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INFRARED THERMOMETRY TO MEASURE SINGLE LEAF TEMPERATURES FOR QUANTIFICATION OF WATER STRESS IN SUNFLOWER

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Abstract

Quantification of water stress by infrared thermometry is routinely done on complete plant canopies to minimize the influence of viewed soil surface. When plants are small or widely spaced, canopies may not be complete. This study was conducted to determine if Crop Water Stress Index (CWSI) values computed from infrared thermometer measurements of single-leaf temperatures of sunflower [*Helianthus annuus* (L.) 'Triumph 566DW'] were correlated with other measures of plant water stress. Plants were grown under an automated rainout shelter and subjected to four water treatments ranging from 0.0 to 100% replacement of evapotranspirational losses. The soil type is a Rago silt loam (fine, montmorillonitic, mesic Pachic Argiustoll). Statistically significant correlations were found between CWSI calculated from single-leaf temperatures and stomatal conductance, CO_2 exchange rate, leaf water potential, transpiration rate, and percent available water in the active root zone. Calculating CWSI from single-leaf temperatures measured with an infrared thermometer can provide a rapid means of assessing plant water status in incomplete canopies.

WATER STRESS can be detected and quantified with a CWSI (Idso et al., 1981a). The CWSI is based on measurements of canopy temperature (made with a hand-held infrared thermometer), air temperature, and vapor pressure deficit. The CWSI has been shown to be closely related to extractable water in the root zone of a wheat (*Triticum aestivum* L.) crop (Jackson et al., 1981), to plant water potential in wheat and alfalfa (*Medicago sativa* L.) (Idso et al., 1981b,c), and cotton (*Gossypium hirsutum* L.) (Pinter and Reginato, 1982), and to leaf diffusion resistance and photosynthesis in cotton (Idso, et al., 1982). These studies have used measurements of canopy temperature to avoid the influence of viewed-soil temperature. Hatfield et al. (1985) discussed how non-water-stressed baselines used for calculating CWSI for situations of partial canopy cover in row crops differ from non-water-stressed baselines from complete plant canopies, even when precautions are taken to ensure no viewed soil surface. But situations exist in viewing partial canopies when it is not possible to avoid viewing the soil surface to make a canopy temperature measurement (e.g., small plants, low plant populations, isolated plants). An infrared thermometer with a narrow field of view can be used to obtain a leaf temperature from an individual plant. This study was conducted to determine if CWSI values computed from infrared thermometer measurements of single-leaf temperatures were correlated with other measures of plant water stress, thereby demonstrating the potential use of this instrument in water stress evaluation of small, isolated plants.

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Materials and Methods

Experimental Design

The study was conducted at the Central Great Plains Research Station (45°09'N, 103°09'W, 1384 m above m.s.l.) near Akron, CO. Sunflower seeds were hand planted on 11 Aug. 1987 into 12 small plots (2.74 by 2.67 m), which could be covered by an automated rainout shelter during precipitation events. The soil type is a Rago silt loam. Each plot consisted of five rows spaced 0.53 m apart. Sunflowers emerged on 17 Aug. 1987 and were thinned to three plants per meter of row. Plots were arranged in a randomized, complete-block design of three replications of four water treatments (0, 33, 66, and 100% replacement of evapotranspirational losses from the non-water-stressed plots calculated by the water balance method). Irrigations were never more than 38 mm per application, so leaching below the measurement profile probably did not occur. Soil-water measurements were made in the center of each plot twice per week with a neutron probe at 0.15-, 0.46-, 0.76-, 1.07-, 1.37-, and 1.68-m depths. Plots were flood irrigated weekly with required amounts of water. Corrugated tin borders around plots ensured that no horizontal surface-water flow occurred between plots. No additional measures were taken to minimize lateral water movement below the soil surface between plots, but plants measured in adjacent plots were separated by at least 1.6 m. Border areas outside the rainout shelter were planted in unirrigated corn. On 24 Sept. 1987 (1200 to 1430 h) several plant measurements were made (described below.)

