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Productive characteristics and water use efficiency in cotton plants under different irrigation strategies[1]

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ABSTRACT

Studies have been carried out on efficient water use in irrigation. The present study evaluates the yield of cotton plants (*Gossypium hirsutum* L. r. *latifolium* Hutch*),* and the use of water for different irrigation strategies. The experiment was conducted under greenhouse conditions, and the cultivar used was CNPA-7H Precocious grown in plastic pots; each pot contained 20 kg of dry soil. The irrigation strategies were selected by taking into account the available water in the soil, the irrigation frequency and the irrigation suppression during flowering and boll development. Water consumption, boll weight, yield, harvest index and water use efficiency were evaluated and the results showed that water consumption resulting from the irrigation strategies used brought expressive variations in the studied parameters. In all strategies, irrigation suppression was the decisive factor in evaluating the water use efficiency.

Key words: *Gossypium hirsutum*, phenology, water availability, water saving

Características produtivas e eficiência do uso de água do algodoeiro sob diferentes estratégias de irrigação

RESUMO

Estudos vêm sendo realizados com o objetivo de se estabelecer maior economia de água no manejo da irrigação sem, no entanto, prejudicar o rendimento das culturas, o que serviu de base para a realização do presente trabalho, visando-se avaliar o rendimento do algodoeiro (*Gossypium hirsutum* L. r. *latifolium* Hutch) e a eficiência no uso da água pela cultura, sob diferentes estratégias de irrigação. O experimento foi conduzido em casa de vegetação, utilizando-se da cultivar CNPA-7H Precoce, cultivada em vaso plástico, contendo 20 kg de solo seco ao ar. As estratégias de irrigação foram estabelecidas levando-se em consideração a água disponível no solo, a frequência de irrigação e a supressão da irrigação na floração e no desenvolvimento das maçãs. Avaliaram-se: consumo de água, peso de capulho, rendimento, índice de colheita e eficiência no uso da água e, segundo os resultados obtidos, o consumo hídrico, influenciado pelas estratégias de irrigação, proporcionou variações expressivas em todos os parâmetros estudados, sendo a época da supressão da irrigação o fator determinante sobre a eficiência de uso da água.

Palavras-chave: *Gossypium hirsutum*, fenologia, disponibilidade de água, economia de água

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INTRODUCTION

In the cotton crop (*Gossypium hirsutum* L. r. *latifolium* Hutch), the irrigation management should provide water availability conditions, securing the genetic potential of the plants. It is important to accurately time the amount of water to be used in order to prevent plants from suffering from either an excess or lack of water (Amorim Neto et al., 2001; Pereira et al., 2002).

Tang & Zhang (2005) obtained excellent results in cotton yields by managing water deficits during plant development, saving water during irrigation. Another procedure that helps to save water in irrigated areas is the definition of the suppression of irrigation correctly, promoting the physiological seasoning of plants without compromising yield (Buttar et al., 2007).

In studies on the effect of irrigation suppression at 50, 65, 80, 95 and 110 days of the cycle of the herbaceous cotton cultivars – CNPA-Precoce 1, CNPA-6H and IAC-20 – Oliveira & Campos (1997) verified that irrigation up to 95 days after the seedling emergence contributed towards an increase in crop yield; the largest increase occurred when the last irrigation was applied to the CNPA-Acala 1 cultivar on the 65th day; and to the CNPA-Precoce 1, CNPA-6H and IAC-20 cultivar on the 80th day. According to Nápoles et al. (1999), the best period for the suppression of irrigation in the case of herbaceous cotton CNPA-7H cultivar – is 30 days at the beginning of blooming. This does not impair yields or the quality of the fiber.

Tennakoon & Milroy (2003) and Ritchie et al. (2004) obtained an increase in water use efficiency by studying some irrigation strategies, aiming at higher water saving.

The use of irrigation strategies are fundamental to save more water without putting at risk crop yield (Jalota et al., 2006; Pereira et al., 2009). In spite of the great number of studies on water management in irrigation, very little has been achieved regarding safe irrigation strategies. This makes further developments in irrigation techniques necessary. The present study evaluates some productive features and some effective methods of water use in different irrigation strategies for plants under greenhouse conditions.

