Crop Water Stress Index (CWSI) as an Indicator of Water Stress and Yield Performance among Cotton Cultivars

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ABSTRACT

Field experiments were conducted in Seville (SW Spain) on a sandy loam soil (Typic Xerofluvent) to investigate the usefulness of CWSI in screening cotton genotypes for drought resistance and yield characteristics. Non-water-stressed baseline equations were determined in 1993 and 1994 by conducting a diurnal study of a well watered crop. Seventeen upland cotton genotypes were evaluated in 1994 in randomized complete blocks with four replications. Eight furrow irrigations were applied from June 8 to August 23 with a total of 800-900 mm of H_2O applied. Crop Water Stress Index (CWSI) was quantified in seven dates. Variance analysis showed that dates and genotypes were highly significant for seasonal CWSI ranging from 0.38 for Acala Germain 510 to 0.59 for La Niña. Seed cotton yield was negative correlated to mean seasonal CWSI (r = -0.28). Seed cotton yields ranged from 4658 kg ha^{-1} for Stoneville 324 to 5723 for La Chata (a Spanish cultivar). CWSI revealed a good water status for some cultivars with low values in this characteristic but it was not a determining factor in the performance of cultivars under well-watered conditions. CWSI corroborates the drought tolerance of some Spanish genotypes such as Maria del Mar and could be a good tool in evaluating genotypic drought tolerance if a low seasonal CWSI is combined with high yields under well watered conditions.

Introduction

Cotton is one of the most important crops in the irrigated lands in western Andalusia, especially in the Guadalquivir Valley, which produces 90% of national cotton output. The growing season for cotton in this area is characterized by a long dry period with high temperatures (40º C is usual in many days during July and August). Rains are rare during the summer. Currently more than 30 cultivars are available to cotton growers. Most of them are American upland cultivars imported from the United States. The available germplasm embraces the cultivars most widely planted in the United States. It is important to bear in mind that cultivars that have been selected for different regions of the USA, situated thousands of miles apart, are grown in a very concentrated zone of Spain, the Guadalquivir Valley. In the last few years water for agricultural use has been decreasing because of periodical droughts. Furthermore, the availability of irrigation is diminishing because of increasing demand for urban water and industrial development. It is foreseen that drought-adapted cultivars will be required by farmers to cope with a forthcoming situation where farmers are faced with a reduction in the availability of irrigation water (Lopez *et al.*, 1995). Indications of plant water status or traits related to water use efficiency may be useful to identify genotypic differences in plant response to drought stress. The main requirement in breeding for drought tolerance is to find easily measurable traits consistently correlated with yield (Ludlow and Muchow, 1990).

Plant temperature, particularly leaf temperature, has long been recognized as a potential indicator of plant water stress (Tanner, 1963). The development of portable infrared thermometers and the definition of the Crop Water Stress Index (CWSI) (Idso *et al.*, 1981; Jackson, 1982) have led to widespread interest in infrared thermometry to monitor water stress. Canopy temperatures of cotton are useful indicators of crop water stress (Howell *et al.*, 1984; Wanjura *et al.*, 1990; Husman and Garrot, 1992).

The aim of this investigation was to study the usefulness of CWSI in screening genotypes for drought resistance and yield characteristics under the local semiarid Mediterranean climate of the Guadalquivir Valley.

Material and Methods

Field experiments were conducted in Seville (SW Spain, 37º 22' N) in 1994 on a sandy loam soil (Typic Xerofluvent). Seventeen cultivars (Table 1) were planted on March 6 under plastic mulch in randomized complete blocks (RCB) with four replications. Plots were two rows 10 meters-long and 95 cm apart. Eight furrow irrigations were applied from June 8 to August 23 with a total of 800-900 mm of H_2O. A first harvest was made on September 12 and a second on October 13.

Non Stressed Baseline (NSBL) equations were determined in 1993 and 1994 by conducting a diurnal study of a well watered crop compound of 10 cultivars (each cultivar with two rows, 40 m long and 95 cm apart). The canopy temperature was measured with a RAY R2 PAG (Raytec, Santa Cruz, California) hand-held infrared thermometer with oblique measurements at 20 to 30° from the horizon. Vapor pressure was determined from a thermo-hygrometer (HANNA Inst. HI 8564).

An average of 15 diurnal NSBL measurements were taken from 8.30 to 20.30 local standard time (LST).

