Water Stress Indices for Research and Irrigation Scheduling in Pearl Millet

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ABSTRACT

The capability to measure the magnitude of water stress in plants is useful for precision irrigation scheduling and other purposes. This paper reports an evaluation of leaf (TL) and canopy (Tc) temperatures, leaf minus air (TL-Ta) and canopy minus air (Tc-Ta) temperatures, and leaf water stress index (LWSI) and crop water stress index (CWSI) in detecting stress in pearl millet (Pennisetum americanum (L.) Leeke) over two growing seasons. Baselines which were used to compute LWSI and CWSI were obtained. The upper and lower baselines for the Tc data, respectively, were Tc-Ta = 4.1o C and Tc-Ta = 3.87-.2001VPD where VPD is vapor pressure deficit in mbars. For the TL data, the upper and lower baselines, respectively, were TL-Ta = 1.97oC and TL-Ta = 1.308-.03006VPD. Tests against photosynthesis, transpiration, and grain yield showed that LWSI and CWSI are better indices of stress than TL-Ta, Tc-Ta, TL, Tc, or Ta. Average seasonal LWSI and CWSI ranged from approximately 0.03 for non-stressed to 0.80 for stressed plants. The reliability of LWSI and CWSI to detect stress and their relation with grain yield suggested the possibility of using these indices for irrigation scheduling decisions.

INTRODUCTION

A great deal of research effort has been put into finding techniques to increase the precision of irrigation scheduling. The measurement of plant temperatures is one technique that has attracted researchers' attention. Plant temperatures often elevate above air temperatures as a result of limiting soil water supply. This fact has been utilized in assessing plant water stress by measuring foliage temperature.

Canopy temperature measurement, particularly with infra-red-thermometry, has been further advanced to develop an index called crop water stress index (CWSI); it is believed convenient for irrigation scheduling and other purposes (Idso et al., 1981; Jackson, 1982). The CWSI is defined as 1 - (ETa/ET_p), where ETa = actual evapotranspiration and ET_p = potential evapotranspiration. It ranges from 0 for no stress to 1 for maximum stress. This paper reports results of a study in which stress indices based on leaf and canopy temperatures were compared for detecting stress in pearl millet (Pennisetum americanum (L.) Leeke).

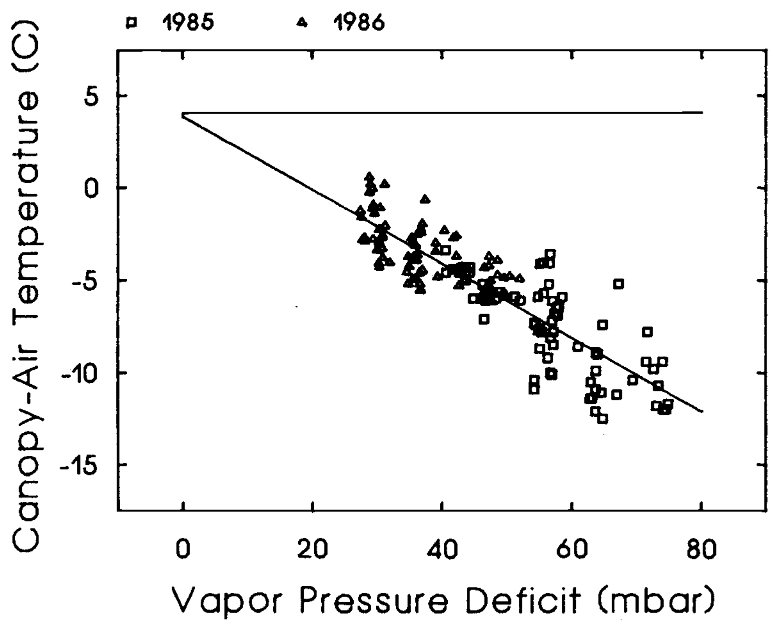
METHODS

A pearl millet hybrid and its two parents were grown under a single line-source sprinkler irrigation gradient system at the Campus Agricultural Center of the University of Arizona during the summers of 1985 and 1986. Physiological measurements including photosynthesis (Ps), transpiration (Tr), and leaf (T_L) and canopy (Tc) temperatures were made throughout the growing seasons at three irrigation levels (low, medium, and high). Stress indices based on T_L and Tc were computed following the methods developed by Idso et al. (1981) and Jackson (1982).

