Leaf Water Potential and Crop Water Stress Index variation for full and deficit irrigated cotton in Mediterranean conditions

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Abstract

Deficit irrigation is a common practice to cope with limited water availability. A two-year field experiment was conducted in order to determine the water status of cotton crop (\textit{Gossypium hirsutum} L.) under full and deficit irrigation conditions. The experiment was set up as a split plot design with four replicates, two main plots (irrigation treatments) and two sub plots (cotton cultivars). The lower (non-stressed) and upper (fully stressed) base lines for the determination of Crop Water Stress Index (CWSI) of cotton crop were estimated. Plant water status, expressed in terms of the water potential index (WPI) and CWSI, was measured throughout the growing seasons. The adopted irrigation schemes produced a clear differentiation among cultivars concerning their plant water status. Water shortage resulted in more negative leaf water potential and WPI and greater CWSI values. Leaf water potential, WPI and CWSI values, variation throughout both growing seasons, indicated greater adaptability for "Julia" in water stress conditions, while "Zoi" showed a significant water stress behavior during the phases of yield formation and ripening, even for the full irrigated treatment. In general, use of limited drip irrigation regime with 50\% of water requirement had significant benefits in terms of saved irrigation water.

Keywords: Cotton water status; leaf water potential; crop water stress index

1. Introduction

Cotton (\textit{Gossypium hirsutum} L.) is an important fibre-producing plant. In addition, cotton seed is used for livestock feed and for cotton oil extraction. Greece is the leading cotton-growing country in the European Union.

Irrigation water availability has been identified as one of the major limiting factors of cotton productivity, especially during the hot and dry summer period of the Mediterranean region. As global climate change continues,
water shortage and drought are becoming an increasingly serious constraint, limiting crop production worldwide (Katerji et al., 2008). Cotton is very sensitive to water stress during the various stages of its growth and development, with daily water use being greatest during the period from flowering to yield formation. Deficit irrigation management is an optimum strategy to address water shortage, resulting in considerable water savings with little impact on the quantity and quality of the harvested yield (Korda et al., 1999). Several studies referring to impacts of deficit irrigation on cotton growth and yield showed that 20 or 25% deviation from full irrigation level did not significantly affect cotton yield (Wanjura et al., 2002; Ertek and Kanber, 2003; Dağdelen et al., 2006; Kang et al., 2012). For the quantitative expression of plant water status, the WPI (Karamanos and Papatheohari, 1999) and CWSI (Idso, 1981; Idso et al. 1981; Jackson et al. 1981; Pinter et al., 1983; Howell et al., 1984; Jackson, 1991; O'Shaughnessy et al. 2011) have been used to describe the water stress of the crop. WPI is derived from the integral of the course of leaf water potential over time for a given period. The WPI provides very useful information as the slope of the linear regression between any crop trait and WPI is considered as an expression of the sensitivity of the trait to water stress. The CWSI (Idso, 1981; Idso et al. 1981; Jackson et al. 1981) is determined by subtracting the air temperature from the crop canopy temperature and comparing the resultant value with that of a well-watered crop at the same vapor pressure deficit (VPD). The CWSI takes values ranging from 0 (no stress) up to 1 (maximum stress) and it is characterized by a lower limit or “a non-water stress baseline” at which the plant is experiencing no stress and an upper limit where the plant is experiencing severe stress.

