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Comparison of Temperature-Time Threshold-and ET-based Irrigation Scheduling for Corn Production

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Abstract. *Techniques using crop canopy temperature measurements to minimize or manage plant water stress have the potential of providing automated irrigation scheduling without resorting to traditional soil water measurement-based or weather-based water budget scheduling. A relatively new canopy temperature technique developed by the USDA-ARS and patented under the name BIOTIC uses a Temperature-Time Threshold (TTT) to schedule irrigation. The TTT method accumulates time that a crop canopy is above a specified temperature. When the accumulated time exceeds the specified TTT value an irrigation event signal is generated. Three corn irrigation scheduling treatments using TTT values of 2.5, 4.0 or 5.5 h above a canopy temperature of 28 C were compared to 100% and 65% of calculated ET_c and to a treatment receiving no further irrigation after mid-July at Colby, Kansas. The results indicate that a TTT treatment using a threshold of 2.5 h corresponds reasonably well to a 100% ET_c replacement treatment. Results also indicate that the measured TTT values were more closely related to the prevailing weather conditions than to irrigation level or plant available soil water.*

Keywords. Automated irrigation scheduling, evapotranspiration, irrigation management, corn, subsurface drip irrigation, TTT, BIOTIC, canopy temperature, Infrared temperature sensors.

Introduction

The Temperature-Time Threshold (TTT) was developed as a new technique for evaluating crop water stress by USDA-ARS research scientists at Lubbock, Texas. This technique has been patented as Biologically-Identified Optimal Temperature Interactive Console (BIOTIC) for Managing Irrigation by the USDA under Patent No. 5,539637 (Upchurch et al., 1996). Briefly, the TTT technique can be described as comparing the accumulated time that the crop canopy temperature is greater than a crop-specific temperature against a specified critical time developed for a well-watered crop in the same region. Irrigation is applied when the threshold time is exceeded. A more detailed description excerpted from the patent abstract is given below:

> *A process and device for managing irrigation of plants or crops using crop canopy temperate measurements by use of a specific time threshold. In this process, the canopy temperature of the target plant is repeatedly measured with an infrared thermometer. After each measurement, the canopy temperature is compared with a predetermined threshold canopy temperature, above which temperature the plant is thermally stressed. If the measured canopy temperature is less than or equal to the threshold canopy temperature, or if the existing humidity is restrictive to plant cooling, then irrigation is not indicated and the canopy temperature measurement is repeated at its designated time. However, if both the measured canopy temperature is greater than the threshold temperature, and the humidity is not restrictive to plant cooling, then an increment of time is added to a time register. The accumulated time in the time register is then compared to the time threshold, a predetermined constant defined as about the mean of the length of time per day that the canopy temperature for the plant, in a well-watered and non-stressed condition, exceeded the threshold canopy temperature in the target geographical area. As long as the accumulated time is substantially less than the time threshold, irrigation is either unnecessary or ineffective to achieve transpirational cooling, and the process is again repeated with measurement of the canopy temperature. However, once the accumulated time exceeds or is approximately equal to the time threshold, transpirational cooling is indicated and an irrigation signal is generated.*

Studies in Texas have shown that TTT technology can be used to effectively irrigate cotton, soybeans, and corn (Wanjura et al. 2003, Evett et al., 2002). Research by Evett et al. (2002) has shown that the TTT technology can be used for different goals such as crop yield optimization or maximization of water use efficiency with just minor adjustments to the protocols. A 28 C canopy temperature was used for corn by Evett et al. (2002) because it has been found to be the center of the thermal kenetic window for optimum growth (Burke 1996). A critical time exceedance (CTE) of 4 hours was used in the USDA-ARS studies at Bushland, Texas (Evett et al., 2002) having been determined from a crop energy balance method suggested by Wanjura et al. (1995).

