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Production components and water efficiency of upland cotton cultivars under water deficit strategies

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The objective of this work was to study water deficits effect on different phenological phases in the production components and water efficiency of upland cotton cultivars. For this, an experiment was carried out at the Federal University of Campina Grande - UFCG, Pombal county Campus, Paraíba State, Brazil. Treatments were formed from a split-plot arrangement in which plots were 6 water deficit periods (P): (P1 = No deficit; P2 = Deficit in the initial growth stage; P3 = Deficit in the flower bud stage; P4 = Deficit in the flower stage; P5 = Deficit in the boll stage; and, P6 = Deficit in the open boll stage) and, the subplots, 2 upland cotton cultivars (C): (C1 = Brazil Seeds 286 and C2 = BRS 336), in randomized block design, with 4 replicates. Cultivars studied were more tolerant to water deficit in stages of initial growth, flower bud and open boll. Water deficit during flowers and bolls stages in upland cotton cultivars was the most detrimental to production components. Between cultivars tested, their behavior was similar only in cotton seed yield and water-use efficiency being BRS 286 higher than BRS 336 in other analyzed variables, except for mean open boll weight.

Key words: *Gossypium hirsutum* L. r. *latifolium* H., Hydric stress, agronomic variables.

INTRODUCTION

Cotton cultivation has great economic importance worldwide and it is also considered one of the main crops of great expression in the Brazilian economy. The cotton planted area in the 2016/17 season in the country was 930,400 ha, with lint production of 1,473,200 t in this harvest. While in the Northeast region, production was 361,000 t, in which the State of Paraíba contributed with 100 t of cotton lint in the 2016/17 season (Conab, 2017).

There is a marked presence of the genotype and environment interaction in the cotton crop, thus, a single cultivar cannot adapt to all cultivation regions of Brazil and it is important to identify the most appropriate

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cultivars for each ones (Carvalho et al., 1995). To this end, Araújo et al. (2013) stated that the success of a good agronomic performance of upland cotton will depend on the correct choice of the cultivar to be planted, as well as the environment and the cultural management.

It is necessary to know the agronomic and industrial characteristics of the cultivars commercialized in Brazil in order to ensure that producers will have technically and economically advantageous choices too. The same authors complement that cultivars that can adapt to different edaphoclimatic conditions are essential for an increase in the yield of any crop.

According to Shah et al. (2010), in the cultivation of upland cotton, the characterization of the stages of development of the crop by the chronological parameter results in extremely important variations regarding the real phenological stage when compared to different environments and/or years, as cultivation is highly influenced by the environment and the cultivar chosen, especially regarding thermal requirements. According to Araújo et al. (2013), knowledge regarding variations in the cotton plant during the development of these phenological stages is fundamental for the cultural management of the species.

According to Faggion et al. (2009), the recognition that water is an increasingly scarce natural resource imposes the need for more efficient production systems to ensure the sustainability of irrigated agriculture. Snowden et al. (2013) stated that the decrease in water availability may imply a need for changes and adaptations in irrigation strategies, since irrigation may be limited by low water availability in many regions. In this way, irrigation management is essential for the rational use of water in agricultural production to increase its efficiency. In the semiarid region, the cultivation of irrigated cotton is a good alternative for farmers, as it presents climatic characteristics that contribute to the production of good quality fibers and it can reach excellent yields (Brito et al., 2011).

However, research should seek to improve the irrigation management of cotton for high yields, high fiber quality and greater efficiency of water use by the crop (Zonta et al., 2015). The efficient use of water with adequate knowledge and the use of optimizing alternatives can contribute to increasing its availability, in this way reducing deficit problems caused by the increase in social demand in relation to environmental supply (Faggion et al., 2009).

It is important to study different cotton cultivars with water deficit applied on phenological stages in the semiarid region, since there may be cultivars that present different responses when subjected to water suppression in a certain stage of the cycle, which may lead to higher water-use efficiency and a more efficient crop production system. In addition, Zonta el al. (2015) stated that it is pertinent to test to what extent new cultivars respond to irrigation since many of them have been developed for the conditions of the Brazilian Cerrado and their cultivation coefficients may be underestimated for the semiarid conditions. Therefore, knowledge about the most tolerant stage of the cotton cycle for water stress can help in the decision of whether to use irrigation with controlled water deficit in some development stages, thus saving water without loss of yield, besides helping in the decision making of whether or not to use complementary irrigation during periods of drought.

The objective of this work was to study the effect of water deficit, applied on different phenological stages, in the production components and water efficiency of cultivars BRS 286 and BRS 336 of upland cotton, in order to relate the rational use of water for sustainable crop production in the semiarid region of Paraíba state, Brazil, and for the most appropriate irrigation management.