MATERIAL AND METHODS

This experiment began on January 18, 2000 in the Laboratory of the Department of Soil and Rural Engineering of the Center of Agrarian Sciences of the Federal University of Paraiba, Campus II, located in Areia, Paraíba. The municipality of Areia lies in the micro-region of the Brejo Paraibano at 6° 58' 12" latitude South, and 35° 42' 15" longitude West at an altitude of approximately 575 m above sea level. The climate of the region is of the "As" type, according to the classification Köppen. It is hot and humid with plenty of rain during autumn-winter time followed by a drought period that varies from 5 to 6 months. The mean annual rainfall is 1,400 mm during the period from March to August, with milder intensity during September to February. The mean air temperature is 24.5 °C. November, December and January are the hottest months, and July and August are the coldest. The annual mean air humidity is 80%, and wind speed is 2.5 m s^{-1}.

Herbaceous cotton (*Gossypium hirsutum* L. r. *latifolium* Hutch) CNPA-7H cultivar was studied with a growth cycle under dryland conditions from 120 to 130 days from seedling emergence. The soil used in the experiment was collected from the surface layer (0 20 cm depth) and classified as typical Dystrophic Yellow Latosol of sandy clay texture (EMBRAPA, 1999) with a composition of 517.69, 90.43 and 391.88 g kg^{-1} of sand, silt and clay, respectively. The water content of the soil was equivalent to 236.84 and 140.36 g kg^{-1}; at 0.01 and 1.5 MPa tensions, respectively. The chemical analysis of the soil presented the following values: pH in H_2O = 5.0; P = 4.69 mg dm^{-3}; K^+ = 30 mg dm^{-3}; Al^{+3} = 0.80 $cmol_c$ dm^{-3}; Ca^{+2} + Mg^{+2} = 2.70 $cmol_c$ dm^{-3}; organic matter. = 31.34 g dm^{-3}; electrical conductivity = 0.11 dS m^{-3}.

The irrigation treatments consisted of four strategies: in E1 strategy, plants were irrigated daily, with a water depth of 60% of the available water in the soil (AW) until the end of the crop cycle; in E2 strategy, plants were irrigated every 5 days, with a water depth equivalent to 80% of AW until the end of the cycle; in E3 strategy, plants were irrigated every 5 days with a water depth of 80% until the end of flowering; and, finally, in E4 strategy – plants were irrigated every 5 days, with a water depth of 80% of the AW until the beginning of fruit development. The AW used in each treatment was calculated by taking into account the retention curve of soil water as determined by the methodology proposed by Forsythe (1975). The available water was obtained by calculating the difference between the amount of water retained in the soil – at the field capacity (FC) obtained at a tension of 0.01 MPa – and the amount of water retained under a tension of 1.5 MPa, which corresponded to the permanent wilting point (PWP). The experimental design was completely randomized, with 4 treatments and 9 replications, totaling 36 plots, consisting of pots with the capacity of 20 L, containing each 20 kg of air-dried soil sample.

The acidity of the soil samples was corrected by applying 11.1 g of $CaCO_3$ to each pot, two months before sowing, which was done by planting 5 seeds in each pot at a depth of approximately 2 cm. As basal dose of fertilizer, the recommendations found in Silva (1999) were adopted. These recommendations consisted of applying 0.31 g of urea, 2.72 g of simple superphosphate, and 0.12 g of potassium chloride to each pot, depositing the fertilizer at 5 cm depth based on soil analysis at the time of sowing. The type of soil was also taken into account. In top dressing, 0.47 g of urea and 0.23 g of potassium chloride were applied to each pot during budding and blossoming. Twelve days after seedling emergence, thinning was performed leaving only one plant in each pot. Prior to the application of the treatments – which occurred 14 days after seedling emergence – soil water was maintained at 80% of AW.

