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Cotton growth in response to water supply in red Latosol cerrado

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There are few studies that demonstrate the influence of water stress in biometric variables and cotton growth. Thus, the objective of this study was to evaluate different levels of water supply in the BRS 2 cotton growth, in the field of Campus Rio Verde - GO, in 2015. Experimental design used was randomized blocks, with three replications in a split-plot scheme of 5 x 4 with five water replacements (WR) (25, 50, 75, 100 and 125%) of evapotranspiration, and four times of evaluation (ET) during the growth cycle (40-60, 61-80, 81-100 and 1-20 days after emergence). The variables analyzed were plant height (PH), leaf area (LA), dry phytomass stem (DPS), dry phytomass of leaves (DPL), dry phytomass of reproductive organ (DPRO), dry phytomass of aerial part (DPAP), absolute growth rate (AGR), relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR). The behavior of PH and LA under the influence of water levels revealed that for a better performance of studied variables, it is important to consider the irrigation management, besides the crop coefficient. Water replacement influenced the cotton growth. Low cotton growth rate was caused by the reduction of water supply until the end of growth cycle.

Key words: *Gossypium hirsutum* L., dry phytomass, drip irrigation, crop evapotranspiration.

INTRODUCTION

Cotton crop (*Gossypium hirsutum* L.) has great socio-economic importance, being one of the main Brazilian agricultural products to be used in the textile industry, animal feed and the production of vegetable oil, as well as, its derivatives for human consumption, among other purposes.

Its cultivation is mainly in the Midwest region of Brazil, with about 627 thousand hectares planted in 2014/15 (Conab, 2015), due to the favorable edaphoclimatic conditions. However, most cases are in a situation of water deficit. During cotton life cycle, cultivation requires between 650 and 900 mm of water (Aquino et al., 2012), with a daily rate of water consumption relatively low (about 6.5 mm day^{-1} during the phase of higher transpiracy

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Table 1. Some physical and chemical characteristics of a 0 - 20 cm soil layer of a dystrophic Red Latosol at Campus Rio Verde.

Depth	Density	Total porosity	Sand	Silt	Clay	Sorption Complex[1]				H+Al	OM	BS	CEC	V	pH
						Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}						
cm	g cm^{-3}	%	g kg^{-1}			$cmol_c$ dm^{-3}					%	$cmol_c$ dm^{-3}		%	-
0 - 20	1.19	53.03	463	174	322	2.71	1.16	0.13	0.52	0.3	4.02	5.41	7.83	69.1	5.50

[1] Ca^{2+} and Mg^{2+} extracted with HCl 1 mol L^{-1} at pH 7.0; Na^{+} and K^{+} extracted using NH_4OAC 1 mol L^{-1} at pH 7.0; pH determined in $CaCl_2$ solution.

of higher transpiratory demand), even in hot climates and with adequate supply of water in the soil (Oliveira et al., 2004).However, according to Bezerra et al. (2010) cotton has a low water demand up to flowering stage which occurs around 50 DAE.

Water availability is a very important factor affecting cotton morphology and physiology, which influence crop productivity. As Oliveira et al. (2012) noted, the best cotton yield was obtained with a certain amony of water corresponding to approximately 20% of soil water content, which exceeds the ETo.

Although cotton shows a good tolerance to water stress, water deficit may cause significant losses in productivity (Batista et al., 2010) due to a reduction in plant growth and vegetative development.According to Baldo et al. (2009), water deficit may cause drops of flowers and fruits, as well as, the production of low fiber content. Oliveira et al. (2008) affirming that biometric variables, like the stem diameter and plant height are affected, in addition to the leaf area and biomass, resulting in lower productivity and worse quality of fiber (Cordão Sobrinho et al., 2007).

There are few studies that demonstrate the influence of water stress in these biometric variables, and the growth of the cotton crop. Thus, the objective of present study was to evaluate different levels of water replacements in the cotton growth.

MATERIALS AND METHODS

The experimental study was conducted in an experimental area of the Federal Institute Goiano, Campus Rio Verde (17°48'S, 50°54'W; 744 m asl.). Sowing was held on July 05, 2015.

The climate is classified according to Köppen and Geiger (1928) as Aw, tropical, with an average annual temperature of 21ºC, annual precipitation between 1,500 to 1,800 mm and a relative humidity of 30 to 85%.

Soil of experimental area is classified as dystrophic Red Latosol (Oxisol), with a medium texture in the cerrado phase (Santos et al. 2013). Soil preparation was performed with a harrow and leveler. In Table 1, the main physical and chemical characteristics of the soil are presented.

Experimental design used was under randomized blocks, with three replications in a split plot scheme of 5 x 4 with five water replacements (WR) (25, 50, 75, 100 and 125%) of evapo-transpiration and four times of evaluation (ET) of culture (40-60, 61-80, 81-100 and 1-20 days after plant emergence, DAE). Each plot consisted of 5 lines and 4.0 m long and 0.90 m spacing between lines. The area of the plot consisted of 3 central lines of 2.0 m/each.