MATERIAL AND METHODS

The experiment was conducted under field conditions between June and December 2015 in the experimental area of the Center for Agricultural Science and Technology of the Federal University of Campina Grande, Campus of Pombal County, Paraíba State, Brazil, located in the following geographic coordinates: 06° 47' 52" S, 37° 48' 10" W and 175 m above mean sea level. The predominant climate of the region is hot semiarid (the BSh type), according to Köppen climate classification. The soil of the experimental area was classified as Fluvic Neo-soil (Santos et al., 2013), loamy sand texture (80% sand, 5.96% clay and 14.51% silt) and water tension curve of 15.49% (at 0.1 atm – Field Capacity - FC), 4.63% (at 15.0 atm – Permanent Wilting Point - PWP) with available water content (AWC) of 6.63% at the depth of 0–40 cm.

Fertilization was carried out according to the technical recommendations for the crop (Cavalcanti, 2008), based on the analysis of soil fertility as presented in Table 1, in the foundation by the application of 30 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 10 kg ha^{-1} of K_2O and in 2 covers, with the application of 30 kg ha^{-1} of N and 5 kg ha^{-1} of K_2O. Liming was not needed. Upland cotton cultivars were planted in single rows, spaced 1.0 m between rows x 0.10 m among plants.

The water used in the irrigation was of C_2S_1 salinity (low alkali and medium salinity hazard, with an electric conductivity - EC of 0.315 dSm^{-1}) and low sodium adsorption ratio (SAR = 1.78). Such water could be used for irrigation whenever there is a moderate degree of leaching and special care in the preparation of the soil. Water was applied by a localized irrigation system, with drip tapes and emitters spaced 0.10 m apart. Each treatment consisted of a lateral line, spaced from the other lines by 1 m with 6 m of length, each. Subsequently, after installation of the irrigation system and beginning of the experiment, a water distribution test was carried out in the field. Through this, the mean precipitation applied was determined as 8.86 mm h^{-1} and application efficiency (Ae) as 91%, according to Bernardo et al. (2008). Irrigations were carried out daily, always in the morning, based on the availability of soil water to plants. The replacement water volume was calculated considering the water evapotranspirated by the crop, which is represented as the difference between the soil water content in the field capacity and the current mean soil water content measured in the depths of 0.10, 0.20, 0.30 and 0.40 m, which were measured before irrigations. The current soil water content was determined by the time-domain reflectometry (TDR) method, using a Delta-T-PR2 probe introduced through access pipes installed in each treatment.

With the data of the current soil water content, using an Excel

Table 1. Chemical characteristics of the soil of the experimental area at different depths. Pombal county, Paraíba state, Brazil. 2015.

Depth	pH Water	OM (%)	P (mg 100 g^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+}
0-20 cm	6.79	1.16	51.5	0.14	0.42	4.28	1.40
20-40 cm	6.94	0.78	49.0	0.15	0.27	4.03	1.89

Source: Irrigation and Salinity Laboratory, UFCG, Campina Grande county, Paraíba state, Brazil.
pH = hidrogenionic potential; OM = organic matter.

Table 2. Detail of the deficit treatments. Pombal county, Paraíba state, Brazil. 2015.

Treatment	Period of application of the deficit	Beginning of the Deficit	Ending of the deficit	Total irrigation depth applied (La - mm)
No deficit (P1)	-	-	-	732.41
Deficit in the initial growth stage (P2)	22/Jul to 04/Aug	29 DAG	43 DAG	686.65
Deficit in the flower bud stage (P3)	03/Aug to 16/Aug	40 DAG	54 DAG	608.39
Deficit in the flower stage (P4)	18/Aug to 31/Aug	54 DAG	68 DAG	603.53
Deficit in the boll stage (P5)	26/Aug to 08/Sep	62 DAG	76 DAG	610.85
Deficit in the open boll stage (P6)	03/Oct to 16/Oct	100 DAG	114 DAG	649.67

(P1), (P6) = treatments designation; DAG = days after germination.

spreadsheet in which the daily values of the current soil water content and the availability of water to plants were recorded, the depth for the replacement of water and the time of irrigation were calculated for the treatments, which were the basis for the determination of the net and gross irrigation depth (NID and GID), according to Mantovani et al. (2009).

Treatments were formed from a split-plot arrangement in which the plots were 6 water deficit periods (P): (P1 = No deficit; P2 = Deficit in the initial growth stage; P3 = Deficit in the flower bud stage; P4 = Deficit in the flower stage; P5 = Deficit in the boll stage; and, P6 = Deficit in the open boll stage) and, the subplots, 2 upland cotton cultivars (C): (C1 = Brazil Seeds 286 and C2 = BRS 336), in randomized block design, with 4 replicates, amounting to 48 experimental subplots. Each period of water deficit consisted of 14 days without irrigation in the predetermined phenological stage, according to Table 2. After this period, the plants had normal irrigation until the end of the cycle. The total irrigation depth applied for each treatment was also presented in Table 2. The necessary phytosanitary treatments were carried out when the first injuries and symptoms of pests and diseases appeared, as well as crop treatments for weed control.

The number of open bolls per plant (NOBP_dimensionless) was determined by counting its total per plant in the subplot. The mean open boll weight (MOBW_g) and fiber percentage (F_%) were respectively determined on the subplot by the mean cotton seed weight (CSyield_kg ha^{-1}) of the 20 open bolls collected in the standard sample at the time of harvest and by weighing the lint/fiber after processing, which result in the percentage rate between total cotton lint weight (CLyield_kg ha^{-1}) and total CSyield in that sample.