Canopy temperatures Tc were computed as the average of 10 measurements taken from the compound well watered crop, using only temperatures in which Tc > 27.4ºC (Wanjura *et al.*, 1990). Measurements of NSBL were taken in 1993 and 1994 two days after irrigation on two very similar dates, July 21 and August 2 in 1993 and July 26 and August 5 in 1994. In both years the phenological stages were pre and post cut-out.

The NSBL was computed from a linear regression analysis of canopy minus air temperature (Tc-Ta) and vapour pressure deficit (VPD) using the data from 1993 and 1994.

Crop Water Stress Index (CWSI) was calculated as Idso *et al.* (1981) and Jackson (1982) using the computer program CWSI (Mateos *et al.*, 1991).

Measurements for CWSI were made on a cloud-free day at 1 - 1½ hours after solar noon one day before irrigation on seven days in the season: July 1, 8, 15, 21, 29 and August 9 and 22.

Average Infrared values were determined from measurements from the four corners of each plot.

Analysis of variance was performed for CWSI. The Pearson Correlation Coefficients were calculated between yield and the average CWSI of the cultivars on every date and for the season.

Results and Discussion

In Figure 1 the NSBL is shown, using data from 1993 and 1994. The analysis of variance for CWSI for seventeen cultivars is shown in Table 2. Significant differences were obtained for date of measurement and genotypes (cultivars). The interaction between genotype and by date of measurement was not significant.

In Figure 2 presents the bi-plot of the values of the average of the four replications of seasonal CWSI and yield (seed cotton) for every cultivars studied and is shown.

In Table 3 is shown the analysis of variance for yield (seed cotton). The effects of genotypes were not significant at the 0.05 level.

In Table 4 the Pearson correlation coefficient between yield and CWSI by dates of measurement and between yield and seasonal CWSI is shown.

Seasonal CWSI for cultivars ranged from 0.38 for Acala Germain 510 to 0.59 for La Niña (Figure 2). Seed cotton yield ranged from 4,658-kg ha^{-1} for Stoneville 324 to 5,723 for La Chata. Taking into account the four quadrants considered in Figure 2 it is possible to observe a differential behaviour of the cultivars with respect to yield and CWSI.

Only a few cultivars, La Chata (6), Maria del Mar (1) and Victoria (2) that were selected under the local conditions of the Guadalquivir Valley, have a low CWSI and high yield. The remaining cultivars are mainly American cultivars selected for other environmental conditions and two Spanish cultivars, Tabladilla 16 and La Niña with a genetic background closely related to Coker 310. The cultivars with lower had a high variability with respect to CWSI. Some cultivars have a low CWSI, for example Acala Germain 510 (17), DP 90 (13), expressing a good water status during the growing season but with low yield. On the other hand, the cultivar DP 20 (14) shows a high CWSI and an acceptable yield. The correlation coefficient between yield and CWSI by dates is significant and negative from date 3 (July 15) to date 7 (August 22) (Table 4). It seems that the first dates of measurement, equivalent to first flowering, are not involved in the negative effects of a high CWSI on yield.

The correlation between yield and seasonal CWSI is highly significant and negative (-0.28). These data are consistent with Wanjura *et al.* (1990) who found a negative correlation between lint yield and the mean CWSI values for cotton grown under different soil water levels and during the boll setting.

As a conclusion, CWSI is not a determining factor in the performance of a cultivar under well-watered conditions. This corroborates the drought tolerance of some Spanish cultivars such as Maria del Mar and Victoria (Gutiérrez, 1997a; 1997b unpublished data, Gutiérrez *et a.*., 1998). CWSI could be a good tool in evaluating genotypic drought tolerance if a low seasonal CWSI is combined with high yields under well watered conditions.

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Table 1. List of cotton genotypes studied in 1994 with reference to their origin.

Genotypes	Code	Origin
María del Mar	1	Commercial Spain
Victoria	2	Commercial Spain
Tabladilla 16	3	Commercial Spain
Coker 310	4	Commercial USA
Saeta (SuperAg. 119)	5	Commercial USA
La Chata	6	Commercial Spain
La Niña	7	Commercial Spain
Crema 111(KC-311)	8	Commercial USA
Nata (HY 39)	9	Commercial USA
Stoneville 506	10	Commercial USA
Alegría (Stoneville 453)	11	Commercial USA
Aria (Stoneville 324)	12	Commercial USA
DP 90	13	Commercial USA
Corona(DP 20)	14	Commercial USA
Vulcano (DP 50)	15	Commercial USA
Koralle (MD 51)	16	Commercial USA
Alba (GC- 510)	17	Commercial USA

Table 2. Analysis of variance for CWSI for 17 cultivars and 7 dates of measurement.