The objective of this study was:

i) to evaluate the water status for two cotton cultivars under full and deficit irrigation conditions

ii) to determine the stress and no-stress baselines for the evaluation of Crop Water Stress Index in order to address its variation during the crop seasons examined and

iii) to evaluate the feasibility of quantifying plant sensitivity to water deficit with Water Potential Index and/or Crop Water Stress Index

2. Materials and methods

2.1. Experimental design and irrigation applications

A field experiment was carried out at the Agricultural University farm located in Athens (southern Greece: latitude 37°58’ N, longitude 23°32’ E, altitude 30 m above sea level) during the 2006 and 2007 growing seasons. The soil was clay loam (29.3 % clay, 33.8 % silt and 36.9 % sand) with pH 7.17, NO₃-N 12.4 mg kg⁻¹ soil, available P 13.2 mg kg⁻¹ soil, available K 201 mg kg⁻¹ soil and 1.17 % organic matter. For the experimental area, volumetric water content at field capacity and wilting point were measured at 0.308 and 0.110 g g⁻¹ on a dry weight basis respectively. Field bulk density measurements at the site do not indicate soil compaction problems and it ranges from 0.9 g cm⁻³ to 1.1 g cm⁻³ throughout the 1.2 m deep profile. The total available soil water content within the top 1.2 m of the soil profile was 237.6 mm. Weather and micrometeorological data (rainfall, maximum and minimum air temperatures, relative humidity and net radiation) were recorded daily by means of an automatic micrometeorological station, established in the experimental field.

The experimental design was split plot with irrigation treatments as the main plot and cotton cultivars as the sub-plot in a randomized complete block design replicated four times. The plot size of each irrigation treatment was 6 m × 12 m and the spacing between each main plot was 4 m in order to minimize water movement among treatments. The experimental plots were 6 m × 6 m and consisted of 6 rows 1.0 m apart. Two commercial cotton cultivars named "Julia" and "Zoi", widely grown in south Greece, were used for the experiments. Julia is a highly productive variety of moderate earliness with excellent fiber properties. It shows good water-use efficiency, vigorous early growth and high adaptability to a wide range of soil and climatic conditions. Zoi is a medium maturity variety with large bolls and provides excellent fiber quality with high yield potential. Seeds were hand-planted on 2 May 2006 (Julian day, JD: 122) and on 28 April 2007 (JD: 118) respectively. Cotton plants were thinned to a spacing of 1.0 m (row width) × 0.65 m when the plants were about 0.15 m in height. Prior to planting, a compound fertilizer of (20:10:10 composite) was applied at a rate of 40 kg ha⁻¹. The crop was kept free of weeds by hand hoeing when necessary.

The irrigation treatments were based on the calculation of daily evapotranspiration which was determined by the pan evaporation method (Allen et al. 1998). For that purpose a Class A evaporation pan was used, placed a few meters apart of the crop. Irrigation was applied daily. Two irrigation treatments designated as full (FI) with no water stress and moderate (MI) water stress, were tested. In the FI treatment the amount of irrigation water applied daily was 100% of the daily crop evapotranspiration. In the moderate water stress treatment (MI), irrigation water was applied
at the rate of 50% of full irrigated treatment on the same day for both genotypes and years. A surface drip irrigation system was used for irrigation. A 16 mm diameter polyethylene pipe with in-line drippers at 0.33 m intervals was placed on one side of each cotton row. The average discharge of emitters was 2.3 l h⁻¹ at the 0.1 MPa. Nine irrigations totaling 294 mm were applied to all treatments from sowing until early July to sustain early emergence and uniform growth crop stand. The different irrigation treatments were started on 10 July 2006 and 5 July 2007 and continued according to regional practice until late-August when 10% of bolls on a plant were fully open. The amount of applied water was about 370 mm and 185 mm for FI and MI treatments respectively, in each experimental period.