An effort is being made by the USDA-ARS to extend this technology to other regions and to develop fully automated TTT-based irrigation scheduling systems for center pivot sprinkler irrigation. However, a brief literature review suggests that TTT technology has been used primarily only in Texas with some additional evaluation of time thresholds for cotton in Mississippi and California (Wanjura et al., 1995). An on-going study was initiated at the Kansas State University Northwest Research-Extension Center at Colby, Kansas in 2005 to evaluate the TTT technology in the Central Great Plains for corn production. This progress report discusses results from the first two years (2005 and 2006) with the study scheduled to be completed in 2008.

Procedures

The study was conducted from 2005 and 2006 in a semi-arid climate in the Central Great Plains (KSU Northwest Research-Extension Center, Colby Kansas. The region has an average annual precipitation of 481 mm with a summer pattern resulting in an average corn cropping season precipitation of 299 mm. The average seasonal total crop evapotranspiration (ET_c) for corn is 586 mm. The latitude is 39.39 degrees north and the longitude is 101.07degrees west with an elevation of 3160 ft above sea level. Corn was grown on a deep, well-drained Keith Silt loam soil (Aridic Argiustolls) with a subsurface drip irrigation system (SDI) system that has a 30-cm emitter spacing, an 1.5 m dripline spacing, and a 0.45 m dripline depth with a nominal emitter discharge of 0.57 L/h. The deep silt loam soil can supply about 445 mm of plant available soil water from a 2.4-m soil profile.

The 1.8 ha study area was approximately 90 m wide and 200 m long with a land slope of approximately 0.25%. Six irrigation treatments were replicated four times in a complete randomized block design. Each plot was approximately 6 m wide and 100 m long with row direction running north to south. This corresponds to eight 76-cm corn rows with driplines spaced every 1.5 m between corn rows. There was a 6 m buffer strip on the east and west edges of the study area. The three TTT treatments were daily time accumulations of 2.5, 4.0, or 5.5 hours of crop canopy temperatures above a critical temperature of 28 C. The two ET-based scheduling treatments were designed to replace 65 or 100% of ET as calculated by a weather-based water budget. An additional sixth treatment received no irrigation after the initiation of the scheduling treatments. All plots were equally irrigated during the early growth stages to establish the crop. The five different scheduling treatments were initiated on July 16, 2005 and July 20, 2006 for the respective years. Irrigation was scheduled for the ET-based treatments whenever those treatments reached a 25 mm calculated soil water depletion. However, an irrigation capacity limit of 7.6 mm/d was imposed. This represents a typical design irrigation capacity in this region. Irrigation amounts for each event were 7.6 mm/day.

Canopy temperatures were monitored for all plots with infrared thermocouple thermometers (IRT) from Exergen IRtc.03[1] with a germanium lens placed 0.3 m above canopy, NE and –45° orientation relative to horizon and shielded). Each IRT was placed in a machined PVC cylindrical rod (75 mm dia.), providing thermal mass, before shielding with a 100 mm white PVC sun shield. The temperatures detected by the IRT sensors (T_{ir}) were adjusted (T_{adj})for bias related to sensor body temperature (T_{sb}) by the equation

$$T_{adj} = T_{ir} + 0.3\ (T_{ir} - T_{sb}) \qquad (1)$$

Accumulated times (CTE) were assessed after 7:00 pm each day to determine if a TTT treatment had triggered for irrigation the following day. Additional constraints placed upon the CTE accumulations were that the net radiation be greater than 200 W/m^2 and that the ambient air temperature was greater than 28 C. These additional constraints were recommended by Wanjura and Upchurch (2000).

Irrigation for the ET-based treatments was scheduled on the basis of data collected from a NOAA weather station located approximately 450 m northeast of the study site. The reference evapotranspiration (ET_r) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ET_r calculations used in this study are fully described by Lamm et al. (1987). Basal crop coefficients (K_{cb}) were generated with equations developed by Kincaid and Heermann (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The basal crop coefficients were calculated for the area by assuming 70 days from emergence to full canopy for corn with physiological maturity at 130 days. This method of calculating ET_c as the product of K_{cb} and ET_r has been acceptable in past studies at Colby (Lamm and Rogers, 1983, 1985). In constructing the irrigation schedules, no attempt was made to modify ET_c with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974). The calculated well-watered ET_c for corn used later in the analysis was simply the product of K_{cb} and ET_r