A drip irrigation system, managed by the method of simplified water balance based on Tank "Class A" (AGR) (Allen et al., 1998), in which, first determined the irrigation efficiency (Ie) system according to Keller and Karmeli (1975), measured daily evaporation (mm) using a micrometer and evapotranspiration of reference (ET_0) was determined by multiplying the evaporation and the tank coefficient (Kp) equal to 0.65. Crop evapotranspiration (ETc) was determined by multiplying the ET_0 the crop coefficient (Kc) determined by Oliveira et al. (2013). The 100% water depth was determined based on ETc and Ei, and then extrapolated to other blades used to compose the treatments.

In each evaluation time (ET), measurements of plant height (PH) were taken, considering the distance from ground level to the plant apex. Afterwards, two plants were collected at ground level in each replicate, and were separated in plant organs: leaves, stems+branches and reproduction organ.The leaf area was determined using the equation proposed by Grimes and Carter (1969): $y = 0.4322\ x^{2,3002}$, where y is 1-leaf, x is the length of the main rib cotton leaf; and then the leaf area per plant was determined by the sum of leaf areas.

Plant material was placed in forced-air circulation greenhouse, at 65°C for 72 h and subsequently weighed to determine dry phytomass stem (DPS), dry phytomass leaf (DPL), dry phytomass of the reproductive organ (DPRO) anddry phytomass of aerial part (DPAP).

AGR (absolute growth rate) per day, was calculated by the equation AGR = (Pn - Pn-1)/(Tn - Tn-1), in which Pn is the dry phytomass accumulated until evaluation to n; Pn-1 is the accumulated dry phytomass to evaluation n-1; Tn is the number of days after treatment when evaluation n; and Tn-1 is the number of days after treatment at the time of evalution n-1.

The RGR (relative growth rate) growth in a certain time interval in relation to the phytomass accumulated at the beginning of this interval, the RGR was calculated by the equation RGR = (ln P2 - P1 ln) / T1 T2-g^{-1} g per day.

The NAR (net assimilation rate) is dry phytomass produced per unit leaf area and time and was calculated using the following equation: NAR = [(Pn - Pn-1) / (Tn - Tn-1)] [(1nAn - 1nAn-1) / (An - An-1)], where An is the leaf area; and An-1 is area leaf of the plant during evaluation n-1.

LAR (leaf area ratio) was calculated by the equation An = LAR/Pn, and the relationship between leaf area responsible for the photosynthesis and total dry phytomass produced.

Results were submitted to analysis of variance and significant variances were compared at 5% probability level. Choice of the models was based on the significance of the regression coefficients using the t-test at 5% probability and the coefficient of determination.

RESULTS AND DISCUSSION

There was a significant effect for the interaction of evaluation time (ET) and water replacement (WR) for the

Table 2. Summary of analysis of variance for the variables plant height (PH), leaf area (LA), dry phytomass stem (DPS), dry phytomass of leaves (DPL), dry phytomass of reproductive organ (DPRO), dry phytomass of aerial part (DPAP), absolute growth rate (AGR), relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) under different water replacement (WR) at different evaluation times (ET) during the crop cycle, in Campus Rio Verde - GO, 2015.

Source of variation	df	Means square[1]					
		PH	LA	DPS	DPL	DPRO	DPAP
WR	4	795.52**	3716703.00**	92.79**	137.66**	31.07**	839.22**
Block	2	3.37^{ns}	52898.61^{ns}	2.82^{ns}	14.48^{ns}	1.63^{ns}	3.97^{ns}
Residue (a)	8	4.08	168623.50	14.28	9.76	0.77	4.08
ET	3	6380.42**	21948699.94**	2127.90**	516.53**	8926.94**	27019.27**
WR x ET	12	58.71**	351302.33**	3.55^{ns}	4.13^{ns}	8.48**	57.89**
Residue (b)	30	4.82	115777.71	9.02	11.09	0.80	4.07
CV (a) (%)		2.58	10.28	10.31	10.15	3.07	2.09
CV (b) (%)		2.80	8.52	8.20	10.82	3.12	2.09

		AGR	RGR	NAR	LAR
WR	4	0.05**	3.00x10$^{-5\ ns}$	1.46x10-8 **	98.77**
Block	2	0.01^{ns}	7.90x10$^{-7\ ns}$	2.56x10$^{-9\ ns}$	4.29 ^{ns}
Residue (a)	8	0.003	1.67x10^{-7}	2.11x10^{-9}	25.46
ET	3	3.22**	1.86x10-3 **	2.40x10-7 **	1088.13**
WR x ET	12	0.44**	1.28 x10-4 **	9.37x10$^{-9\ ns}$	60.25 ^{ns}
Residue (b)	30	0.016	3.00x10^{-6}	1.84x10^{-9}	13.60
CV (a) (%)		3.71	1.80	11.40	11.40
CV (b) (%)		8.60	7.68	10.65	8.33

