MONITORING TURF WATER STATUS WITH INFRARED THERMOMETRY

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ABSTRACT

New advances in the Crop Water Stress Index (CWSI) technique pioneered by Idso et al. (1981), Jackson et al (1981), and others have reduced the data requirements and development time for detection of water stress. These new methods, sometimes called the empirical CWSI (eCWSI, O'Shaughnessy and Evett, 2009) were adapted for the Northern Water turf studies program. The adapted methods compare turf surface temperature measured with an infrared thermometer to surface temperature of a spray-pump wetted turf surface. The eCWSI of a plot of spray irrigated tall fescue was compared to the eCWSI of an adjacent plot of subsurface drip irrigated (SDI) tall fescue. Attempts were made to keep the eCWSI of each plot close in value with irrigations applied as needed to the more stressed plot. Although weather conditions in 2009 often precluded collecting data as frequently as needed, results indicated that the SDI plot was often more stressed than the spray plot. The SDI plot had less applied water than the spray-irrigated plot and soil moisture in the SDI plot also was consistently lower than in the spray plot. These results suggest that maintaining eCWSI at equal levels would increase the applied irrigation to the SDI plot. Information in 2010 will help define whether true applied irrigation differences exist between the SDI and spray-irrigated plots. The new eCWSI approach for turf is robust, simple, and has potential for technology transfer to turf managers with inexpensive, off-the-shelf instrumentation and equipment.

INTRODUCTION

Infrared thermometry to detect plant water stress was pioneered by Idso et al. (1981) and Jackson et al. (1981). Jackson et al (1981) showed that the empirical approach of Idso et al (1981) was well-grounded in theory. The CWSI represents the ratio of actual evapotranspiration (E) to potential ET (E_p) in the following way: $1\text{-}E/E_{p,}$ where 0 is non-stressed, and 1.0 indicates no transpiration. In practice, the CWSI was typically implemented using hand-held infrared thermometers and on-site humidity and air temperature data. While robust and sensitive, the technique had several drawbacks that limited its practical application on a wide-spread basis.

One major limitation was that the empirical non-stressed baseline had to be pre-developed for each crop and sometimes for each variety. The technique required a wide range of vapor pressure deficit conditions to be transportable among locations or even among years at the same location. Another drawback was that baselines had to be

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developed for various canopy cover conditions. A baseline developed for full cover was not appropriate for partial canopy cover.

A recent resurgence of interest and activity in the CWSI has yielded several improvements in usability of the technique. Instead of developing baselines for each crop or variety, Jones et al (1999) used natural wet and dry reference surfaces to provide the upper and lower limits of the CWSI. The wet reference surfaces ranged from spray-wetted leaves or canopies (Möller et al, 2007) to fully-irrigated crops (Grant et al. 2007). Artificial wet reference surfaces were also used to standardize the wet reference against crop condition or spatial variability (Cohen et al., 2007; O'Shaughnessy and Evett, 2009).

Using a wet reference surface eliminates the need to pre-develop a well-watered baseline for each crop or variety. The wet reference evaporation varies with immediate weather conditions and so provides a site-specific, time-specific method for a non-stressed data point with which to compare actual crop surface temperatures. If the crop surface itself is wetted, the wetted surface then has the color, texture, and similar sunlight and shaded portions as the measurement areas of the crop. However, variability in color or density of crop surfaces can lead to problems in consistency of the wetted reference surface. Also, if a number of different crops or varieties are monitored, wetted canopy reference surfaces for each crop should be used.

The upper limit of the CWSI is theoretically the canopy minus air temperature value at any given vapor pressure deficit at which transpiration is zero. Idso et al (1981) described a method of finding an approximate upper limit. O'Shaughnessy and Evett (2009) documented an approach to the upper limit which used maximum daily air temperature plus 5 degrees C.

A method was needed to determine turf water status in comparative plots that was robust and quick. The CWSI approach of Idso et al (1981) is well-known, but not without drawbacks, chief of which was that a well-watered baseline was not available for our site and would have to be developed over time. The sources outlined in this section allowed us to develop an immediately usable technique that appears to be robust and relatively simple in its ancillary data requirements.

The 2009 test study at Northern Water compared applied water on a tall fescue spray-irrigated plot to applied water on an SDI tall fescue plot. The empirical CWSI (eCWSI) method of O'Shaughnessy and Evett (2009) was modified to monitor turf water status and independently verify that the irrigation schedules were maintaining the tall fescue at similar plant water status.