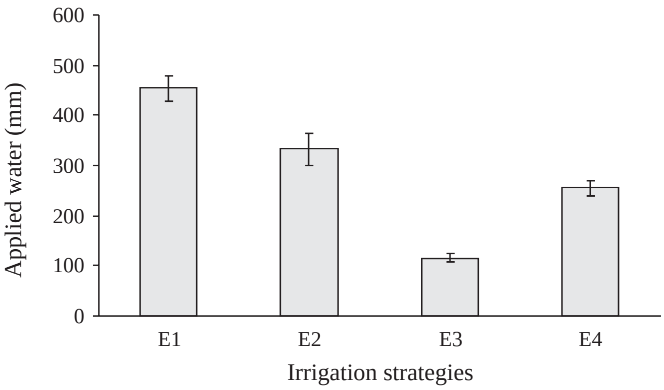
Evapotranspiration was determined by the difference between the weight of the pot containing the plant – with 60 and 80% of AW – and the weight of the pot taken on the day the plant was irrigated according to the irrigation frequency defined by the treatment, obtaining the accumulated water consumption during the experimental period. The yield of the cotton in plume – seed (gram per plant), and the mean weight of cotton-wool per plant (g) were calculated, adjusting humidity to 10% in all treatments. The buds which were about to blossom were collected separately from each plant. The crop yield was calculated by the ratio between the total biomass and the production of cotton-foliage per plant. The data concerning the efficient use of water were estimated by the ratio between cotton-foliage yields – with 10% humidity – and the quantity of water applied during each irrigation strategy, with values expressed in kg m^{-3}.

The data obtained for the variables were submitted to analysis of variance by using SAEG – System for Statistic and Genetic Analyses of the Arthur Bernardes Foundation, Viçosa. The F test and the Tukey test of comparison of means were applied, at 5% probability.

RESULTS AND DISCUSSION

Water consumption

Figure 1 illustrates the estimated water consumption for the whole cycle, starting with the evapotranspiration accumulated from plants under E1 and E2 irrigation strategies when irrigation was interrupted. Figure 1 also shows the data obtained from E3 and E4 strategies. Some significant variations ($p < 0.01$) were observed in all treatments. Plants under the E1 regime consumed more water: a total of 453.43 mm. This was followed by plants under the E2 regime (332.72 mm) which showed a decrease of 26.6% in water consumption (120.71 mm). Plants submitted to E4 (254.82 mm) and E3 (116.04 mm) irrigation strategies showed the highest water saving during budding and flowering phases, respectively.



* Each histogram corresponds to a mean of nine replications and bars represent the standard error

Figure 1. Water depth (mm), applied in the irrigation of the herbaceous cotton plant cv. CNPA-7H based on the four irrigation strategies under greenhouse conditions

Water consumption was greatly reduced with the adoption of irrigation strategies. The plants in E1 were irrigated every day, and soil humidity maintained at 60% for the whole cycle. These plants consumed more water compared to all the ones treated with different strategies. Such conditions caused the rate of evapotranspiration to rise, and, consequently, increased the volume of water consumed. This was also observed by Detar (2008) and by Eholpankulov et al. (2008). Mansur et al. (2007), working with the cv. 7MH – a genotype of the CNPA-7H species, used in the present study – observed that its capacity to resist water deficiency derived from its higher degree of stomatal opening, which reduced the water potential of leaves in order to secure steady water flow from the soil to the roots. According to Munier & Hutmacher (2003), it is not necessary to raise the water level in the soil because this has no effect on either plant development or plant yield.