CSyield was determined by harvesting and weighing the cotton seed production of the useful area of each subplot, extrapolating per hectare (kg ha^{-}1). Mean CLyield was calculated by multiplying the mean CSyield by F. Water-use efficiency (WUE_kg m^3) or water yield was defined as the ratio between the CSyield found (Ya) (kg ha^{-1}) and the total water used during the cycle (La) (m^3 ha^{-1}) for each treatment considered in the study (Geerts and Raes, 2009).

The obtained data were subjected to analysis of variance through the F-test and the means of the factor levels or treatments, both qualitative, were compared by the Tukey test at 5% of probability using the statistical program SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

According to Amaral and Silva (2008), the soil moisture profiles were evaluated in this layer during 126 days in all treatments of water deficit periods as presented in Figure 1, comparing them to the water content in the FC and PWP averages of soil of experimental area, because the higher concentration of cotton roots is in the 0.0 to 0.40 m depth layer. It can be observed that soil moisture in all treatments of each water deficit period was very close to the PWP, which increased during the period of application of the deficit and remained in approximately 50% of the AWC after this application. The deficit treatment applied in the open boll stage presented the same behavior of the irrigated treatment until a little before the application of the deficit period as presented in Figure 1.

According to Sun et al. (2015), tolerance to water stress depends on the plant growth stage and, when water deficit occurs at critical stages such as the reproductive stage, plant growth and development may be affected. Thus, it is very likely that the metabolic and physiological functions of the plants have been severely affected in this study.

The deficit Periods (P) affected the NOBP, MOBW, CSyield, CLyield, F and WUE ($p \leq 1\%$). Cultivar (C) influenced the NOBP, MOBW, CSyield and F ($p \leq 1\%$). Regarding the interaction (P x C), there was effect only for MOBW ($p \leq 1\%$) as can be seen in Table 3.

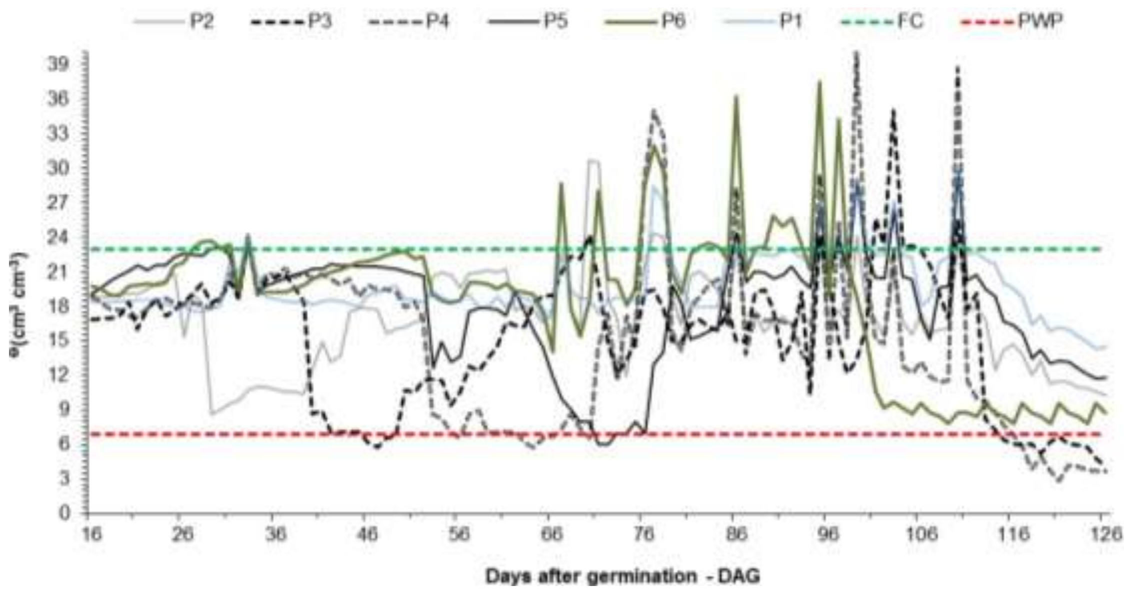

Figure 1. Variation of soil water content on the different water deficit treatments along experimental period. Pombal county, Paraíba state, Brazil. 2015.

Table 3. Summary of the analysis of variance for production components and water efficiency variables of two upland cotton cultivars under different water deficit strategies in the phenological stages. Pombal county, Paraíba state, Brazil. (2015).