The purpose of this paper is to discuss the technique and to relate the eCWSI relationship to applied irrigation and soil moisture for spray and subsurface drip irrigated plots.

METHODS

Tall fescue was established in 2 plots in 2005. Each plot was wedge-shaped and 1400 sq ft in size. Fixed spray heads (4” pop-up sprinkler heads with 10’, 12’, and 15’ fixed spray nozzles) were installed in one plot. Subsurface drip tubing was installed in the second plot 5” below grade on 15” spacing. The dripline consisted of polyethylene pipe with internal emitters (0.26 gph) at 18” intervals. The soil type in the plots was amended silty clay. Turf was maintained at industry standards for best management practices. Each plot had a Baseline biSensor™ (soil moisture sensor) installed at the 8” depth. Flow meters measured water applied to each plot, and the spray plot had three rain gauges installed. Northern Water’s Berthoud onsite weather station independently monitored air temperature, solar radiation, wind speed, rainfall, soil temperature, and humidity.
Total rainfall from April-October 2009 was 14.4 inches. Irrigation water was applied at approximately 90% of ETo (standardized grass reference ET) for each plot. Initially soil moisture was the primary basis for irrigation occurrence.

The instrument used for measurement of crop temperature was a Scheduler Plant Stress Monitor (Standard Oil Engineered Materials Company). Although an older instrument, calibration checks indicated that it was still accurate. The Scheduler collects a variety of data and provides a variety of information. The only data used from the Scheduler was the canopy temperature value, which was manually recorded. Temperatures were converted to Celsius for calculation of the eCWSI. Time of data collection was also recorded.

A large separate plot of tall fescue, also seeded in 2005, was used for the wet reference. This plot was maintained at about 90% of ETo and monitored for its overall eCWSI status as well. The irrigation system in this plot was rotor heads at 30’ spacing.

The wet reference surface was established by spraying a 4’ by 4’ area with water from a hand-held sprayer, similar to Möller et al (2007) on grapevines. This method was chosen because it was 1) convenient and 2) in Möller et al (2007), the actual wetted plant canopy was least affected by any seasonal changes as it incorporated color and texture of the plant canopy into the wet reference temperature.

The turf wet reference temperature was obtained from each cardinal direction with the instrument held at a consistent angle and height by the user. From three to five complete data sets of the wet reference were collected. Because the data had to be collected sequentially and not simultaneously from each direction, data were collected until it was apparent that the surface was warming appreciably. It took approximately 2 minutes to complete each sequence of the cardinal directions. Care was taken to exclude shadows from the instrument or the user in the field of view.

During data analysis, the sequential wet reference datasets were scrutinized and measurements were eliminated during a short initial period during which the sprayed-on water would come into equilibrium with the grass surface. Data from the cardinal directions were averaged from the selected sequence or sequences and used as the lower limit of the eCWSI.

Three canopy temperature data points from each cardinal direction were collected in the spray and SDI plots between 1100 and 1200 MDT. Data collection was distributed throughout each plot and averaged into one canopy temperature value representative of the entire plot.

In order to calculate an eCWSI value on the same day as data collection, the National Weather Service (NWS) forecast high temperature for Berthoud, CO, obtained close to the time of data collection, was used to provide the daily maximum air temperature value required by the eCWSI calculation. Actual maximum daily air temperature at Northern Water's Berthoud weather station was obtained from the weather database on the following day and compared to the NWS forecast value.

The eCWSI is calculated by

$$eCWSI = (T_c - T_{wet})/[(T_{dry}) - T_{wet}] \quad (1)$$

$$T_{dry} = T_{max} + 5^oC \quad (2)$$

where T_c is the measured canopy temperature, T_{wet} is the measured wet reference temperature, and T_{max} is the NWS forecast or actual daily high air temperature. T_{dry} is the upper limit at which no transpiration occurs.

The eCWSI was used both as a turf water status monitor and as an irrigation trigger later in the season. Irrigations were not applied unless a plot exceeded about 0.2 eCWSI. This value is typical for keeping crops, including turf, at a well-watered state. Unfavorable weather conditions prevented data collection on many days, making it more difficult to keep turf conditions at comparable well-watered levels.

RESULTS AND DISCUSSION

Total irrigation applied to the SDI plot in 2009 was 16.1 inches, while 17.7 inches were applied to the spray plot (Figure 1).

