycles.

The maximum plant height and bulb diameter of onion (Figure 2) were directly influenced by the amount of water applied by treatment, which increased according to the increment of water between them. It can be noted that T1 was the only treatment that reached the maximum height above 60 cm, considered normal for onions; plants in the other treatments could not develop normally due to the induced water stress. According to Reichardt (1996), the availability of water in the soil governs plant production, so its lack or excess decisively affects the development of plants. The F test shows the model for the maximum plant height (Figure 2A) and bulb diameter of onion (Figure 2B) obtained in R2 with 99.44 and 94.38%, respectively, being considered as adequate adjustment and with low dispersion. The F test was highly significant with $p \leq 0.05$ for the maximum plant height, hence indicating the influence of the irrigation depth on onion development.

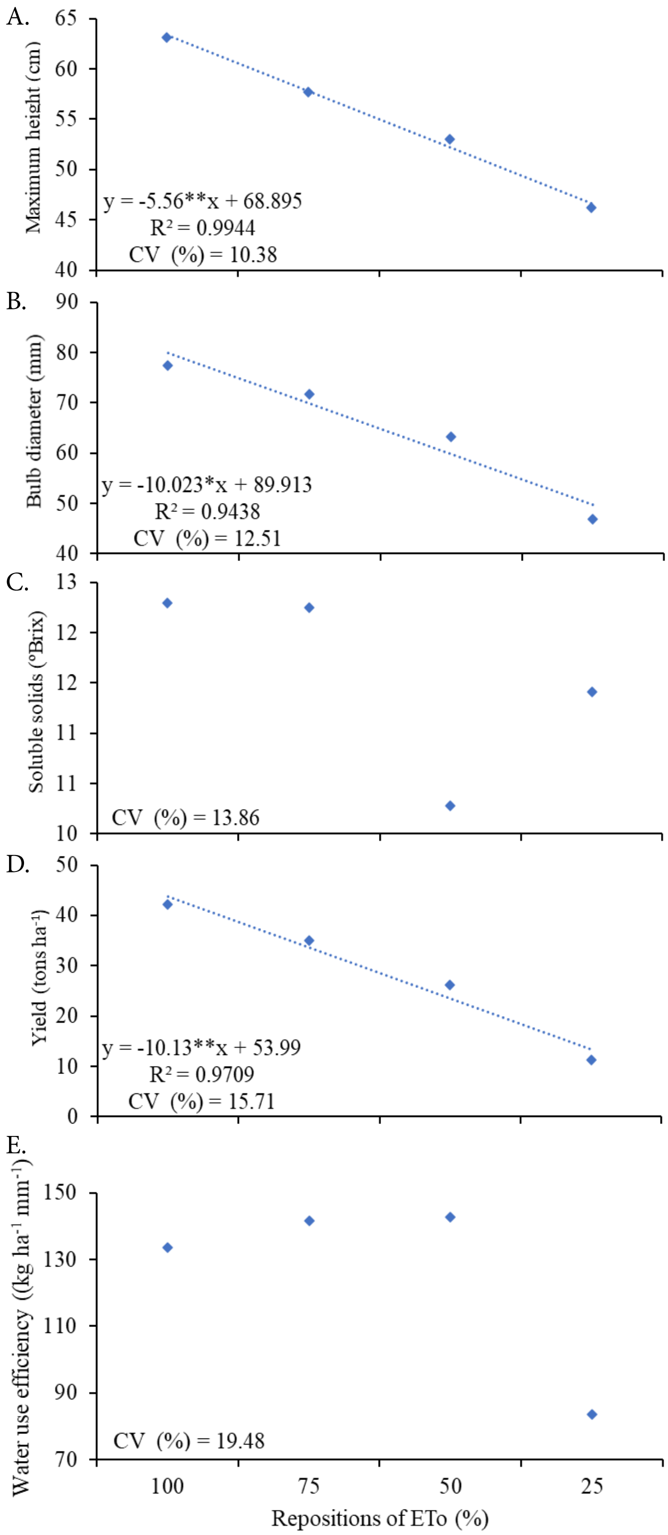
Figure 2C also shows the concentrations of soluble solids (SS) ranging between 10.28 and 12.29%. These values demonstrate similarity with Araújo et al. (2004); Grangeiro et al. (2008); and Bandeira et al. (2013) who found with 11.65, 10.61, and 10.81% in the SS for "Vale Ouro IPA 11" genotype, respectively. For this variable, there was no adjustment; thus demonstrating that the values of soluble solids did not varies in function of irrigation depth.