SV	DF	NOBP	MOBW	CSyield	CLyield	F	WUE
		MS					
Blocks	3	2.48	0.01	180438.55	24812.51	2.77	0.0042
Deficit periods (P)	5	115.82**	2.32**	11515815.40**	1950556.14**	8.65**	0.1796**
Error 1	15	3.66	0.12	565194.48	97831.48	0.84	0.0135
Cultivar (C)	1	56.87**	9.72**	184973.56^{ns}	590693.37**	403.68**	0.0056^{ns}
P × C	5	2.40^{ns}	0.53**	314496.20^{ns}	27220.60^{ns}	4.32^{ns}	0.0071^{ns}
Error 2	18	2.33	0.07	122054.23	19502.74	0.89	0.0028
Total	47						
General mean		8.72	6.23	2971.01	1235.93	41.57	0.45
CV 1 (%)		21.95	5.70	25.30	25.31	2.21	25.84
CV 2 (%)		17.50	4.29	11.76	11.30	2.27	11.87

^{ns}, ** and *: not significant and significant at p≤0.01 and p≤0.05, respectively (F-Test). MS = Mean squares; CV = coefficient of variation.

Bezerra et al. (2003), when studying the effect of soil water deficit on the cotton lint yield of the upland cotton cultivar BRS 201, have reported that yield was affected by the water deficit in the various crop development stages, with a significance level at 1% probability. Zonta et al. (2015) have also found significance at 1% probability for the studied factors when evaluating the effect of irrigation on cotton lint quality and yield; in addition, Zonta et al. (2017) also have found significant differences at 1% probability for the factors studied when evaluating the response of cotton to water deficit in different stages of the crop cycle. Relative to the effect of the water deficit strategies studied (deficit periods), upland cotton showed a tendency to decrease the NOBP when the plants were subjected to water deficit in different phenological stages, which was present when irrigation was stopped in the stages of P2, P3, P4 and P5, but not in P6, when this decrease was smaller as presented in Figure 2A.

Mean NOBP decreased in 44.44, 43.13, 58.16, 75.16 and 37.25%, respectively, in relation to the treatment without water deficit (P1) as shown in Figure 2A. This is probably because the water deficit caused a decrease in flower buds, flower abortion and/or shedding of bolls,

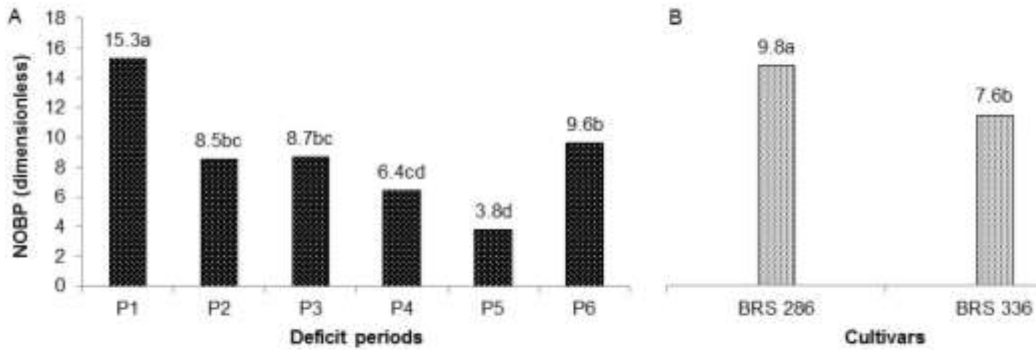

Figure 2. Mean number of open bolls per plant of two upland cotton cultivars under different water deficit strategies in the phenological phases (A. Deficit periods; B. Cultivars). Pombal county, Paraíba state, Brazil. 2015. Same letters in the factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).

resulting in lower NOBP. According to Zonta et al. (2017), the water deficit applied in the initial growth (P2) and open boll (P6) stages had the least effect on the NOB per meter, since either the plant did not yet have reproductive structures or it already had most of its bolls formed, as the stage of formation of open bolls (maturation stage) is tolerant to water stress (Jalota et al., 2006), which are similar to the results obtained in this study.

These results also are similar to those reported by Silva et al. (1998), who studied the effect of water stress on the phenology and some technological characteristics of the upland cotton fiber CNPA 6H and by Ünlü et al. (2011), who stated in their studies that deficit irrigation caused a significant decrease in the NOBP. As well as they were the same of Almeida et al. (2017), when studying the effect of water deficit on upland cotton production, stated that there was a decrease in the NOBP in the water deficit periods, and Zonta et al. (2017), who stated that an important characteristic related to yield is the NOBP, since the higher retention of open bolls will represent higher yield. The latter authors also stated that the NOBP was affected by water deficits and the best results were obtained by the treatments without water restriction, followed by treatments with water restriction in the stages of initial growth (P2) and first boll opening (P6) and lastly the worst results were in the stages of appearance of the first flower bud (P3), the first flower (P4) and the first boll (P5) (Zonta et al. 2017), as observed in this work.

The stage of flowering (flower) and fruiting (boll) (P4 and P5) were the less tolerant to soil water deficit as presented in Figure 2A, whose result was similar to Souza et al. (1997), who found decreases of 23 and 53% in the NOBP on the fourteenth day of stress when studying the influence of soil water saturation on the physiology of cotton CNPA 7H. According to Beltrão (2006), these stages are triggered from the flowering to the opening of the bolls during a variable period, after which fiber is obtained, which is considered the main product of cotton.