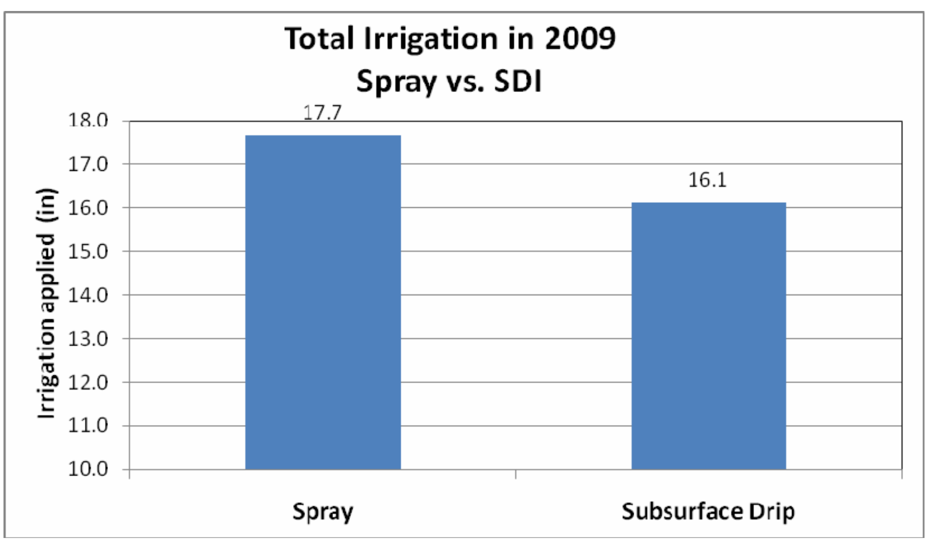

Figure 1. Total applied irrigation to tall fescue spray vs. SDI irrigated plots in 2009.

While the NWS forecast typically overestimated the actual high temperature value by a few degrees (Figure 2), the eCWSI values were accurate enough that they provided a good prediction of whether irrigation should occur (Figures 3 and 4).

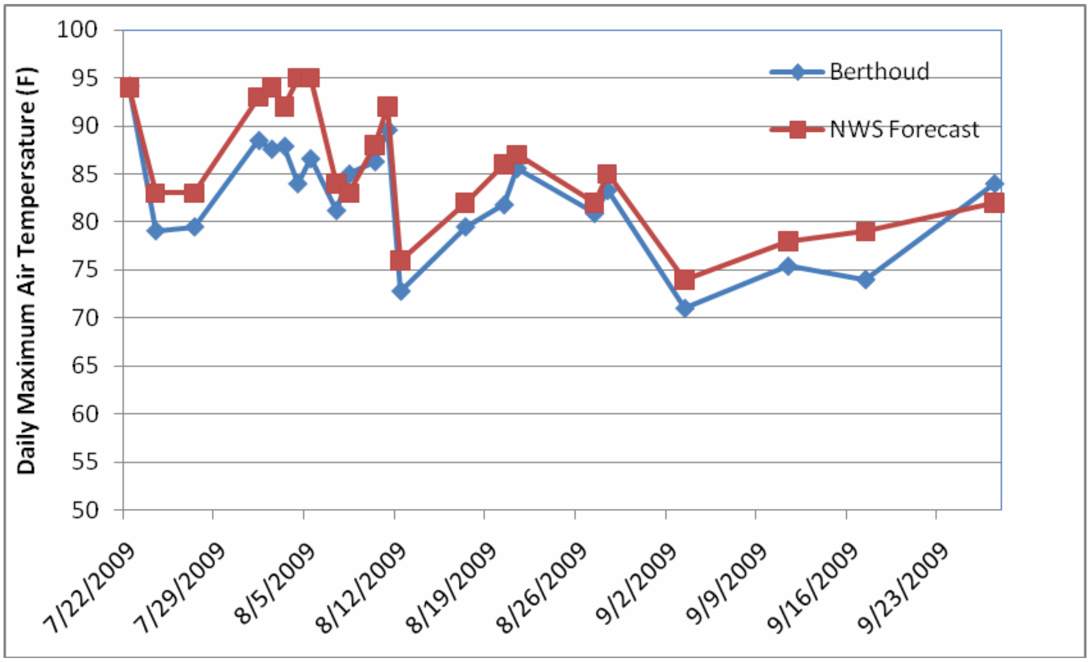

Figure 2. Comparison of NWS forecast daily high temperature and actual Berthoud daily maximum air temperature.