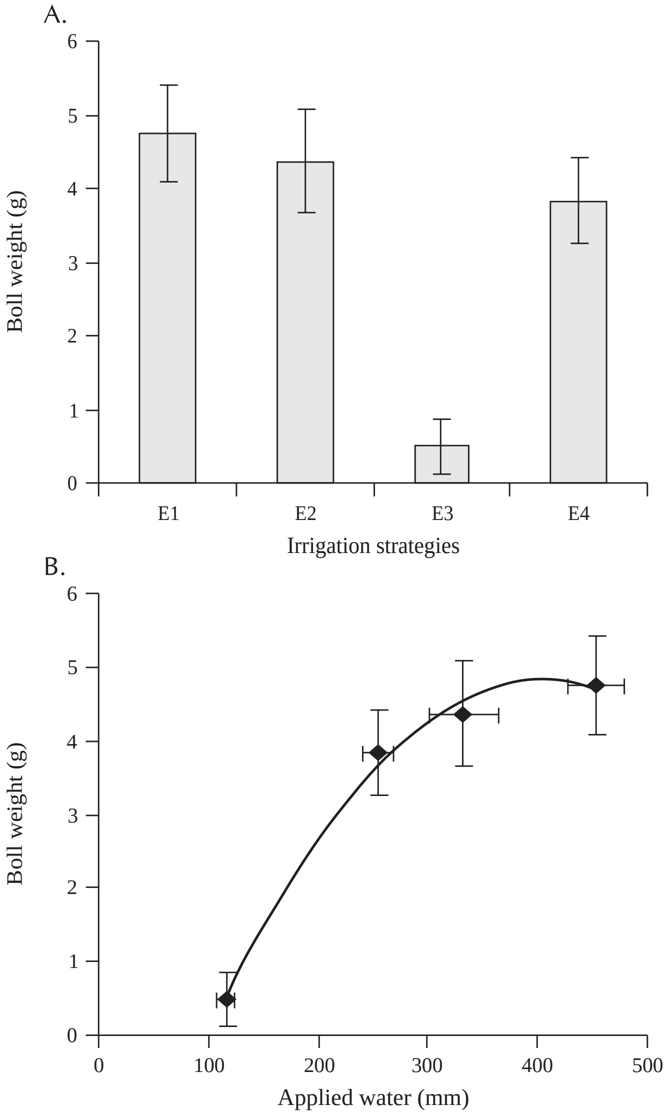
In the E2 treatment, in spite of the fact that irrigation levels went as high as 80% of the AW, there occurred a reduction of 26.6% in water consumption relative to the plants in E1 on account of the 5-days interval between the irrigation periods (Figure 1). The same results were observed by Arruda (1999) after testing different ways of managing the water quantity for irrigating the same cotton genotype.

The plants under E3 and E4 irrigation strategies presented higher water saving, resulting in reductions of 74.4 and 43.8% when compared to the plants under E1, respectively. This was due to irrigation suppression during both budding and flowering periods. Nápoles et al. (1999) and Ritche et al. (2004), studying the different irrigation strategies in cotton crops, observed differences in water consumption relative to the time of irrigation suppression, which gave rise to higher water saving as the irrigation suppression approached the beginning of flowering, a fact also observed by Oliveira & Campos (1997) and Jalota et al. (2006).

Weights of cotton bolls

Figure 2 shows the ratio between the volume of the water applied and the mean weight of bolls as a result of the various irrigation strategies. There were no significant differences ($p > 0.05$) among the weight of the bolls from the plants submitted to E1, E2 and E4 strategies with mean values of 4.74, 4.37 and 3.83 g, respectively (Figure 2A). The E3 strategy produced the lowest mean value of boll weight 0.40 g, which resulted in a reduction higher than ($p < 0.05$) 86% compared to treatments with lower water deficits (E1 and E2), differing significantly from values produced by the plants under other irrigation regimes.

As to the information presented in Figures 1 and 2, it was observed that E3 plants, which received less water (116.04 mm), produced bolls with only 0.49 g. Heavier bolls (4.75 g) were obtained with 453.43 mm (E1) daily irrigations, thus, responding well to soil water maintenance at 60% of AW. With 74.41% decrease in water consumption between treatments E1 and E2, the reduction of the mean weight of bolls was higher (89.68%). With lesser water used (332.70 mm) in E2 – about 26.63% of the amount spent in E1 – the mean boll weight decreased from 4.75 g in E1 to 4.37 g in E2: a reduction that corresponded to only 8% (Figure 2A). No significant difference was seen to occur between these two strategies which led to the conclusion that the adoption of E2 strategy is an advan-



* Each dot represents the mean of nine replications. The mean standard error is represented by bars