RESULTS

The relationship between vapor pressure deficit (VPD) and canopy minus air temperature (Tc-Ta) of pearl millet with no stress was Tc-Ta = 3.87-0.2001(VPD) where Tc-Ta is in ^{o}C and VPD is in mbars (Fig. 1). With extreme stress, Tc-Ta at any VPD was approximately 4.1 ^{o}C (Fig. 1). Idso et al. (1981) refers to the line of the former equation as the lower baseline and the later one as the upper baseline. These two baselines were used to compute CWSI. Similarly, two baselines were obtained for the T_L data : The upper baseline was T_L-Ta = 1.308-0.03006(VPD) and the lower one was T_L-Ta = 1.97 ^{o}C. This enabled us to compute another stress index that will be designated as leaf water stress index (LWSI) which is the same as the CWSI except that LWSI is based on TL.

Figure 1. Canopy-air temperature differential vs vapor pressure deficit of non-stressed (lower baseline) and extremely stressed (upper baseline) pearl millet in 1985 and 1986



The potential of LWSI, CWSI, T_L-Ta, Tc-Ta, T_L, and Tc in detecting water stress in pearl millet was tested by correlation with Ps or Tr. Table 1 shows stronger negative correlations of Ps and Tr with LWSI and CWSI than with TL-Ta, Tc-Ta, TL, or Tc. Air temperature (Ta) alone was not correlated with either Ps or Tr and may not be used to indicate stress in plants.

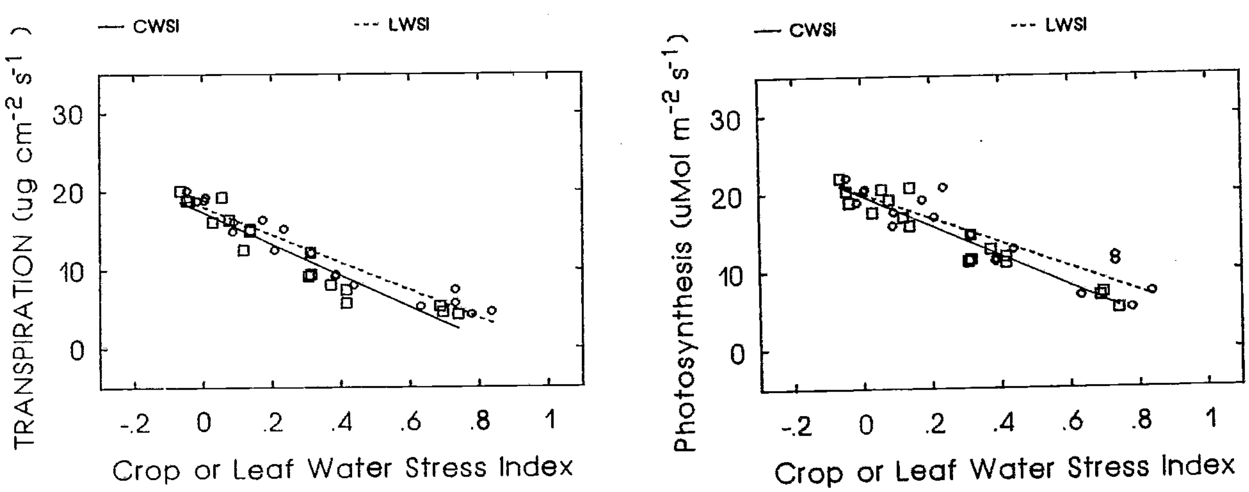
Both LWSI and CWSI are equally useful in assessing stress (Fig. 2) and, therefore, either one can be used effectively, depending on whether TL or Tc is convenient to measure. LWSI may be a better choice when assessment of stress in single leaves or individual plants is wanted. The disadvantage of LWSI is that a relatively large amount of TL data may be required to adequately represent a field (Jackson, 1982).