[1] ^{ns} – F - value non-significant at p ≥ 0.05. ** - F - value significant at 1% of probability.

following variables: plant height (PH), leaf area (LF),dry phytomass of the reproductive parts (DPRP), dry phytomass of aerial part (DPAP), absolute growth rate (AGR) and relative growth rate (RGR). The variables, dry stem phytomass (DPS), dry leaf phytomass (DPL), net assimilation rate (NAR) and leaf area ratio (LAR) showed significant variability for isolated factors. The coefficients of variation were low (2.09 - 10.82%), which shows relatively good experimental precision (Table 2).

Several researchers have noted the importance of study related to irrigation levels on the growth, development and production of different cultures, because of this, allow the identification of the level that provides the best conditions to culture, as an example of Smith et al. (2015) found that variability in biomass and production of sunflower under the influence of irrigation levels, as Morais, et al. (2016) on growth and development of the bean crop and Zonta et al. (2015) in the production of cotton.

Changes in the performance of plants related to irrigation is explained to the stress caused by excess water in the soil, causing the death of root tissues due to lactic fermentation and acidosis in the cells, the moment that the soil is in lack of oxygen , which leads to lack of energy, and causes the plant to reduce the potential for absorption of nutrients.On the other hand, the soil water deficiency can lead to plant water stress and thus cause a reduction in cell growth, leaf area, ratio of the biomass of roots and shoots, lower nutrient absorption, stomatal closure and reduction in photosynthesis (Taiz and Zeiger, 2010).

Figure 1 shows the positive linear adjustment of variables DPS and DPL due of WR and ET. DPS and DPL increased with WR (Figure 1A), with estimated increase of 0.22 and 0.35%, respectively, with a unit increase in WR. Still, for DPS and DPL (Figure 1B), there was an increase in the estimated daily from 15.69 and 1.92%, respectively, in a 20-days period.Thus, it is clear that even for ET of 101-120 days, the cotton plants is still able to assimilate production by stems and leaves.

Increased water stress resulted in the formation of small leaves with reduced leaf area, and consequently reduction in light absorption by plant and lower production of assimilates (Souza, 2014).

Figure 2 shows the WR split within each level of ET. It was found that for 60, 80, 100 and 120 DAE a larger PH was estimated (62.4; 94.6; 106.1 and 108.6 cm for 109.2; 119.7; 125 and 125% WR, respectively) (Figure 2A). This fact shows that plants did not enter the senescence before 120 DAE. In unfolding the ET in each level WR, noted that 25% RH the 7.31% PH increased daily 50% WR greater PH was estimated at 120 DAE, while WR 75, 100 and 125 found to be larger PH (99.48; 107.30 and 104.63 cm) at 120, 114 and 114 days, respectively

DPS = 31.38 + 0.070**WR $R^2 = 0.99$
DPL = 24.36 + 0.085**WR $R^2 = 0.99$

DPS = - 2.7923 + 0.4382**ET $R^2 = 0.902$
DPL = 11.266 + 0.2167**ET $R^2 = 0.909$

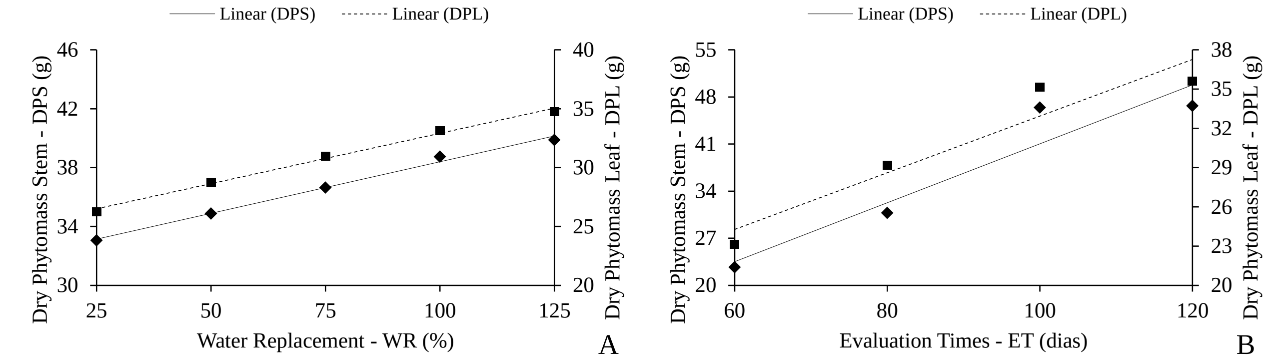
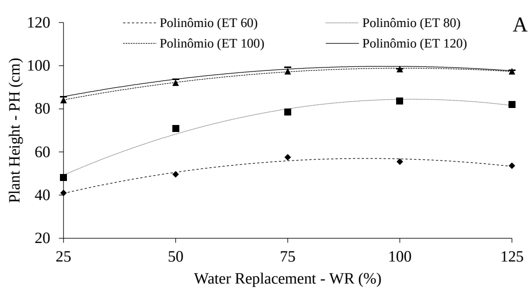
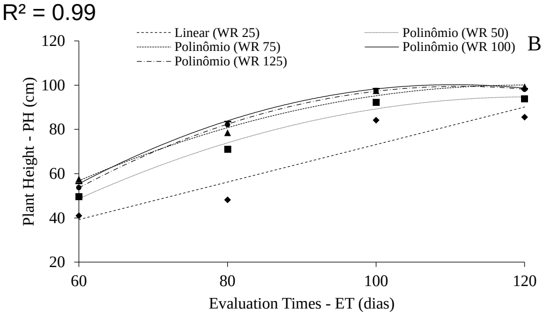