Leaf Temperature Measurements and CWSI Calculations

Leaf temperature was measured on a single, upper canopy, fully sunlit leaf on 12 plants per plot with a hand-held infrared thermometer (Model 112 Agritherm, Everest Interscience, Fullerton, CA)[1]. The infrared thermometer (IRT) was held as close to the leaf as possible without shading it (typically about 5 cm from the leaf). The sun was to the back of the IRT operator and the leaf presentation was nearly perpendicular to the incident solar beam. No clouds were present during the measurement period. The IRT had a 3° field of view and detected radiation in the 8- to 14-μm waveband. Spot size for the IRT was measured following the technique described by Jackson et al. (1980) in which a piece of aluminum foil is moved into the IRT field of view from around the perimeter of the viewed area until the signal from the IRT drops rapidly. Spot size remained nearly constant (approximately 15 cm^2) over a range of target distances varying from 4 to 37 cm. Data were recorded with a portable data logger (Polycorder, Model 516B, Omnidata Int., Logan, UT). Individual leaf areas ranged from 31.3 to 114.6 cm^2, averaging 64.3 cm^2. Plants averaged 0.19-m tall with eight nodes. Dry and wet bulb temperatures were measured in the plot area before and after the leaf temperature measurements with an aspirated Assman-type psychrometer at a height of 1.5 m. This procedure was repeated following the other water stress measurements described below. The CWSI values were calculated following the method of Idso et al. (1981a) using the non-water-stressed baseline equation given by Idso (1982) for sunflowers (T_l-T_a = 0.66 − 1.95 × VPD, where T_l and T_a are leaf and air temperatures (°C), respectively, and VPD is vapor pressure deficit (kPa)). An average CWSI value was computed for each of the 12 plots from the measurements made on each of the 12 leaves per plot at the beginning and end of the measurement period (24 measurements per plot).

Other Water Stress Measurements

Following the first set of leaf temperature measurements with the IRT, a single, upper canopy, fully sunlit leaf of each of four plants in each plot was measured for leaf CO_2 exchange rate, transpiration rate, and stomatal conductance with a portable photosynthesis system (LI-6000, LICOR, Inc., Lincoln, NE). The leaf directly opposite the one used for these measurements was excised and then measured for leaf water potential using a pressure bomb (Water Status Console, Model 3003, Soil Moisture Equipment Corp., Santa Barbara, CA). The procedure outlined by Turner (1987) was followed by immediately covering the leaf with a plastic sheath after excision. Typically, < 20 s passed between excision and pressurization. The four replicate measurements of leaf CO_2 exchange rate, transpiration rate, stomatal conductance, and leaf water potential were averaged to give single representative values of these parameters for each plot.

Percent available soil water was calculated from the measured available soil water in the surface to 0.30-m layer divided by an assumed field capacity soil water content of 53 mm for this layer.

Results and Discussion

Quadratic regression curves of CWSI against stomatal conductance, leaf water potential, transpiration rate, percent available soil water, and CO_2 exchange rate (Fig. 1) were fitted to the data. Coefficients of determination (r^2) ranged from 0.62 to 0.93. All of the water stress parameters measured showed a decline with increasing CWSI.

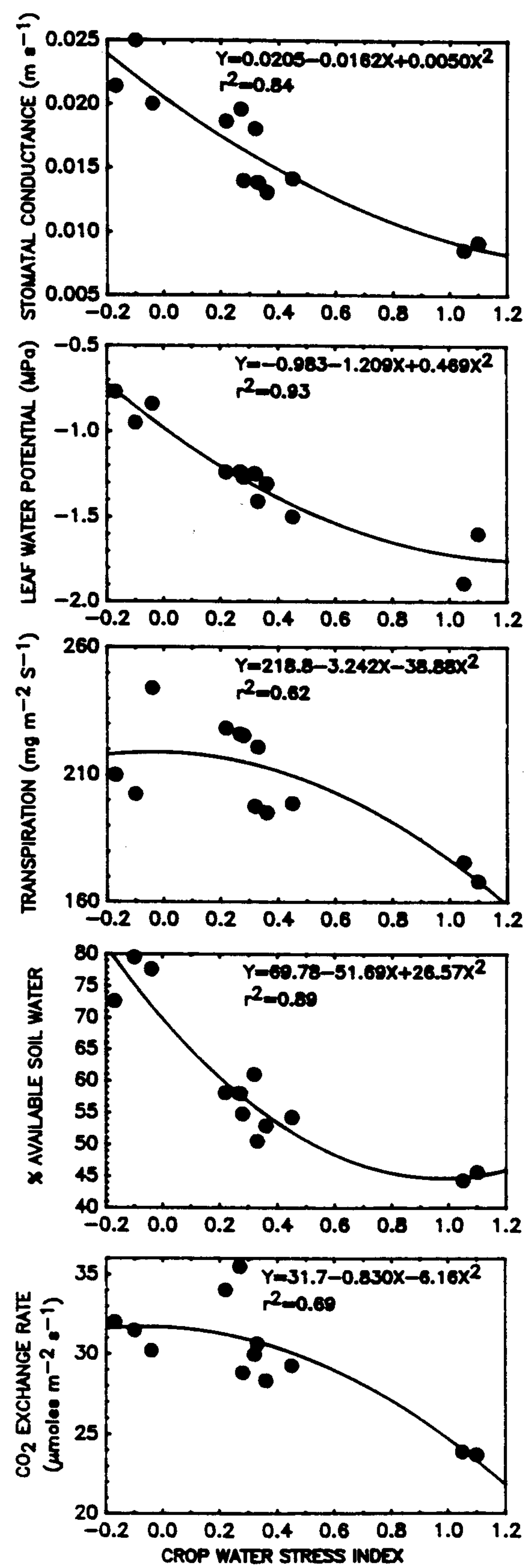

Fig. 1. Relationship between single leaf Crop Water Stress Index and stomatal conductance, leaf water potential, leaf transpiration, percent available water, and leaf CO_2 exchange rate.