The full season (118 day maturity) corn (Pioneer hybrid 32B33) was planted on May 5, 2005 and April 27, 2006 on 1.5 m beds with resulting plant populations of 82,500 and 88,200 plants/ha, respectively. Starter fertilizer was applied as a mixture of urea-ammonium-nitrate (UAN 32-0-0) and ammoniated superphosphate (10-34-0) at planting at a rate of 18.3 kg/ha of nitrogen and 30.4 kg/ha P_2O_5. An additional 225 kg/ha of nitrogen (UAN 32-0-0) was applied through the SDI system (fertigation) during the period June 10-June 30 each year. Herbicides and insecticides were applied as needed according to typical practices for the region.

Water use was monitored in all plots with a neutron probe with measurements centered in the corn rows and taken in 30 cm increments to a depth of 2.4 m. These data along with irrigation and precipitation amounts was used to determine crop water use temporally and for the whole season. Plant available soil water was calculated as the soil water between a site-derived field capacity and a lower limit of soil water availability and could be expressed as a percentage or as a depth in mm for a specified profile depth. Measured crop water use was calculated as the sum of irrigation, precipitation, and the change in profile soil water between the first and last sampling dates. Corn yield and yield components of plant population, ears/plant, kernels/ear and kernel mass were determined from 6-m hand-harvested samples for each plot.

Results and Discussion

Weather Conditions and Irrigation Requirements

The corn emerged on May 15, 2005 and May 18, 2006 which was about normal for the region. Seasonal precipitation from emergence to treatment initiation on July 16, 2005 (DOY, 197) was 206 mm. In 2006, a total of 137 mm of precipitation occurred between emergence and treatment initiation on July 20 (DOY, 201). After treatment initiation, precipitation was approximately 80% of normal for the remainder of the corn growing period in both years (Figure 1). Seasonal evapotranspiration for the 120 day period from May 15 through September 11 was 598 mm in 2005 and 577 mm in 2006 which is near the long time average of 586 mm.

In this study the irrigation treatments were delayed until the crop fully shaded the ground and until the IRTs could be installed and data quality could be assessed (July 15, 2005 and July 20, 2006). Irrigation requirements prior to treatment initiation were provided at 100% of ET_c and resulted in amounts of 89 and 155 mm for 2005 and 2006, respectively. Seasonal irrigation requirements for the various treatments ranged from 89 to 356 mm in 2005 and from 155 to 361 mm in 2006 (Figure 2. and Table 1).

Irrigation requirements for the 2.5 h TTT treatment were similar to the 100% ET_c treatment in both years. The irrigation requirement for the 5.5 h TTT treatment was similar to the 65% ET_c treatment in both years. Irrigation requirements for the TTT technology were reduced approximately 11 and 17% for each additional CTE hour increase from 2.5 h in the respective years 2005 and 2006.