Snowden et al. (2014) also observed decreases of 60% in the NOBP when comparing the treatments with water deficit for 3 weeks after the flowering and control treatment, with similar results to those found in this study in the water deficit treatment in the stage of appearance of the first open boll (P6). Gwathmey et al. (2011) stated that water deficit at the beginning of flowering tends to increase the shedding of floral buds, whereas water deficit at the end of it reduces the rate of flowering and retention of bolls, which also is similar to the results obtained in this study.

Regarding the cultivar factor, cultivar BRS 336 had a lower value for the NOBP in relation to cultivar BRS 286, with mean values of 7.63 and 9.81 NOBP, respectively as presented in Figure 2B. According to Iqbal et al. (2010), Baloch et al. (2011) and Niu et al. (2013), tolerance to abiotic stress, including drought tolerance, varies according to genotype.

Within the effect of the cultivar in the water deficit strategies (deficit periods) in MOBW, cultivars BRS 286 and BRS 336 differed statistically among all water deficit periods except in P5. Overall, the MOBW of cultivar BRS 336 was less affected than BRS 286 by the applied water deficits as shown in Figure 3A.

Related to the deficit periods in the cultivars for MOBW, it can be observed that cultivar BRS 286 showed the highest MOBW values in the deficit periods P1 and P2 (control and water deficit in the initial growth stage); in turn, cultivar BRS 336 presented the same behavior as presented in Figure 3B. In general, for both cultivars, MOBW decreased as the deficit periods were applied in the different phenological stages of the cotton plant, but water deficit was more restrictive after the flower bud (P3) stage as can be seen in Figure 3B.

Therefore, cultivars BRS 286 and BRS 336 presented differences between each other in most of the studied treatments and regarding the variety standards, which is 5.5 to 6.0 g for BRS 286 (Silva Filho et al., 2008) and 6.6 g for BRS 336 (Morello et al., 2011) and some treatments had MOBW above or below these ones as presented in Figure 3 A and B. Silva et al. (1998), studied the effect of

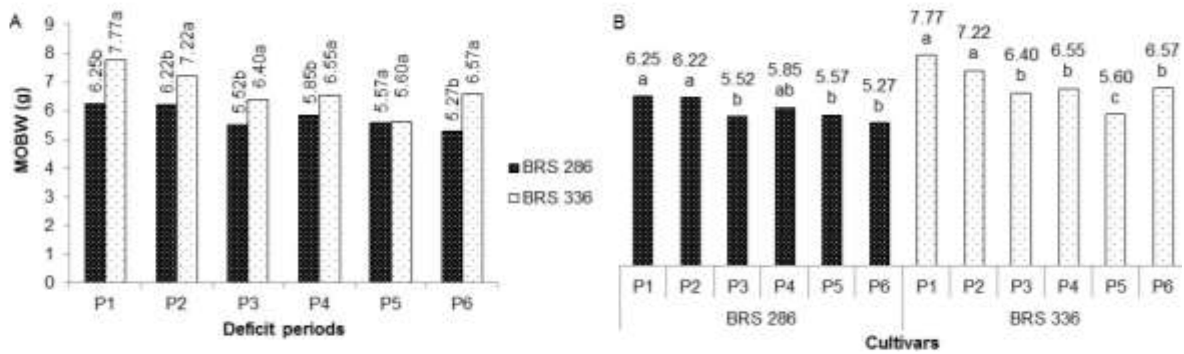

Figure 3. Development (A) of the cultivars in each deficit period and (B) deficit periods in each cultivar for mean open boll weight of two upland cotton cultivars under different water deficit strategies in the phenological phases. Pombal county, Paraíba state, Brazil, 2015. Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).

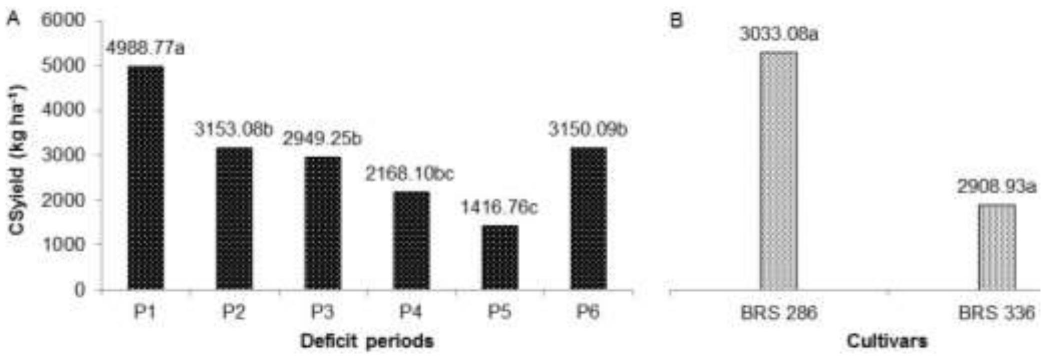

Figure 4. Mean cotton seed yield of two upland cotton cultivars under different water deficit strategies in the phenological phases (A. Deficit periods; B. Cultivars). Pombal county, Paraíba state, Brazil. 2015. Same letters in the Factors (A and B) indicate no significant difference among means (Tukey, p<0.05).

the water deficit on the lint technology and phenology of cotton CNPA 6H, and found similar results as this study when reporting a decrease in the MOBW per plant subjected to water stress.