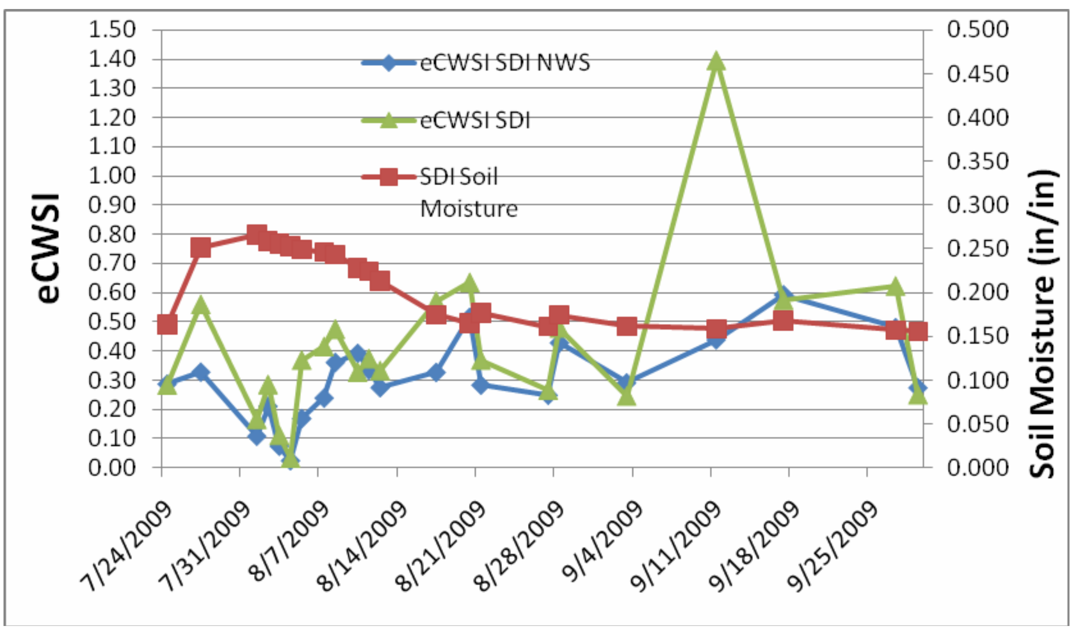

Figure 3. Comparison of eCWSI for SDI calculated with NWS forecast high and the actual Berthoud daily maximum temperature.