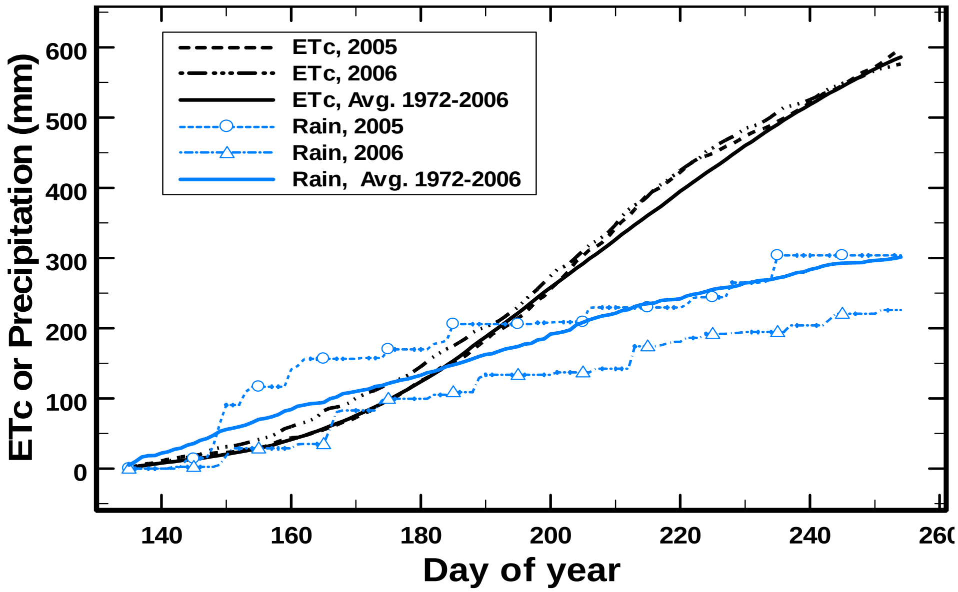

Figure 1. Seasonal precipitation and calculated corn evapotranspiration for a well-watered crop at the KSU Northwest Research-Extension Center, Colby, Kansas, 2005-2006 as compared to long term averages (1972-2006).

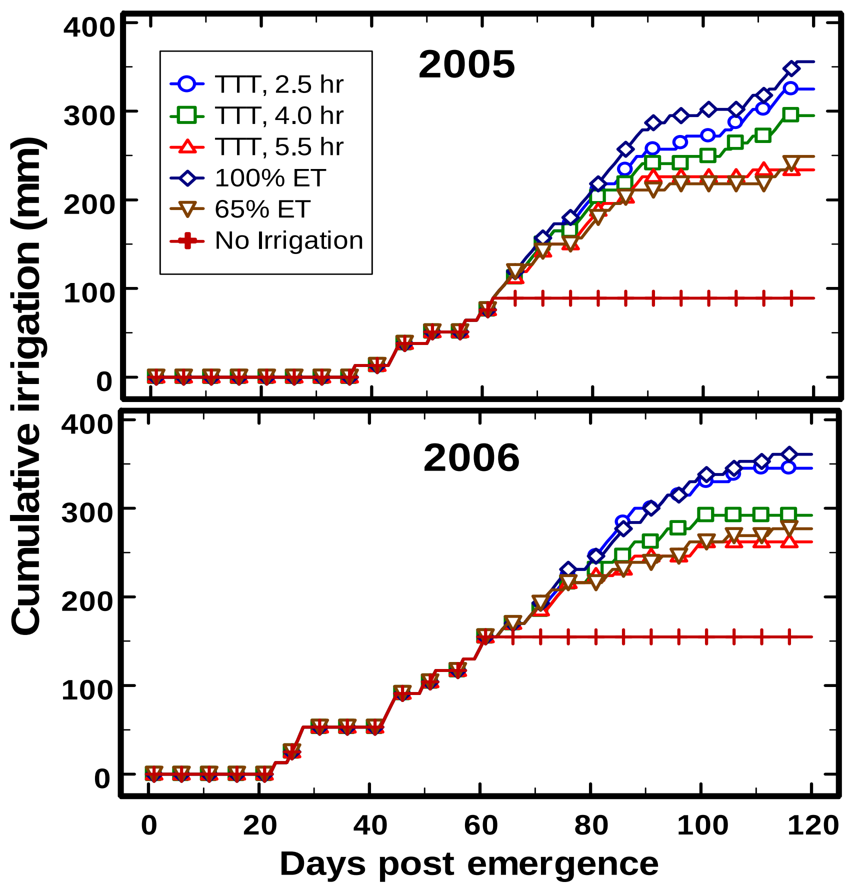

Figure 2. Irrigation requirements for 2005 and 2006 in an evaluation of TTT technology for corn production, KSU Northwest Research-Extension Center, Colby, Kansas.