Figure 1. Regression analysis for following variables: dry phytomass leaf and stem (A) depending water replacement and dry phytomass leaf and stem (B) due cotton in evaluation time, Campus Rio Verde, March 2016. ** - F - value significant at 1% of probability.

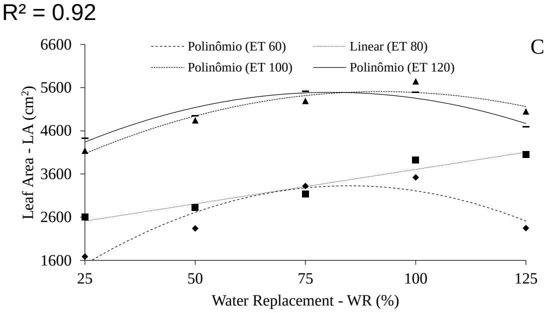
ET (40-60) = 26.66 + 0.655**WR - 0.003**WR^2
$R^2 = 0.97$
ET (61-80) = 23 + 1.197**WR - 0.005**WR^2
$R^2 = 0.99$
ET (81-100) = 72.85 + 0.516**WR - 0.002**WR^2
$R^2 = 0.99$
ET (101-120) = 74.23 + 0.525**WR - 0.002**WR^2
$R^2 = 0.98$



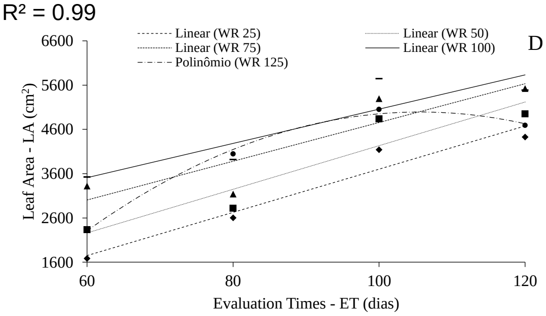
WR (25) = - 11.59 + 0.847**ET
$R^2 = 0.87$
WR (50) = - 86.38+ 2.99*ET -0.012**ET^2
$R^2 = 0.98$
WR (75) = - 72.6+ 2.874**ET -0.012**ET^2
$R^2 = 0.99$
WR (100) = - 114.2+ 3.881**ET -0.017**ET^2
$R^2 = 0.99$
WR (125) = - 116.3+ 3.876**ET -0.017**ET^2
$R^2 = 0.99$



ET (40-60) = - 329.1 + 86.15**WR -0.507**WR^2
$R^2 = 0.87$
ET (61-80) = 2110 + 15.95**WR
$R^2 = 0.94$
ET (81-100) = 3074 + 59.85**WR - 0.370**WH^2
$R^2 = 0.92$
ET (101-120) = 3074 + 59.85WR - 0.370**WR^2
$R^2 = 0.92$



WR (25) = - 1181 + 48.83**ET
$R^2 = 0.945$
WR(50) = - 693.1 + 49.24**ET
$R^2 = 0.88$
WR(75) = 378 + 43.79**ET
$R^2 = 0.80$
WR(100) = 1189 + 38.68**ET
$R^2 = 0.80$
WR(125) = – 9372+ 271.9**ET -1.287**ET^2
$R^2 = 0.99$