Table 1. Correlation coefficients of Ps and Tr with water stress indices based on plant temperatures.

	Correlation coefficient	
Index	Photosynthesis	Transpiration
CWSI	-.91	-.86
Tc-Ta	-.82	-.82
Tc	-.78	-.77
LWSI	-.92	-.78
T_L-Ta	-.70	-.57
T_L	-.55	-.38
Ta	-.41	-.23

The plant-air temperature differentials were also well correlated with seasonal average Ps and Tr. When data of each day were considered separately, the T_L-Ta and Tc-Ta were less reliable in detecting stress. Variation of T_L-Ta and Tc-Ta with changing VPD also makes these indices unsuitable for stress assessment.

Figure 2. Relationships of average crop or leaf water stress index with average transpiration or photosynthetic rates.



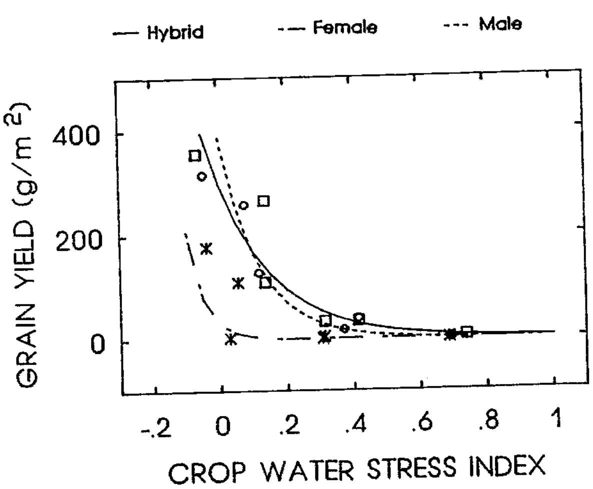
Discrimination among genotypes with differences in Tr was possible by their corresponding LWSI and CWSI values. Average LWSI (Table 2) and CWSI of the female parent, which transpired more than the hybrid or the male parent, were lower than those of the other genotypes. However, a lower LWSI or CWSI can be misleading when the grain yield is considered. Grain yield of the ìfemale parent, which had lower average LWSI and CWSI, is less than that of the hybrid or the male parent.

Table 2. Average transpiration, photosynthesis, stress indices and grain yield of the three genotypes over all irrigation levels and years.

Genotype	Transpiration ($ug\ cm^{-2}\ s^{-1}$)	Photosynthesis ($umol\ m^{-2}\ s^{-1}$)	LWSI	CWSI	Grain Yield ($g\ m^{-2}$)
Hybrid	11.90	14.55	.36	.28	133.50
Female	13.47	14.98	.23	.22	48.63
Male	11.03	14.62	.40	.27	126.00

Grain yields of the hybrid and male parent showed a logarithmic relationship with either LWSI or CWSI (Fig. 3). Yield dropped rapidly after an average LWSI or CWSI value of 0.2. It appears that irrigation has to be made at LWSI or CWSI of approximately 0.2 in order to prevent severe yield loss. In wheat, Jackson (1982) suggested a CWSI range of 0.3 to 0.5, but his suggestion was based on growth, not grain yield.

Figure 3. Average grain yields of the hybrid, female and male pearl millets over a range of CWSI. The relationships of grain yield with LWSI were similar.



References

Idso, S. B., R. D. Jackson, P. J. Pinter Jr., R. J. Reginato, and J. L. Hatfield. 1981. Normalizing the stress degree day for environmental variability. Agric. Meteorol. 24:45-55.

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