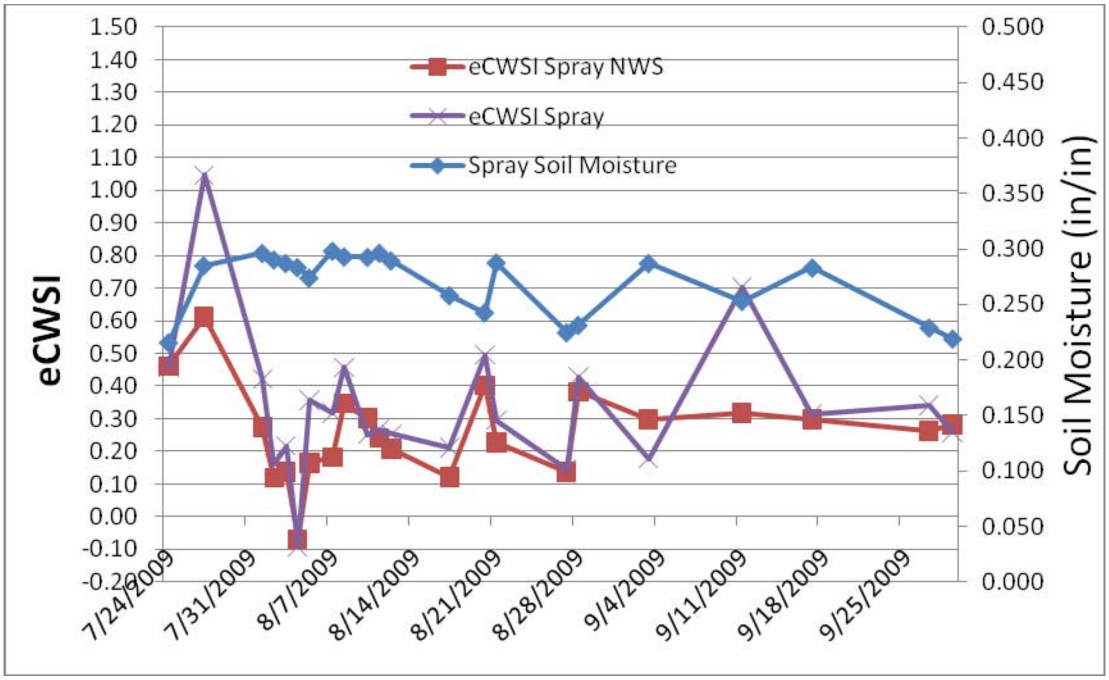

Figure 4. Comparison of eCWSI for spray irrigation calculated with NWS forecast high and the actual Berthoud daily maximum temperature.

The eCWSI values calculated with the NWS high and the Berthoud daily Tmax tracked well, with eCWSI in the SDI plot showing greater differences than the spray irrigated plot eCWSI for about a week in August. This corresponds with a larger difference between the NWS forecast and the Berthoud Tmax during the same period. On 27 July 2009 and 11 Sept 2009, there is a wide divergence of eCWSI values, with eCWSI based on the Berthoud Tmax ranging above 1.0, the zero transpiration upper limit. Because there is no concurrent change in soil moisture (Figures 3 and 4), the NWS value was considered to be the more accurate value to use in the eCWSI calculation.

Figures 3 and 4 generally validate the use of the NWS forecast high as a surrogate for an onsite daily maximum air temperature value if immediate decisions are required. Usually, the turf water status was evaluated on the same day as data collection and therefore the NWS forecast-based eCWSI value was used to make decisions and is shown in subsequent figures.

The eCWSI varied for the spray and SDI plots in 2009 (Figure 5). Well-watered conditions generally are indicated by an eCWSI of 0.2 or less. Negative values can occur during highly-variable environmental conditions during data collection, which contribute to variability in the turf surface temperature. The early data point for the SDI eCWSI reflects conditions after heavy rainfall. The SDI plot showed moderately high stress on July 24. This was likely because of saturated soils from heavy rains, which contributed to lower oxygen content in the soil. Lack of oxygen in soils can inhibit plant water uptake, leading to apparent water stress conditions. There is no data point for the spray-irrigated plot on July 24, as a storm front came in during data collection. In September, the SDI plot was not irrigated from September 15 through September 28 and became water stressed. The eCWSI on September 27 was used as a trigger for the September 28 irrigation. The amount applied was 90 percent of replacement ETo (grass reference ET) from the last irrigation date to the current date. The eCWSI value on September 29 showed that water stress on the SDI plot was relieved on that date.

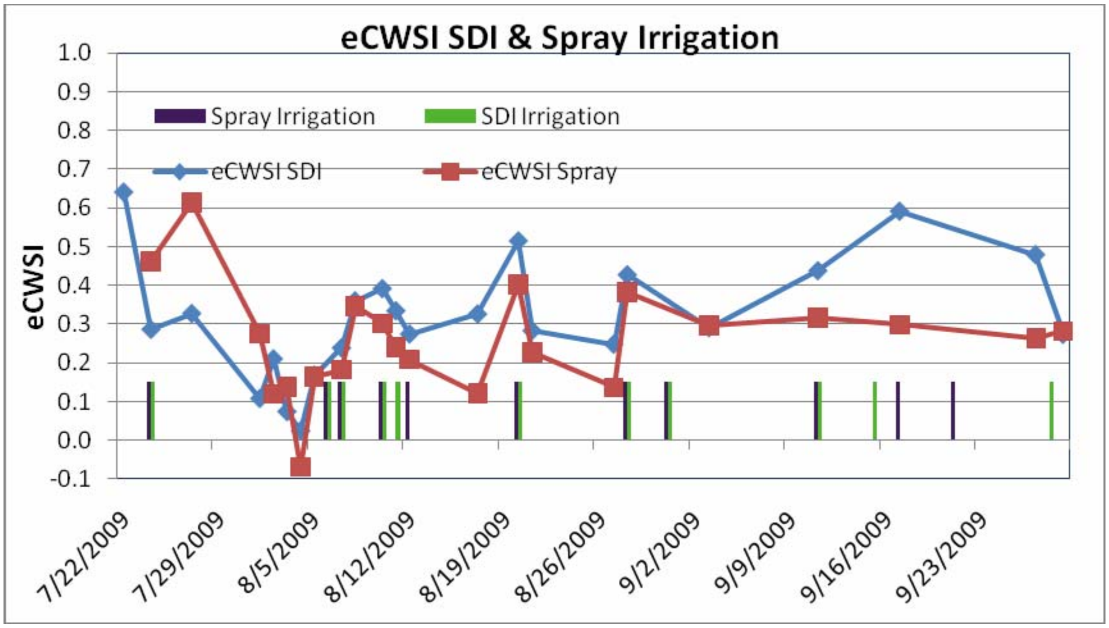

Figure 5. Spray and SDI eCWSI values for July –Sept 2009. Irrigation bars denote timing, not amount applied.