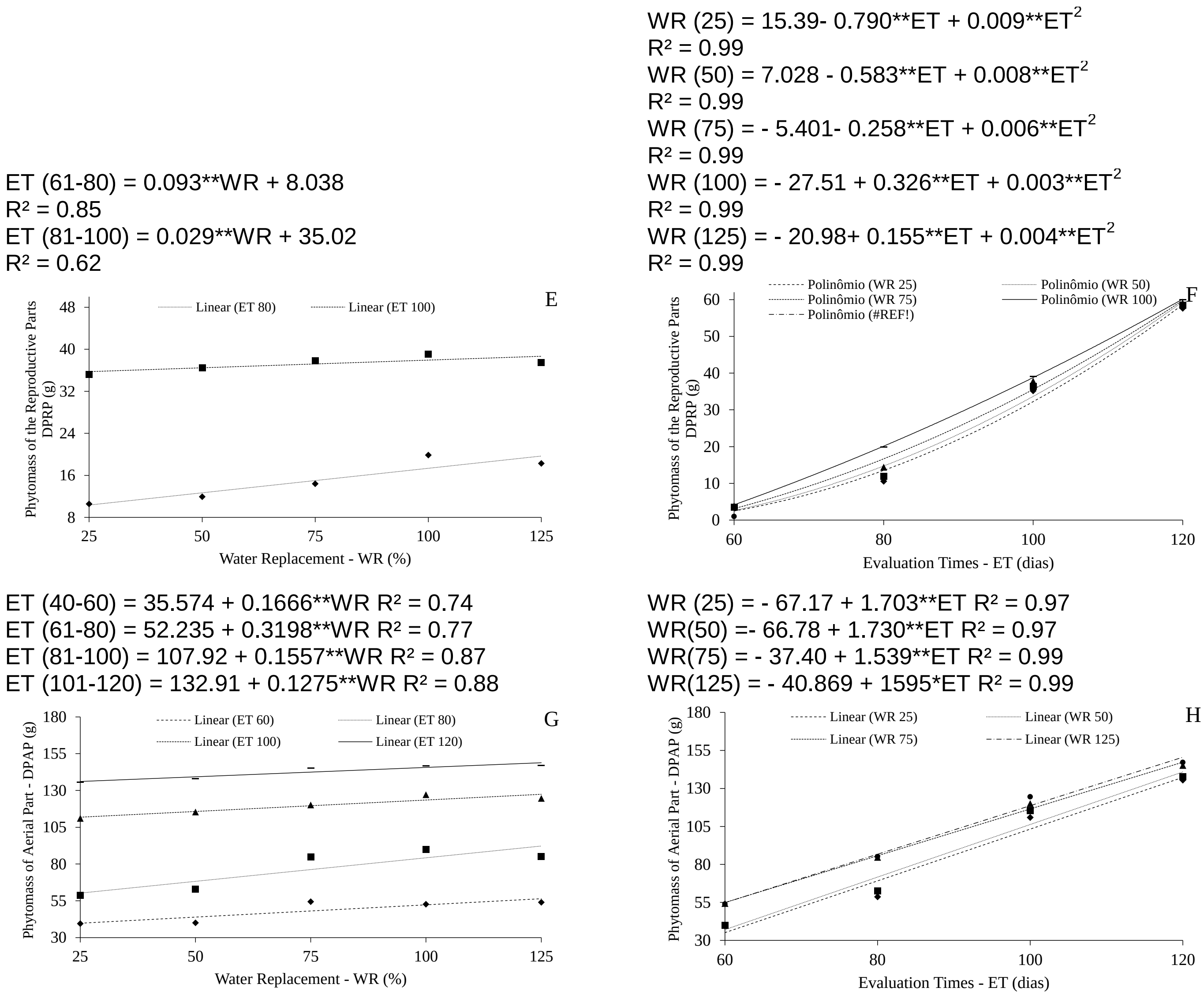


Figure 2. Plant height (A), leaf area (C), dry phytomass of reproductive part (E) dry phytomass of aerial part (G) each evaluation period due to the water replacement levels and plant height (B), leaf area (D), dry phytomass of the reproductive part (F) dry phytomass of aerial part (H) due cotton in evaluation times, Rio Verde, March 2016.

(Figure 2B). These results indicate that when cotton does not suffer water stress has its continued growth to 120 DAE.

Its noted that LA to 60, 100 and 120 days showed the highest increases (3326.03, 5508.98, and 5491.78 cm^2), the WR 84.85; 92.04; and 80.78%, respectively, on day 80 there was an increase of 0.38% per unit WR (Figure 2C). In the WR 25, 50, 75 and 100% LA presented respectively increments of 3.13; 2.83; 2.33; and 1.99% at an interval 20 days, as 125% WR and AF showed the largest increase (4992.03 cm^2) at approximately 106 days of development (Figure 2D).