The deficit periods affected CSyield which decreased when the plants had no irrigation in different phenological stages, that is in the stages of P2, P3, P4, P5 and P6, with mean reductions of 36.80, 40.89, 56.55, 71.61 and 36.86%, respectively, in relation to P1. The phenological stages P3, P4 (floration) and P5 (fruiting) were the less tolerant to water deficit as shown in Figure 4A. Such results were similar to Zonta et al. (2015) and Zonta et al. (2017) who stated that the deficit in cotton irrigation provided decreased CSyield, as a consequence of the sharp shedding of flowers and young bolls, which is reflected in crop yield and also to Onder et al. (2009) who showed that deficit irrigation causes a decrease in yield and yield components, as observed in this study.

Regarding the cultivars evaluated, BRS 286 and BRS 336 showed similar cotton yields (3,033.08 and 2,908.93 kg ha^{-1}, respectively) as shown in Figure 4B. Almeida et al. (2017), evaluating the production of upland cotton cultivars under water deficit, found similar results in terms of yield. These data also was similar to results obtained by Jalota et al. (2006) and Almeida et al. (2017) who stated that the stage of formation of open bolls (P5) is less tolerant to water stress and that water deficit promoted the fall of flower buds, flower abortion and/or shedding of bolls and open bolls, resulting in lower yield. Zonta et al. (2017), in turn, stated that when water deficit is applied in these stages (formation of flower and boll), the plant has a decreased formation and a marked shedding of reproductive structures (flowers and young bolls), which compromises yield, thus corroborating the results obtained in this study.

Sousa Júnior et al. (2005), Cordão Sobrinho et al. (2007) and Mendez-Natera et al. (2007) have reported that low levels of soil water caused a decrease in CSyield. In addition, the same authors have verified that water deficit reduces flowering and the retention of bolls

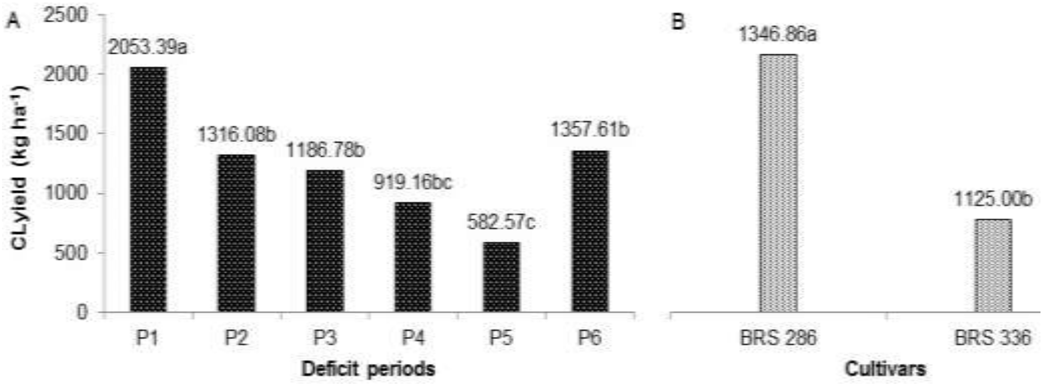

Figure 5. Mean cotton lint yield of two upland cotton cultivars under different water deficit strategies in the phenological phases (A. Deficit periods; B. Cultivars). Pombal county, Paraíba state, Brazil. 2015. Same letters in the Factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).

and causes the inadequate formation of the different parts of the plant such as stems, leaves and bolls, thus causing a decrease in yield. Adequate water availability provides increased yield. On the other hand, water deficit decreases yield (Nunes Filho et al., 1998; Cordão Sobrinho et al., 2007).

The behavior of cotton CLyield was similar to CSyield and it decreased when the plants had no irrigation in different phenological stages, that is in the stages of P2, P3, P4), P5 and P6, with mean decreases of 36.76, 37.45, 55.92, 73.46 and 35.90%, respectively, in relation to P1. The phenological stages of P3, P4 (floration) and P5 (fruiting) were the less tolerant to water deficit as seen in Figure 5A.

Cultivar BRS 286 showed higher CLyield because of its variety characteristics of higher fiber percentage in relation to BRS 336 (1,346.86 and 1,125.00 kg ha^{-1}, respectively) as presented in Figure 5B. Except for treatment P1 (without water deficit), mean values of CLyield were below the variety standard in all other deficit treatments as presented in Figure 5B, which is 1,995 kg ha^{-1} for cultivar BRS 286 and 1,527 kg ha^{-1} for cultivar BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively. CLyield was influenced by CSyield, and by F of the cultivars. Finally, the cultivars evaluated presented lower CLyield than the national average, which was 1,473.2 kg ha^{-1} in the 2016/17 season (Conab, 2017). The results presented was similar to Wen et al. (2013), who found decreases in CLyield when testing several cotton cultivars subjected to water deficit irrigation.