2.2. Measurements and calculations

Plant vegetative growth was monitored by means of subsequent destructive samplings manually realized throughout the two growing periods (2006, 2007). In each sampling, all plants within a 0.5 m section of a row (from the second and fifth row of each plot) were cut at ground level at weekly intervals, starting from mid July to late August. In all experiments, measurements of the water potential of the youngest fully expanded leaf (fourth to fifth node from the top of main stem) were taken once a week, around noon, when it reaches its lowest diurnal value, throughout the growing seasons. The pressure chamber technique (Schollander et al., 1964) was used at a pressurization rate of 0.05 MPa s⁻¹. Five leaf samples per plot from each replicate were randomly chosen for water potential measurements. To eliminate water loss, sampled leaves were wrapped immediately with aluminum foil, and placed in small polyethylene bags during cutting. The bags were then sealed and placed in dark and humid containers for the time required for water potential determination. The water potential index (WPI) was calculated from Leaf Water Potential versus time relationships in each plot according to Karamanos and Papatheohari (1999). For the calculation of CWSI, a non water stress baseline for cotton was determined at the local climatic conditions throughout the growing seasons. This was achieved, by measuring the crop temperature (Tc) using a hand-held infra-red thermometer, while the air temperature (Ta) and the corresponding vapor pressure deficit, were determined by means of micrometeorological data, taken from the automatic micrometeorological station, placed among the fully irrigated plants. The mean Tc for each plot was calculated as the average of 12 instantaneous measurements. All data for the non water stressed base line were taken above the fully irrigated (FI) plots at sunlit conditions. The upper baseline was determined using the canopy temperatures measured from plants which were kept non-irrigated (fully stressed). Since upper and lower base lines were known, CWSI for a specified (Tc-Ta) and VPD was calculated by equation (1).

\[
CWSI = \frac{(T_c - T_a) - (T_c - T_a)_{lower}}{(T_c - T_a)_{upper} - (T_c - T_a)_{lower}}
\]

Where the indices "upper" and "lower" indicate the values of the difference (Tc-Ta) given from upper and lower baselines estimated, respectively.

All measured and derived data were subjected to analysis of variance (ANOVA), using the statistical software package Statistica V.8. As test criterion for looking differences between means the LSD (P<0.05) was used (Steel and Torrie, 1982). The years were not pooled for ANOVA because the sampling dates were not comparable among years.

3. Results and Discussion

Average air temperatures during the two growing periods did not vary considerably from the long-run averages; however, during July and August 2007 and August 2006 the average and maximum temperatures were higher than the normal. Furthermore, relative humidity of the air from June to August was in both years lower than the averages. Long-term mean annual rainfall at the site is 401 mm, but temporal variability is high. There was no rainfall from June to September 2007 and only 13.6 mm of rain in June and July 2006. Above-normal rainfall occurred in May 2007 and September 2006 before or after the applied irrigation. Total rainfall during the experimental period was 84.6 and 0 mm, with 4 and non effective rainfall events (>5 mm) in 2006 and 2007. These variations are typical for
the Greek-Mediterranean climate that is characterized by a long, hot and dry summer during which full irrigation is essential for growing crops. Figures 1 and 2 show applied irrigation water amounts and the average air temperatures (Taverage), during 2006 and 2007 growing seasons respectively. The daily irrigation events applied were calculated and presented on a weekly basis.

Fig. 1. Irrigation water applied and average air temperature during 2006 crop season.

Fig. 2. Irrigation water applied and average air temperature during 2007 crop season.

Figures 3 and 4 show the variation of Leaf Water potential with time as affected by two irrigation treatments (FI and MI) and two cultivars (Julia and Zoi) during 2006 and 2007 growing seasons respectively.
It can be clearly seen that plant response, expressed in terms of LWP, was very much dependent on the applied irrigation regimes. The LWP of the stressed plants (MI treatments) was significantly lower than that of the FI ones reaching minimal values between -2.18 and -2.31 MPa in 2006 and -2.22 and -2.41 MPa in 2007. In FI treatments Julia in most cases exhibited, higher LWP than Zoi, while in MI treatments the differences between the two varieties were small. In the second year the values of LWP were more negative than those of the first one, due probably to the higher temperatures, especially in July and the end of August. The differences among irrigation treatments and varieties were statistically significant for WPI (see Table 1). Increasing water shortage resulted in more negative WPI values, which were lower in 2007 than 2006 and higher in Julia than Zoi, especially in FI treatments.