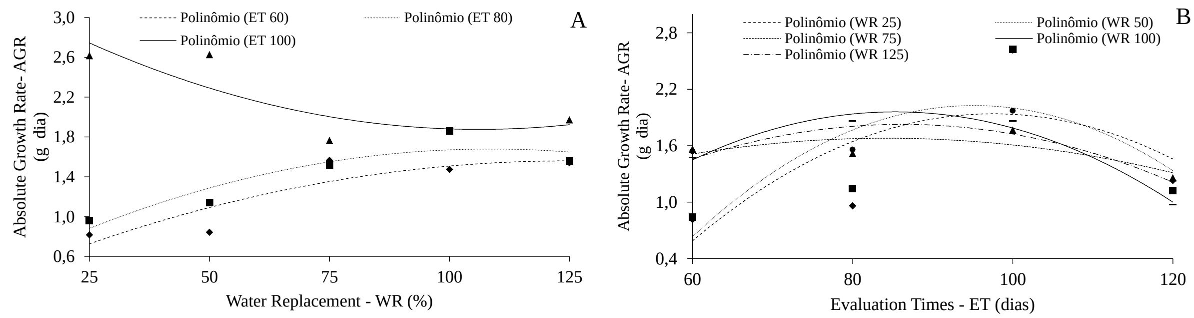
The behavior of plant height and leaf area under the influence of water replacement levels, reveal that for a higher performance variables, it is important to consider in the design of the irrigation management, besides the crop coefficient (Kc) Results research as demonstrated by study.

Its noted that DPRP was difference betwem WR only after 80 and 100 days and the regression equation as presented increments of 1.16 and 0.08% per unit increase in WR, respectively (Figure 2E). According to the equations EA scrolling regressions within each WR level, the largest accumulations of DPRP (58.8; 59.4; 60.1; 60.6; and 59.6 g) were scanned at 120 days in respective WR 25, 50, 75,100 and 125% (Figure 2F).

There is difference between WR in all the DPAP and ET and at 60, 80, 100 and 120 days showed increases DPAP 0.47; 0.61; 0.14 and 0.10% per unit increase of WR, respectively (Figure 2G). At 100% WR, there was no

$ET (40\text{-}60) = 0.258 + 0.020^{**}WR - 0.00008^{**}WR^2$
$R^2 = 0.80$
$ET (61\text{-}80) = 0.334 + 0.024^{**}WR - 0.0001^{**}WR^2$
$R^2 = 0.86$
$ET (81\text{-}100) = 3.361 - 0.028^{**}WR + 0.0001^{**}WR^2$
$R^2 = 0.73$

$WR (25) = - 7.1664 + 0.1866^{**}ET - 0.001^{**}ET^2$
$R^2 = 0.49$
$WR(50) = - 8.1696 + 0.2142^{**}ET - 0.0011^{**}ET^2$
$R^2 = 0.55$
$WR(75) = - 0.3498 + 0.0482^{**}ET - 0.0003^{**}ET^2$
$R^2 = 0.57$
$WR(100) = - 3.8409 + 0.136^{**}ET - 0.0008^{**}ET^2$
$R^2 = 0.98$
$WR(125) = - 2.1636 + 0.0926^{**}ET - 0.0005^{**}ET^2$
$R^2 = 0.61$



$ET (40\text{-}60) = 0.014+0.0005^{**}WR - 0.000002^{**}WR^2$
$R^2 = 0.81$
$ET (61\text{-}80) = 0.015+0.0002^{**}WR - 0.000001^{**}WR^2$
$R^2 = 0.61$
$ET (81\text{-}100) =0.044-0.0005^{**}WR+0.000002^{**}WR^2$
$R^2 = 0.83$

$WR (25) = - 0.0321 + 0.0015^{**}ET - 0.000009^{**}ET^2$
$R^2 = 0.48$
$WR(50) = - 0.0357 + 0.0016^{**}ET - 0.00001^{**}ET^2$
$R^2 = 0.67$
$WR(75) = 0.1305 - 0.002^{**}ET + 0.000008^{**}ET^2$
$R^2 = 0.97$
$WR(100) = 0.0924 - 0.001^{**}ET + 0.000003^{**}ET^2$
$R^2 = 0.99$
$WR(125) = 0.1128 - 0.0015^{**}ET + 0.000006^{**}ET^2$
$R^2 = 0.96$