[1]Trade names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or the USDA.

As the stomata closed in response to decreased availability of soil water and lower leaf water potential, transpiration rates declined, leaf temperature increased, and CWSI increased. In response to increased water stress, the leaf CO_2 exchange rate declined. Some of the variability of the data points about the regression lines may be explained by the fact that the leaves measured for stomatal conductance, leaf water potential, transpiration rate, and CO_2 exchange rate were not the same leaves measured for temperature used to calculate CWSI.

The stomatal conductance, transpiration rate, and CO_2 exchange rate measured at CWSI near 1.0 are not as low as we would have expected under near maximum water-stress conditions. Perhaps we really had not achieved maximum water stress in our 0.0% water replacement treatment and the correct CWSI for these plots should have been lower. This is a possible consequence of using an incorrect non-water-stressed baseline. The CWSI values < 0.0 and > 1.0 (the theoretical limits of CWSI) also suggest that the published non-water-stressed baseline for sunflower canopies that we used to calculate CWSI may not be appropriate for use with single leaves. Another possible explanation would be that the same effects on the non-water-stressed baseline noted by Hatfield et al. (1985) for multi-leaf, partial canopies (e.g., small plants subject to the high radiant and convective thermal load of adjacent hot soil surfaces plus the steep air temperature gradient that exists near the soil surface) are present for single leaf, partial canopy measurements. Therefore, a non-water-stressed baseline with a more shallow slope would be appropriate. This would indeed have lowered the high CWSI to values more in line with the other water-stress parameters measured, but it would also have made the low CWSI values negative. Measurements made on single leaves of complete canopies would possibly require a different baseline as well. Studies should be conducted to compare non-water-stressed baselines from (i) single leaves in complete canopies, (ii) multiple leaves in complete canopies, (iii) single leaves in partial canopies, and (iv) multiple leaves in partial canopies.

The limited data set presented here is not meant to show definitive water-stress relationships for sunflower, but to demonstrate the use of infrared thermometry to detect and quantify water stress based on single leaf temperatures. The total time required for making temperature measurements on 288 individual leaves was under 26 min. Therefore, many small plants could be sampled in a short time. We see this technique as having great value in allowing researchers and producers to rapidly determine presence and severity of water stress for broadleaf plants that are small and/or widely spaced.

References

Hatfield J.L., D. F. Wanjura, and G.L. Barker. 1985. Canopy temperature response to water stress under partial canopy. Trans. ASAE 28:1607–1611.

Idso, S.B. 1982. Non-water-stressed baselines: A key to measuring and interpreting plant water stress. Agric. Meteorol. 27:59–70.

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

Idso, S.B., R.J. Reginato, R.D. Jackson, and P.J. Pinter, Jr. 1981b. Measuring yield-reducing plant water potential depressions in wheat by infrared thermometry. Irrig. Sci. 2:205–212.

Idso, S.B., R.J. Reginato, and J.W. Radin. 1982. Leaf diffusion resistance and photosynthesis in cotton as related to a foliage temperature based plant water stress index. Agric. Meteorol. 27:27–34.

Idso, S.B., R.J. Reginato, D.C. Reicosky, and J.L. Hatfield. 1981c. Determining soil-induced plant water potential depressions in alfalfa by means of infrared thermometry. Agron. J. 73:826–830.

Jackson, R.D., S.B. Idso, R.J. Reginato, and P.J. Pinter, Jr. 1981. Canopy temperature as a crop water stress indicator. Water Resour. Res. 17:1133–1138.

Jackson, R.D., P.J. Pinter, Jr., R.J. Reginato, and S.B. Idso. 1980. Hand-held radiometry. USDA-SEA Western Region. Agric. Rev. Manual-W-19.

Pinter, P.J., Jr., and R.J. Reginato. 1982. A thermal infrared technique for monitoring cotton water stress and scheduling irrigations. Trans. ASAE. 25:1651–1655.

Turner, N.C. 1987. The use of the pressure chamber in studies of plant water status. p. 13-24. *In* Proc. Int. Conf. on Measurement of Soil and Plant Water Status, Vol. 2, Logan, UT. 6-10 July 1987. Utah State Univ., Logan, UT.