PLANS FOR 2010

Five Apogee SI 121 infrared thermometers were purchased in early 2010. These sensors will be mounted on a portable frame and connected to a datalogger. The frame will be constructed such that shadow effects are avoided and maximum field of view can be obtained. The frame-mounted sensors will be used to collect canopy temperature data in each of several studies at Northern Water. The wet reference technique will be modified to follow the technique of Möller (2007) and O'Shaughnessy and Evett (2009). Both used a wetted fabric surface floating in a shallow water reservoir as the wet reference. Changing to this technique will provide a standardized reference for several turf grasses. Time constraints and limited plant material preclude using the wetted turf itself as a wet reference for the various Northern Water turf studies.
The canopy temperature variability in the SDI vs. the spray plot will also be analysed. Some studies have shown that canopy temperature variability is an important consideration in whether a crop has become stressed.

One of the main studies that will be monitored is a Smart Controller comparison. Smart Controllers are designed to irrigate landscapes based on climatic data. The eCWSI will provide an independent measure of how well each Smart Controller performs. Another study will compare turf water status of 11 varieties irrigated with a line source irrigation system.

An commercial infrared thermometer purchased for less than $100 at a local hardware store will be tested. This instrument, while of lower accuracy than the instruments currently used, may prove to be effective in detecting turf water status and have utility in technology transfer to turf managers.

Data from 2010 will be included in the presentation.

SUMMARY

The eCWSI method was fairly easy to implement and interpret. The results are robust and provided a good method for monitoring turf water status. The on-the-spot, accessible methods considerably reduce the data requirements to produce a good eCWSI value, although with the wet reference technique used here, some user experience and discretion is necessary. Rapid and simultaneous logging of the wet reference surface temperature plus ancillary weather data may provide data for developing guidelines on selecting the best wet reference data for the eCWSI if using the wetted canopy technique.

Soil moisture changes tracked reasonably with the eCWSI, lending more confidence to the technique and its execution. Modifications and extensions of the technique will provide better turf water status information for the ongoing studies at Northern Water.

Total applied irrigation was higher for the spray plot than the SDI plot in 2009. However, the eCWSI for the SDI plot often was higher than the spray plot eCWSI, and the soil moisture values lower. More frequent data collection in 2010 and closer monitoring of the spray and SDI plots may improve the study results.

REFERENCES

Cohen, Y., V. Alchanatis, M. Meron, Y. Saranga, and J. Tsipris. 2005. Estimation of leaf water potential by thermal imagery and spatial analysis. J. Exp. Botany 56(417): 1843-1852.

Grant, Olga M., Lukasz Tronina, Hamlyn G. Jones, and M. Manuela Chaves. 2007. Exploring thermal imaging variables for the detection of stress responses in grapevine under different irrigation regimes. J. Exp. Botany 58(4): 815-825.

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

Jackson, R. D., S. B. Idso, R. J. Reginato, and P. J. Pinter, Jr. 1981. Canopy temperature as a crop water stress indicator. Water Resources Research 17(4): 1133-1138.

Jones, H. G. 1999. Use of thermography for quantitative studies of spatial and temporal variationof stomatal conductance over leaf surfaces. Plant, Cell, and Environment 22: 1043-1055.

Möller, M., V. Alchanatis, Y. Cohen, M. Meron, J. Tsipris, A. Naor, V. Ostrovsky, M. Sprintsin, and S. Cohen. 2007. Use of thermal and visible imagery for estimating crop water status of irrigated grapevine. J. Exp. Botany 58(4): 827-838.

O'Shaughnessy, Susan A. and Steven R. Evett. 2009. Infrared thermography to assess spatial variation of water stressed cotton. Wetting Front: Water Management Research Unit newsletter. 2009 June, p. 3-7. http://ddr.nal.usda.gov/dspace/handle/10113/32620. Accessed April 7, 2010.