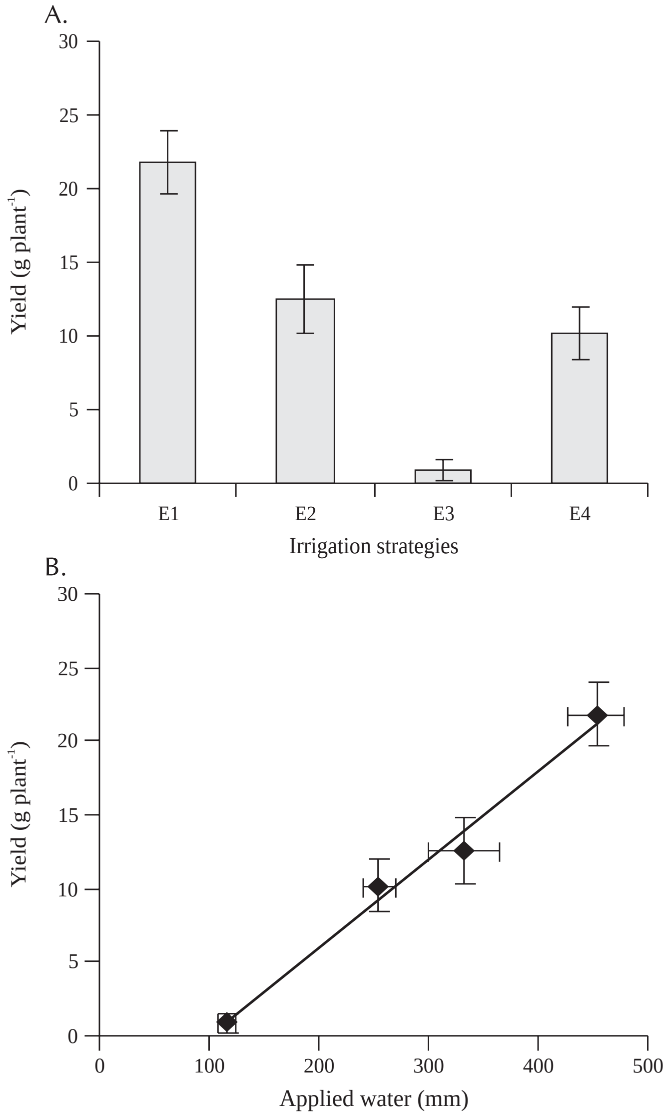
Figure 2. Mean boll weight (A) of the herbaceous cotton plant cv. CNPA-7H (A) under 4 different irrigation strategies under greenhouse conditions, and the relation between the water applied and the boll weight (B)

tage i.e. to irrigate the plants every 5 days: based on 80% of AW until the end of the crop cycle.

The fact that there was no significant difference ($p > 0.05$) between the mean weight of the bolls in plants under E1, E2 and E4 irrigation strategies may be explained by the absence of water deficit in all these strategies during flowering, a phase in which the plant needs more water (Amorim Neto et al., 2001; Wanjura et al., 2002). The lack of irrigation during flowering in E3 resulted in bolls with less weight. This was due, possibly, to a decrease in photosynthesis because of the closing of the stomata, limiting, as a result, CO_2 diffusion for the mesophyll in cotton plants of the Pima species: a fact showed in plant physiology texts (Castro et al., 2005 and also verified by Tang & Zhang, 2005). The resulting reproductive structures did not have photosynthates or enough water to carry out the expansion process and the cell division, as stated by Tang & Zhang (2005). This resulted in the production of fewer bolls by plants under the E3 irrigation strategy.

Yield

Figure 3 shows the yield of the herbaceous cotton plant relative to the amount of water used and the variable with the mean standard error in relation to the different irrigation strategies studied. The cotton yield was significantly affected ($p < 0.01$) by these treatments: the plants under E1 strategy, with a mean yield of 21.8 g of cotton foliage, presented higher yield than those under E2, E4 and E3 treatments: 42.4, 53.2 and 96.0% with mean values of 12.5, 10.2 and 0.86 g, respectively. The mean yields of plants under E2 and E4 regimes were statistically similar; however, they differed significantly ($p < 0.05$) from the weight of the cotton foliage produced by plants under E3 strategy.