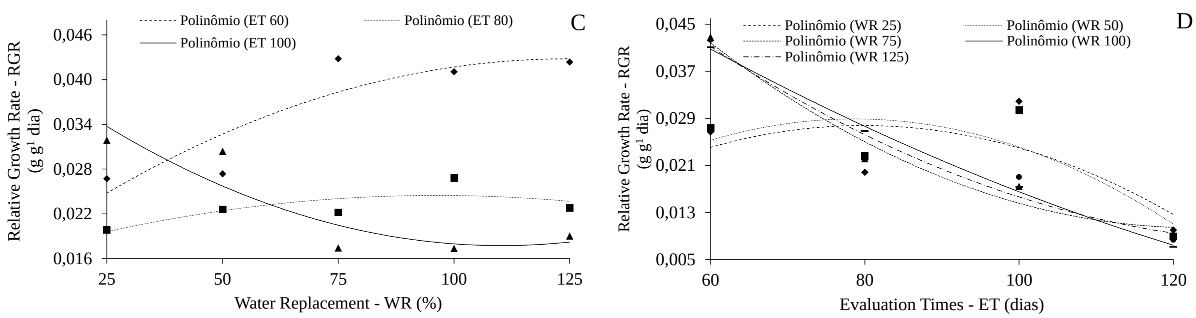


Figure 3. Absolute growth rate - AGR (A) and relative growth rate - RGR (C) for each evaluation time interval depending on the water replacement levels and absolute growth rate (B) and relative growth rate (D) due cotton in evaluation times, Rio Verde, March 2016. ** - F - value significant at 1% of probability.

significant difference between ET, but WR 25, 50, 75 and 125%, the DPAP accumulation in a 20 day interval was increased by 50.71; 51.81; 82.30 and 78.05%, respectively (Figure 2H).

The result of the largest responses for plants growth in height and leaf area between 100 and 120 days, the culture also showed greater assimilates productions shoot and thus the reproductive part linked to a water replacement of 100% of evapotranspiration.

Studying the behavior of cotton cultivar Delta Opal under water stress in controlled environment, Baldo et al. (2009) found that smaller plant height, stem diameter, number of leaves and also the commitment of the formation of reproductive structures were water deficit of the consequences of 25% of the total pores, and even the best results for production of dry phytomass of aerial part and root were provided by replacement of 100%.

Figure 3 showed the settings variables evaluated for WR unfolding in each level of ET. In time slots 40 to 60 and 61 to 80 days, it was found according to the regression equation, the highest absolute growth rates with 1.51 and 1.87 g per day, the WR 125 and 124%,