Source	df	Mean square
D (Date measured)	6	1.9481*
D*R (error a)	15	0.5618***
G (Genotypes)	16	0.0853**
G*D	96	0.0267 ns
Error	240	0.0308

*,**,*** significant at the 0.05, 0.01 and 0.001 respectively.
ns, not significant at the 0.05 level.

Table 3. Analysis of variance for yield (seed cotton) for 17 cultivars.

Source	df	Mean square
G (Genotypes)	16	302168.5 ns
R (Replications)	3	908757.7**
Error	43	9436744.3

**, significant at the 0.01 level.
ns, not significant at the 0.05 level.

Table 4. The Pearson correlation coefficient between yield and average CWSI (n = 68 for dates of measurement and n = 374 for seasonal) is shown.

Date 1	2	3	4	5	6	7	Seasonal
0.013	0.1511	0.315**	0.44***	0.52***	0.31**	0.27*	0.28***

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Figure 1. Non stressed base line relationship between canopy-air temperature differences and vapor pressure deficit for a well watered crop compound of 10 upland cotton cultivars.

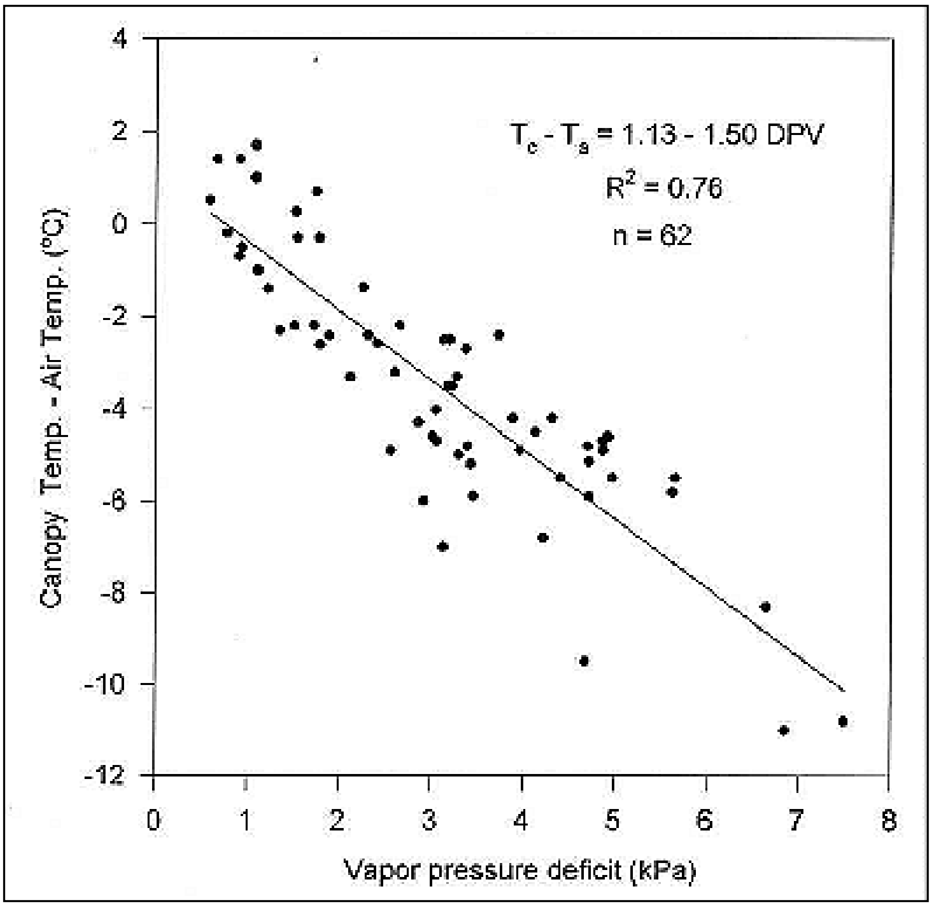

Figure 2. Biplot of the values of the average of four replications of seasonal CWSI and seed cotton yield for 17 cultivars.