* Each dot represents the mean of nine replications. The bars represent the standard error of the mean

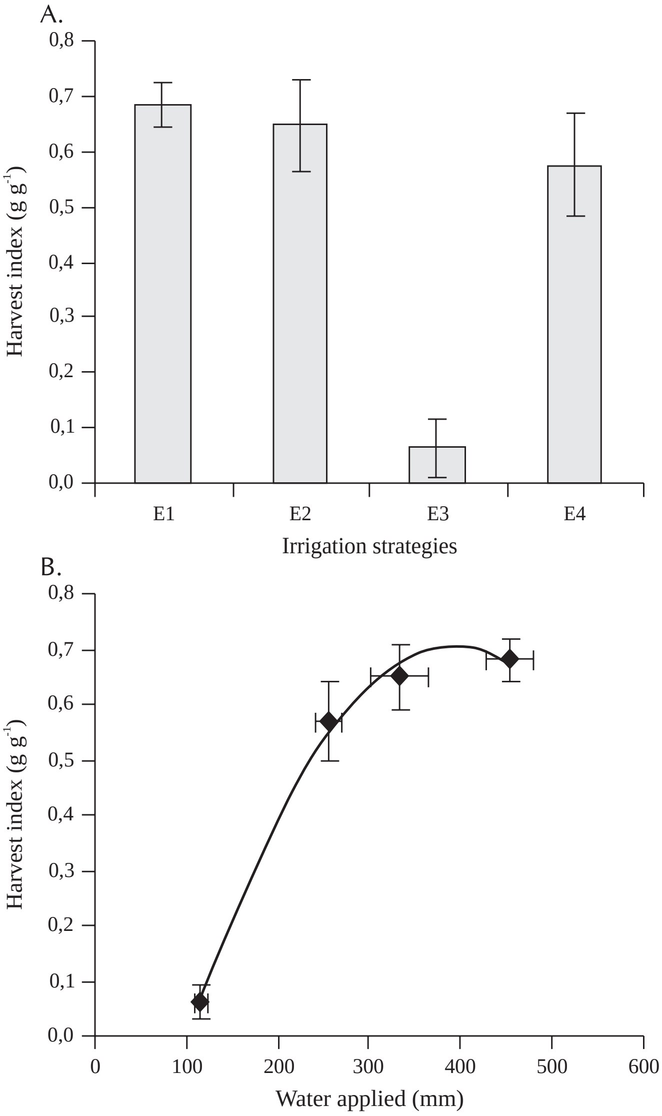
Figure 3. The yield of the herbaceous cotton plant cv CNPA-7H with 10% humidity (A) and the relation between the water applied and the yield variable (B) under the four irrigation strategies under greenhouse conditions

The E3 plants (Figure 3A) exhibited very poor yield: about 96.3% lower than that shown by plants in the E1 strategy. This was due to the suppression of irrigation during flowering period, when the plants required higher quantity of water

(Amorim Neto et al., 2001; Tang & Zhang, 2005). The authors observed that during this period the plantation developed a larger leaf area, requiring more transpiration. This bore close relation to the flowering and fruiting phases (Chaves & Oliveira, 2004). Plants under the E3 irrigation strategy presented higher levels of leaf abscission and reproductive forms (this has not been examined in the present study), producing lower yields per plant: a fact brought about by reducing photo-assimilates, as mentioned by Chaves & Oliveira (2004).

Leaf abscission rates and budding rates were lower in plants treated under E1 strategy with 60% of AW, resulting in higher yields of cotton foliage. Arruda (1999) also observed that the level of 60% of AW in the soil was responsible for higher yields of cotton foliage. When the plants were submitted to the E2 strategy, where irrigation management actually brought about an increase in soil water with 80% of AW and 20% higher than that in E1, cotton yield per plant dropped 41% approximately. This occurred because of the five-days irrigation interval in E2; in contrast to the situation in E1 where irrigation was applied every day due to the fact that the plants were kept in pots and the five-days irrigation period would harmful to them. In such circumstances, the water deficit might have increased, making the plants close their stomata and reduce photosynthesis and yields as observed by Tang & Zhang (2005) and Mansur et al. (2007). Plant yields were also reduced in the E4 regime. However, this did not differ very much from E2, from which it was concluded that with the same irrigation period (five days) there was no difference, whether irrigation was interrupted at the time the first buds appeared, or it was extended until the end of the crop cycle (E2) even when soil water corresponded to 80% of the AW. Once again it should be taken into account the fact that the development of plants in pots containing small quantity of soil have contributed to these findings.