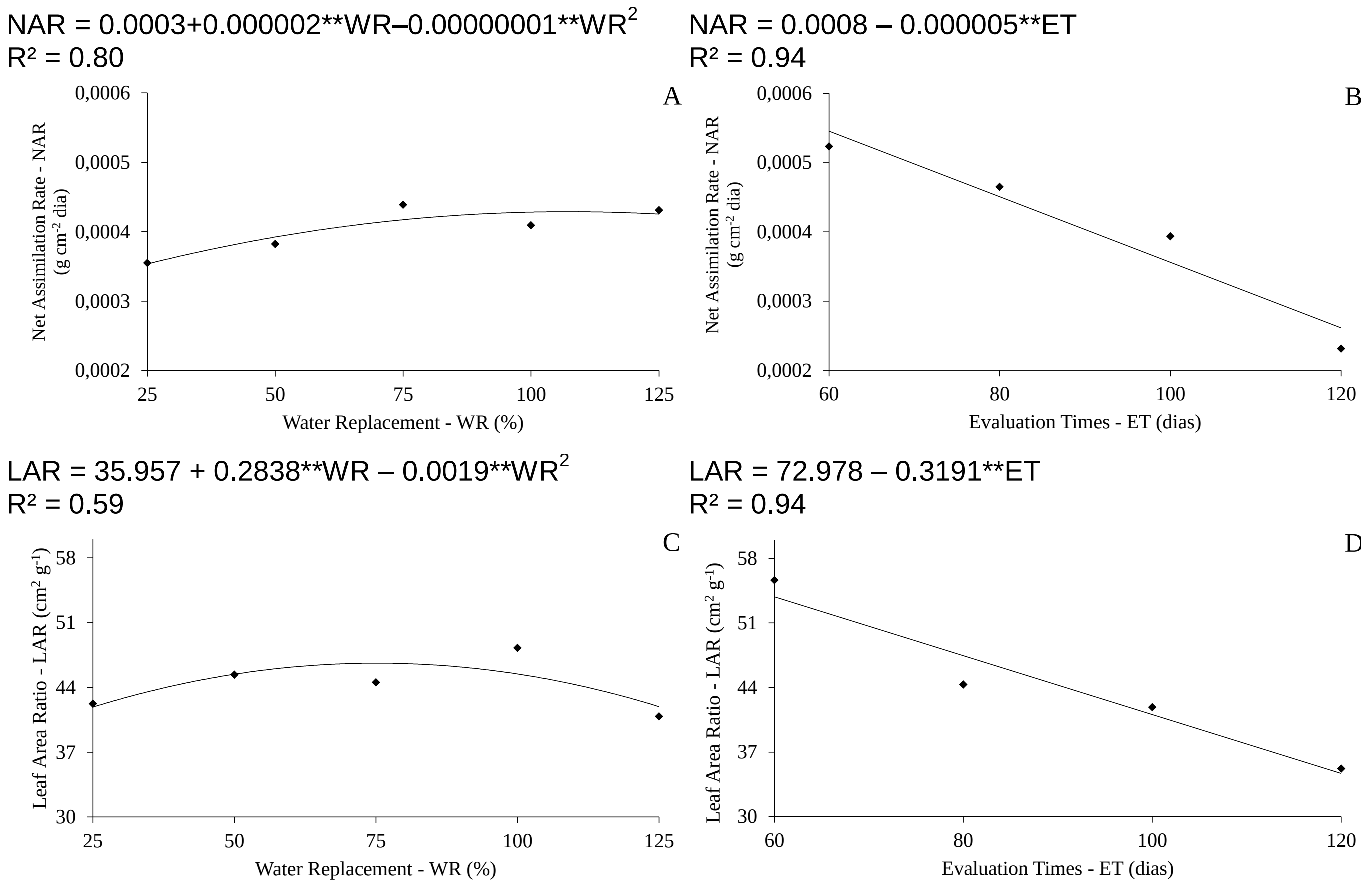


Figure 4. Net assimilation rate - NAR (A) and leaf area ratio - LAR (C) due of levels and net assimilation rate - NAR (B) and leaf area ratio - LAR (D) due cotton in evaluation times, Rio Verde, March 2016. ** - F - value significant at 1% of probability.

respectively, since the period of 81 to 100 days greater AGR (2.72 g daily) was afforded by 25% WR (Figure 3A). The highest AGR (1.54, 2.26, 1.59, 1.94 and 2.12 g per day) in the WR 25, 50, 75, 100 and 125% were observed at 93.3, 97.4, 80.3, 85.0, 92.6 days, respectively (Figure 3B).

In the intervals 40 to 60 and 61 to 80 days, the WR 100 to 125%, showed highest RGR (0.045 and 0.025 g g^{-1} per day), respectively, and length of 81 to 100 days found reduction RGR due levels of RH. 25% WR estimated a RGR 0.033 g g^{-1} per day, exceeding 125% WR growth of 61.07% (Figure 3C). In the WR 25 and 50%, there was the highest estimated RGR (0.030 to 0.028 g per day) after 83 and 80 days, respectively, and the WR 75, 100 and 125% decreased the RGR from 60 days; however, the RGR at 75% WR was higher than in the 100 and 125% in the range 61-80 days of development of cotton (Figure 3D).

In cotton, the reduction absolute growth rates and on the period between 81 and 100 days is expected, since any increase in phytomass, plant height and leaf area at the end of the cycle culture is smallest; , this increase is directly relating to value obtained in the previous period, as the growth rate of a plant varies throughout the plant cycle, it depends on two other growth factors: the useful leaf area for photosynthesis and leaf area ratio (LAR), and net assimilation rate (NAR), which is gross photosynthetic rate, discounting breathing and how this period there were decreases in the LAR and NAR (Figure 4A and B) the AGR and RGR were influenced directly.

The reduction of absolute and relative growth rates in the period of 81 to 100 DAE of cotton is explained by the fact that this period coincides with the flowering period and training of apples, which are effective plant drains (Freitas et al., 2006). At this stage, it is important to irrigate for HR 75% of evapotranspiration to soften these reductions.

The larger NAR was estimated for 100% WR (Figure 4A), showing that WR is ideal for keeping a good phytomass production and consequently the plant achieve higher net photosynthesis. A linear reduction of 12.5% NAR was observed for each increase of 20 DAE (Figure 4B). This reduction in NAR due to the increase plant leaf area influenced in greater or lesser net photosynthesis produced by plants.

The behavior NAR (Figure 4B) was similar to RGR

(Figure 3D). Thus, a more efficient dry phytomass by leaves occurred. To alleviate the problems by reducing the NAR, it is recommended to adopt a 100% WR, regardless of the ET.

The higher LAR (46.55 cm^2 g^{-1}) was verified in the 74.7% WR (Figure 4C) and in relation to ET, observed a reduction of 6.38 cm^2 g^{-1} in the LAR 20 for each intervals days of development of culture (Figure 4D). The LAR high in the initial stage indicates there was investment in the development of the leaves to the light energy capture and then, due to the aging of the leaves was the direction of assimilates to other plant parts.

The reduction LAR in the course of crop development is explained according Benincasa (2003), by the fact upper leaf to cause self-shadowing of lower leaves, and to the extent that the crop will develop during their cycle, this problem it is increased. Urchei et al. (2000) found that reduction of LAR in the course of crop development is due to the emergence of reproductive structures (and apple bud) are designed as highly competitive drains.

The study of water replacement levels showed great importance with regard to the growth and development of cotton, by the fact that it was identified levels that can be used in a specific developmental stage, in order to ease the reduction of the problems of growth rate and provide better agronomic performance and productivity to cotton.

Conclusions

Water replacement influenced the cotton growth. Low growth rate was conditioned by the reduction of water supply, until the end of cotton cycle. Water supply of 100% provided higher phytomass production of reproductive organ.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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