In general, the treatments with water deficit in the stages of P2 and P3 as shown in Figures 4 and 5 were less affected since the plant had time to recover from water stress, as observed in the study of the gas exchange of these cultivars when CSyield and CLyield were little impaired. The water deficit applied in the P6 also did not seriously influence yields, as most bolls were already formed at that stage. This comment was similar to Zonta et al. (2017) who stated that irrigation with controlled water deficit can be used in the cotton crop, with smaller irrigation depths in these stages (P2, P3 and P6), when the cotton is more tolerant to drought, which would increase the efficiency in the use of irrigation water.

Furthermore, Guinn and Mauney (1984) stated in their research that (severe) water restriction reduces cotton yield because of the decrease in the NOB per area, given the decrease in flowering and the shedding of young bolls. Other authors such as Pettigrew (2004) and Wen et al. (2013) also pointed out that water limitation in cotton causes the shedding of bolls and consequently lower yield. Loka and Oosterhuis (2012) stated that the reproductive stage is the less tolerant to water stress in the cotton crop, while Kock et al. (1990), Plaut et al. (1992) and Radin et al. (1992) stated in their works that the filling stage of the bolls is the less tolerant to water stress, which is similar to the results found in this study.

Cotton when subjected to treatment P3 presented lower F than the other deficit treatments, but it did not differ statistically from P1 and P5, whereas when the plant was subjected to treatment P6 it presented a higher F, but it was statistically equal to P4 as presented in Figure 6A. Thus, differences can be observed in F in relation to the water deficit periods, although F was higher than 40% in all stages in which the cotton plants underwent either water restriction or not, which is similar to the values/results found by Basal et al. (2009), Onder et al. (2009) and Hussein et al. (2011), who stated that F is not affected by water deficit but by the hereditary characteristics of the cultivars. Cultivar BRS 286 presented a mean of 44.47% above the variety standard that is 39.5 to 41.0% (Silva Filho et al., 2008); cultivar BRS 336 presented a mean of 38.67% within the variety standard that is 38.0 to 39.5% (Morello et al., 2011). Cultivar BRS 286 had a higher F than BRS 336 as presented in Figure 6B.

The results mentioned above was similar to Zonta et al.

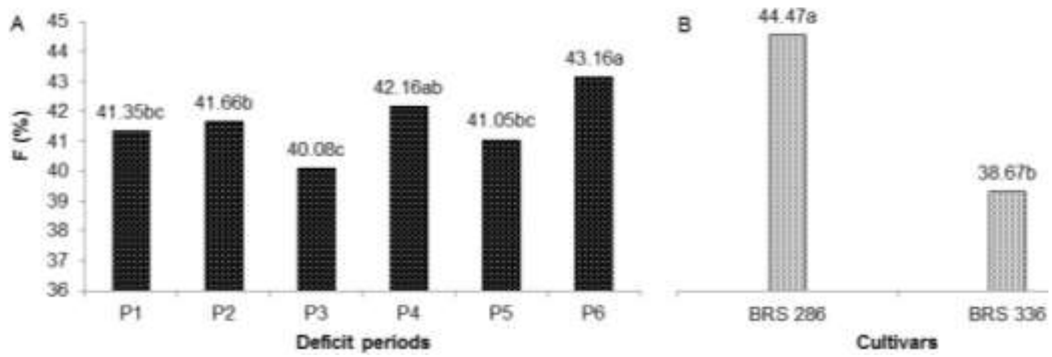

Figure 6. Means of fiber percentage of two upland cotton cultivars under different water deficit strategies in the phenological phases (A. Deficit periods; B. Cultivars). Pombal county, Paraíba state, Brazil. (2015). Same letters in the Factors (A and B) indicate no significant difference among means (Tukey, p<0.05).

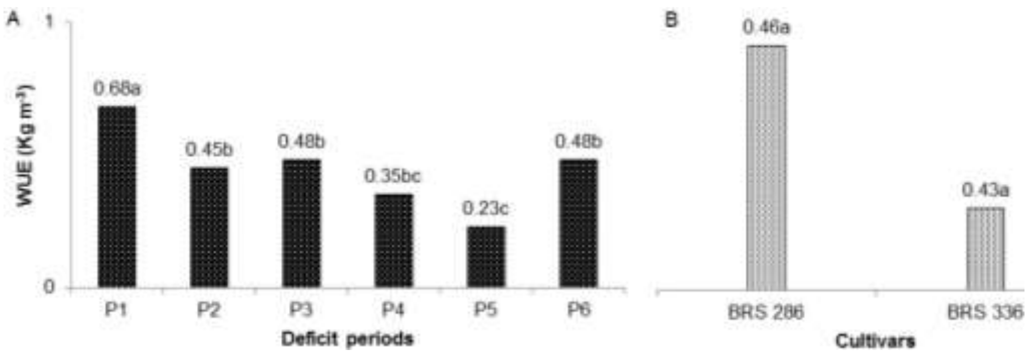

Figure 7. Means of water-use efficiency of two upland cotton cultivars under different water deficit strategies in the phenological phases (A. Deficit periods; B. Cultivars). Pombal county, Paraíba state, Brazil. (2015). Same letters in the Factors (A and B) indicate no significant difference among means (Tukey, p<0.05).