Tang & Zhang (2005) observed that the period between the beginning and the ending of flowering is more vulnerable when the plants are subjected to water deficit. This may give rise to higher reductions in crop yield.



* Mean data of nine replications; the bar represents the mean standard error

Figure 4. Harvest index (A) and the ratio between the applied water and this variable (B) under four different strategies used for the herbaceous cotton cv. CNPA-7H grown under greenhouse conditions

Harvest Index

Figure 4 illustrates the mean values of harvest index (Figure 4A) and the rate of the variable in relation to the quantity of water applied (Figure 4B) regarding the different irrigation strategies. A considerable difference ($p < 0.01$) between the harvest index and the irrigation strategies was observed; as it can be noticed from the standard deviation of the mean as a consequence of the rather poor yield of E3. As to the other treatments, E1, E2 and E4, with mean values of 0.68, 0.65 and 0.57, respectively, no significant difference was observed in harvest index.

The harvest index (HI) is commonly employed to calculate the ratio between the dry matter from the harvested part and the total dry matter produced. In the present study, only aboveground biomass was taken into account. Except for E3, all values of HI in the other treatments that did not differ from one another were taken, indicating, therefore, the mean standard error (Figure 4). In E1, regarding cotton wadding, crop indices reached 68% , whereas values in E2 and E4 were 65 and 75%, respectively; consequently, over half the dry mass formed was found in the production structures, constituting, therefore, strong drains to receive the photo-assimilated as stated by Castro et al. (2005).

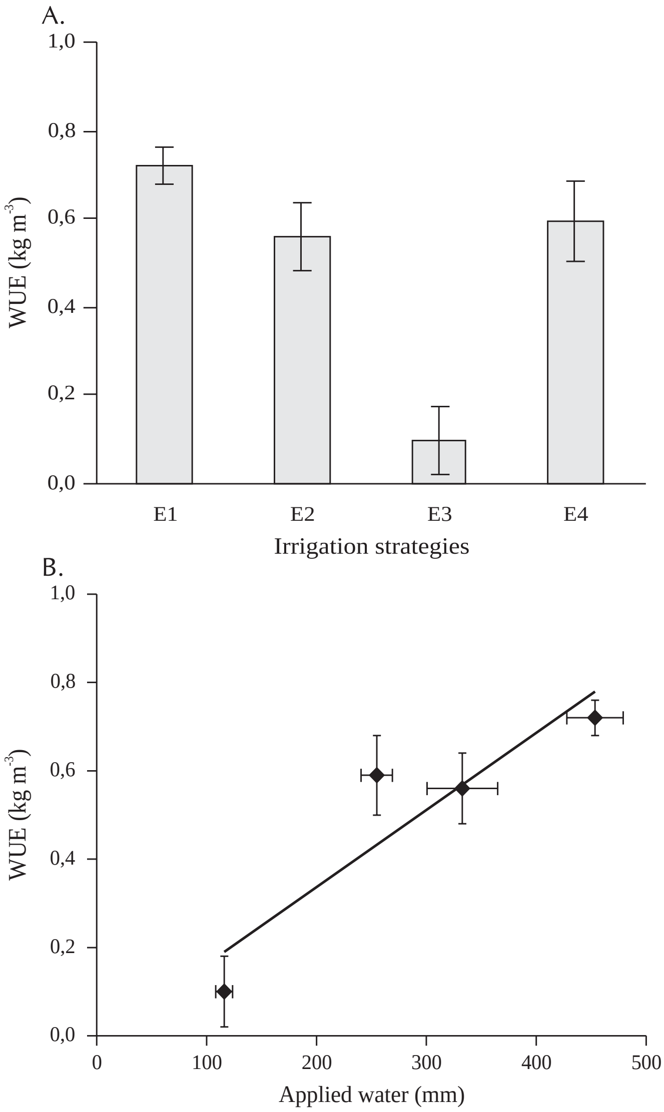
Harvest indices in E3 was very low (6%), stemming from the low yield of cotton wadding as a result of irrigation suppression at the beginning of flowering. This revealed clearly how vulnerable cotton plants are to water deficit at this stage of development (Detar, 2008). From a total of 14.5 g of phytomass accumulated by the plants submitted to this treatment, only 0.06% fell within the yield structures (cotton wadding). Boyer (1982) observed a reduction in values of HI as opposed to an increase in the levels of water deficit.