Oliveira et al. (2013) worked with different irrigation treatments, based on ET_c obtained by evapotranspirometers,

Table 4. Crop coefficients obtained by Allen et al. (1998) in this study

Stage	Crop coeficiente	
	Allen et al. (1998)	Experimental
Initial	0.70	0.68
Development	0.70	0.89
Bulbing	1.05	0.99
Maturation	0.75	0.73

Values represent the means between the two cycles



Values represent the means between the two cycles. *, ** - Significant at $p \leq 0.01$ and $p \leq 0.05$ by F-test, respectively

Figure 2. Maximum plant height (A), final bulb diameter (B), soluble solids concentration (C), yield (D) and water use efficiency (E) of onion in function of percentage of repositions of ETo.

irrigation based on ET_o of the Class A Tank and ET_o by Penman-Monteith and found SS values of 10.3, 9.8 and 10.4%, which did not differ much from the contents found in the experiment.

The model that adjusted for productivity (Figure 2D), as well as for the other variables. Onion yield was higher with 100% of substitution of reference evapotranspiration, decreasing until reaching the lowest value of the experiment in T4 (25% of substitution), and the mean estimated values by the adjusted regression were 43.86, 33.73, 23.6, 13.47 tons ha^{-1}, respectively.

The reduction of applied water in treatments T1 to T3 increased the WUE_{ET} from 133.71 to 142.76 Kg ha^{-1} mm^{-1} between the treatments, respectively, and reduced on average to 83.47 kg ha^{-1} in the treatment with less water application, without satisfactory adjustment of the regressions as well as the soluble solids. There was an increase in WUE_{ET} according to the reduction of water application in treatments T2 and T3, followed by a greater reduction in this efficiency for the onion in the treatment T4, this dispersion of results also showed a high CV with 19.48%.

Santa Olalla et al. (2004) evaluated the amount of water in onion cultivation also for the semiarid region and obtained water use efficiency estimated values ranging from 91.6 to 116.0 kg ha^{-1} mm^{-1}. These authors reported that, in general, the lower the volume of water applied, the higher the efficiency achieved.

Besides, focusing on the studied variety, Tosta et al. (2014) evaluated the response of onion genotypes to water deficit in order to support improvement programs in the development of genotypes with greater efficiency in water use (WUE) for ten onion genotypes according to the levels of water deficit and the variety IPA 11 was ranked 3rd among the best WUE, succeeded by Grano TX-08 and CNPH 6179org. Furthermore, for variety IPA 11, the lowest WUE was observed in the treatment of 20% of evapotranspiration compared to treatments with greater replacement like in the Treatment 4 obtained the lowest water use efficiency because it was subjected to the greatest water stress, which limited plant growth and especially bulbing.

Vilas Boas et al. (2014) observed reduction in onion yield with the application of water depths corresponding to 150 and 200% of the Class A tank evapotranspiration, because high water content in soil reduced the adequate aeration in the region of highest concentration of roots. This pattern causes physiological changes, which led to reduced yield, also due to nutrient leaching, proving that not only water deficit, but also the excess water supplied to the soil is quite harmful to the crop.

Conclusions

1. The values of crop evapotranspiration present higher variability under higher water stress.
2. The application of the water depths of 75 and 50% of ETo resulted in the higher water use efficiency.
3. The crop coefficients for onion under drip irrigation were 0.68, 0.89, 0.99 and 0.73 for the initial, development, bulbing and maturation stages, respectively.
4. The onion growth and yield decreased linearly with decreasing percentage of repositions of ETo, whereas, the soluble solids were not influenced.

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