(2015) found when evaluating the effect of irrigation on CLyield and quality in which cultivar BRS 336 presented the lowest performance in CLyield, as well as the lowest performance in relation to F and CSyield. Opposite results were found by Almeida et al. (2017) when evaluating the production of upland cotton cultivars under water deficit, as they found different results in terms of F with treatments and cultivars that did not differ among themselves.

According to Zonta el al. (2017), when using irrigation with controlled water deficit, an important factor to be evaluated is the WUE of crops, especially in arid and semiarid regions, where water availability is limited. Cotton when subjected to treatment P1 presented higher mean WUE than the other deficit treatments, whereas when it was subjected to treatment P5 it presented the lowest absolute value, being statistically equal to only treatment P4 as presented in Figure 7A. Both cultivars presented the same WUE as shown in Figure 7B. The WUE decreased as the deficit periods were applied in the different phenological stages (from P1 to P6). As the applied volume was practically the same (low variation) from P2 to P6, what determined this variable was the yield, or rather, the effect of the deficit periods on yield, so that P2, P3 and P6 suffered the least effects. Compared to the results obtained by Embrapa Algodão (2006), whose overall WUE for cotton seed yield varies from 0.4 to 0.6 kg m^{-3}, all treatments are within this range, except for P4 and P5 (0.35 and 0.23 kg m^{-3}). The decrease in WUE in treatments with water deficit can be attributed to a decrease in the number of reproductive organs in relation to the vegetative ones, that is, a decrease in the harvest index. It should also be noted that in areas where water is a limiting factor, such as in the semiarid region, maximizing WUE is often more economically profitable for the producer than maximizing yield (Geerts and Raes, 2009). Zonta et al. (2017), working with 8 upland cotton cultivars subjected to water deficit at different stages of the crop, stated that the WUE behavior was very similar for all cultivars, varying between 0.39 and 0.84 kg m^{-3}.

According to last author, the worst results occurred in general for the treatment with water restriction in the stage of appearance of boll and flower and there was no statistical difference for the treatments with water restriction in the stages of initial growth and appearance of flower buds. In addition, most cultivars behaved very similarly when subjected to water deficit, regardless of the stage of the crop cycle, which corroborates the results found in this study.

Regarding the range of values, the WUE obtained can be considered high, except for treatment with water deficit in the stage P4 and P5, as Dagdalen et al. (2009), Singh et al. (2010) and Zonta et al. (2016) found values for WUE ranging from 0.4 to 0.8 kg m^{-3} in the well-irrigated treatments, that is, without water deficit. Zonta et al. (2017) demonstrated that irrigation with controlled water deficit can be an option to save water in cotton irrigation if it is carried out in the stages when the crop is more tolerant to water stress, which are the stages of initial growth, appearance of flower buds and appearance of open bolls.

Cultivar BRS 336 showed lower performance in the NOBP (7.63), CLyield (1,114.17 kg ha^{-1}) and F (38.19%), but it was better in MOBW (6.68 g); both cultivars were similar in performance in CSyield and in WUE.

In general, virtually for all variables studied, a decrease was observed when water deficit was applied in the periods of appearance of flower and boll. Corroborating this research, Bauer et al. (2012) stated that the problem of water deficit at the beginning of flowering is that the crop is acclimated to vegetative growth, which has no restrictions, as the plant is in optimal water conditions. According to Oosterhuis and Wullschleger (1987), the sudden water stress in a previously non-stressed plant can cause severe damage to plants. Brito et al. (2011) stated in their work that the reproductive stages coincide with the stage of increased water demand of the crop, which varies from 2.5 to 6 mm day^{-1}, thus, water deficit in these stages has more severe consequences as stated by Bauer et al. (2012). According to Yeates (2014), bolls are less affected by water deficit and will maintain growth after the leaves and internodes have stopped growing. This is because water is supplied to the bolls by the phloem and not by the xylem; therefore, they do not depend on the water potential gradient between the plant and the soil or atmosphere (Zonta et al. 2017).

Furthermore, according to Yeates (2014), abortion of fruit structures can occur up to 14 days after anthesis (<2 cm in diameter), when thickening of the cell wall between the fruit and the stem, prevents the formation of an abscission layer. Guinn (1982) presented another interpretation that large flower buds and flowers are more tolerant to shedding under water stress than young bolls, which corroborates the results obtained in this study.

Conclusions

Cultivars studied were more tolerant to water deficit in the stages of initial growth (P2), flower bud (P3) and open boll (P6). Water deficit during the flowers and bolls stages in upland cotton cultivars was the most detrimental to production components. Between cultivars tested, their behavior was similar only in cotton seed yield and water-use efficiency being BRS 286 higher than BRS 336 in the other analyzed variables, except for mean open boll weight.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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