When the data obtained from HI were compared to plant yields (Figure 3), it could be seen that the water deficit had a much stronger effect on yield than on the remaining biomass of aboveground cotton plants, because higher weight of cotton wadding was obtained in the E1 treatment without significant difference between E2 and E4. However, in the HI variables, those effects were similar for E1, E2 and E4 (Figure 4).

Water Use Efficiency

The data concerning efficiency in the use of water (WUE) and the ratio of water applied to the herbaceous cotton cv. CNPA-7H, when submitted to the four irrigation strategies, are shown in Figure 5. Highly significant differences ($p < 0.01$) were detected by the analysis of variance between the WUE data, concerning the strategies studied. The standard error of the mean was very small (Figure 5B).

Strategy E1 presented the highest WUE value (0.72 kg m^{-3}), differing significantly from the other irrigation procedures; however, between E2 (WUE = 0.56 kg m^{-3}) and E4 (WUE = 0.59 kg m^{-3}), where irrigation was applied every 5 days (based on 80% of AD) till the end of the cycle and the appearance of the first buds, respectively, no significant differences were noticed. The analysis of variance detected significant differences ($p < 0.01$) in the WUE data and in the strategies studied. The mean standard error, consequently, was very small (Figure 5B). E3 strategy exhibited the smallest WUE value (0.10 kg m^{-3}), equivalent to a reduction of 86.6% when compared to the plants under Strategy E1, differing significantly ($p < 0.01$) from the other treatments.



* Each dot represents the mean of nine replicates, the bars (I) represent the standard error of the mean

Figure 5. Water use efficiency (WUE) (A) for the upland cotton cv. CNPA-7H grown under the four irrigation strategies under greenhouse conditions and the ratio between the applied water and the variable (B)

On carrying out an investigation of the two irrigation treatments till the end of the cycle, in which E1 strategy was applied, on account of which 60% of the available water was provided, and also the E2 strategy in which there was an interval of five days in between irrigations which restored soil water to the level of 80% of the AW, the EUW data fell 22.22% (Figure 5). This certainly accounts for an enormous fall in raw cotton yield per plant between treatments, while the quantity of water applied dropped to 26.62% (Figure 1). However, between E1 and E2, yield increased to 42.46% (Figure 3). Because the plants were grown in pots, an increase in the irrigation time interval caused some damage to them, even after the amount of water was increased from 60 to 80% of the AW.

On re-examining the data on water consumption relative to WUE data (Figure 5), one can see the benefits of irrigation obtained from E4 strategy. This corresponded to much more efficient and much more economical use of water. Relative to E1 strategy, the plants submitted to E4 treatment consumed 43.80% less water, and the WUE data dropped only 18.06%.

The water use efficiency (WUE) is a relevant factor in studies on the irrigation of crops. This shows how much a plant can economize in water without lowering yields (Tang & Zhang, 2005). In E3, when irrigation was interrupted at the beginning of the flowering period, larger water saving was verified (Figure 1); however, the WUE was very low, judging by the poor yield of plants (Figure 3A). Oliveira & Campos (1997) and Nápoles et al. (1999) have also observed a decrease in WUE when irrigation was interrupted close to flowering.

Irrigation throughout harvesting (E1 and E2), though it resulted in higher values of WUE, it was uneconomical, because of the minimum water requirement of cotton plant after the opening of the first bolls (Tang & Zhang, 2005; Detar, 2008). The suppression of irrigation following the appearance of the first buds (E4), resulted in higher WUE within the limits found in the literature (Tennakoon & Milroy, 2003; Buttar et al., 2007).

Conclusions

1. Increased production and greater efficiency in water use are obtained with daily irrigation throughout the cycle; replenishing soil moisture to 60% of the available water.

2. Irrigation suppression at the early phase of flowering reduces yields and the mean weight of bolls.

3. Major water savings and more efficient use of water are obtained by suppressing irrigation during fruiting.

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