Leaf water potential is considered as a reliable indicator of plant water balance (Karamanos, 2003). Similarly, WPI represents an adequate description of the water stress history experienced by plants (Karamanos and Papatheohari, 1999; Karamanos et al., 2009; Karamanos and Travlos, 2012). The imposed irrigation schemes produced a clear differentiation in LWP and WPI among the treatments and the genotypes (Fig. 3, Fig. 4 and Table 1). The degree of differentiation and the overall time course of LWP were also affected by the environmental
conditions prevailing during each experimental year. The upper and lower base lines for the determination of CWSI for cotton in Greek local conditions are shown in Fig. 5. Also in Fig. 6 the time course of Crop Water Stress Index as affected by two irrigation treatments and two cultivars during 2006 and 2007 crop seasons, is presented.

![Graph of Crop Water Stress Index](image)

Fig. 5. Non-stressed (lower) and fully stressed (upper) base lines as determined during the two years of experiments for the evaluation of Crop Water Stress Index (CWSI) by using the empirical method of Idso (1981).

![Graphs of Crop Water Stress Index](image)

Fig. 6. Time course of Crop Water Stress Index as affected by two irrigation treatments and two cultivars during 2006 and 2007 crop seasons.

It may be seen that "Zoi" requires more irrigation water than "Julia" during the phases of yield formation and ripening, as the corresponding CWSI values for "Zoi" are close to 0.80 during these phases. The crop response to water stress in terms of Leaf Area Index, biomass accumulation and harvested yield, as well as their relationships
versus WPI have been presented by the two first authors of the present paper, in an earlier published one (Papastylianou and Argyrokastritis, 2014). The average values of the WPI and the CWSI calculated under the two different irrigation treatments, for the two years of experiments, were subjected to Analysis of Variance and the results are shown in the following Table 1.

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<tbody>
<tr>
<td>Julia</td>
<td>FI</td>
<td>-1.66 a 1</td>
<td>-1.74 a</td>
<td>0.55 a</td>
<td>0.53 a</td>
</tr>
<tr>
<td></td>
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<td>Zoi</td>
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<td>0.60 a</td>
<td>0.51 a</td>
</tr>
<tr>
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<td>-2.25 b</td>
<td>0.88 b</td>
<td>0.83 b</td>
</tr>
<tr>
<td>Cultivar</td>
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<td>-1.89 A</td>
<td>0.57 A</td>
<td>0.52 A</td>
</tr>
<tr>
<td>means</td>
<td>MI</td>
<td>-2.20 B</td>
<td>-2.23 B</td>
<td>0.87 B</td>
<td>0.83 B</td>
</tr>
</tbody>
</table>

C, cultivars, IRR, irrigation treatments (FI – full irrigated, MI – medium irrigated) ns, not significant; significant at * P<0.05, ** P<0.01, *** P<0.001.

1Different lower-case letters within a column indicate significant differences between cultivar mean values (P<0.05).

2Different upper-case letters within a column indicate significant differences between the marginal means of irrigation treatments (P<0.05).

4. Conclusions

The adopted irrigation schemes produced a clear differentiation among cultivars concerning their plant water status. Water shortage resulted in more negative leaf water potential and WPI and greater CWSI values. The LWP of the stressed plants (MI treatments) was significantly lower than that of the FI ones reaching minimal values between -2.18 and -2.31 MPa in 2006 and -2.22 and -2.41 MPa in 2007. In FI treatments Julia in most cases exhibited, higher LWP than Zoi, while in MI treatments the differences between the two varieties were small. The differences among irrigation treatments and varieties were statistically significant for WPI. Leaf water potential, WPI and CWSI values, variation throughout both growing seasons, indicated greater adaptability for "Julia" in water stress conditions. "Zoi" showed a significant water stress behaviour during the phases of yield formation and ripening, even for the full irrigated treatment, which means that "Zoi" requires more irrigation water than "Julia". In general, use of limited drip irrigation regime with 50% of water requirement had significant benefits in terms of saved irrigation water.

References