Corn Yield and Yield Components

Overall grain yields were very high for the irrigated treatments. There were no significant differences in corn yield for either year for all treatments that received irrigation after the treatment initiation date but there was a relatively strong trend for increased grain yields with increased irrigation amount (Table 1). The number of ears/plant was not significantly different for the irrigation treatments in either year with only the control treatment (no irrigation after treatment initiation) having a significantly smaller value in 2005. The number of kernels/ear was also not significantly different for irrigated treatments but tended to increase with increased irrigation. The silking period of the corn occurred about July 20 in both years. As a result it was anticipated that ears/plant or kernels/ear would not be appreciably affected for the irrigated treatments because the treatments were not initiated until mid-July. Kernel abortion could still occur for about two weeks after silking as the data clearly suggests for the treatment receiving no further irrigation, but there would not have been large irrigation differences for the irrigated treatments during this period of time. The grain filling period would be most affected by any irrigation treatment difference. Generally kernel weight increased with irrigation amount but was only significantly reduced in 2005 for the 65% ET_c and Control treatment.

Table 1. Summary of yield and water use data from an irrigation scheduling study of corn, 2005 to 2006, KSU Northwest Research-Extension Center, Colby, Kansas.

Irrigation treatment	Yield (Mg/ha at 15.5%wb)	Ears/ plant	Kernels/ ear	Kernel Wt. (g/100 kernels)	Irrigation (mm)	Water use (mm)	WUE (Mg/ha-mm)
Corn for the Year, 2005							
TTT of 2.5 hours	17.6	0.99	649	33.19	325	721	0.0245
TTT of 4.0 hours	17.3	1.00	626	33.49	295	693	0.0249
TTT of 5.5 hours	16.7	0.99	643	32.09	234	671	0.0248
100% of ET	17.1	0.99	647	32.34	356	767	0.0223
65% of ET	16.1	0.98	641	30.24	249	673	0.0239
No Irr. after 7/15	6.6	0.71	376	28.36	89	550	0.0120
Mean	15.2	0.94	697	31.62	-	679	0.0223
LSD 0.05	3.7	0.20	114	2.17	-	40	0.0060
Corn for the Year, 2006							
TTT of 2.5 hours	17.1	0.98	565	35.18	345	690	0.0248
TTT of 4.0 hours	15.9	0.98	568	32.73	292	660	0.0241
TTT of 5.5 hours	15.5	0.99	535	32.43	262	649	0.0238
100% of ET	17.3	0.95	579	35.40	361	711	0.0244
65% of ET	15.9	0.98	551	34.25	277	660	0.0241
No Irr. after 7/19	12.1	0.94	468	31.17	155	583	0.0207
Mean	15.6	0.97	544	33.53	-	659	0.0236
LSD 0.05	2.3	NS	NS	NS	-	42	NS

Corn Water Use and Water Use Efficiency

The measured corn water use was significantly different between irrigation treatments with reductions in water use for treatments with increased TTT hours or reduced ET_c replacement (Table 1). The 2.5 hour TTT treatment had 46 mm less crop water use than the 100% ET_c replacement treatment for a corresponding 21 mm of less seasonal irrigation in 2005. In 2006, similarly the 2.5 hour TTT treatment had 21 less mm of crop water use and 16 less mm of irrigation than the 100% ET_c replacement treatment. There were no significant differences in water use efficiency (grain yield/measured crop water use) in either year for irrigated treatments tended to be slightly greater for the TTT treatments than the ET_c replacement treatments.

Relationship of Canopy Temperature and CTE to Air Temperature

Canopy temperature interpreted as a measure of plant thermal stress by BIOTIC would be expected to be related to weather conditions such as ambient air temperature or maximum daily air temperature. It would also be expected to vary with irrigation level. In this study with deep silt loam soils in the semi-arid Central Great Plains over the wide range of irrigation levels, ambient air temperature was a much greater factor affecting canopy temperature and CTE than irrigation level (Figures 3, 4 and 5). Over a four day period (August 21 to 24, 2006) during the latter part of the irrigation season, after irrigation treatment differences would have widened, maximum canopy temperature differences (Figure 3) between the wettest and non-irrigated treatment were only about 2.2 C on two moderate days (August 21 and 22) and were only about 5.0 C for two hot days (August 23 and 24). Temperature differences among the irrigated treatments averaged were less than 2 C for all four days.

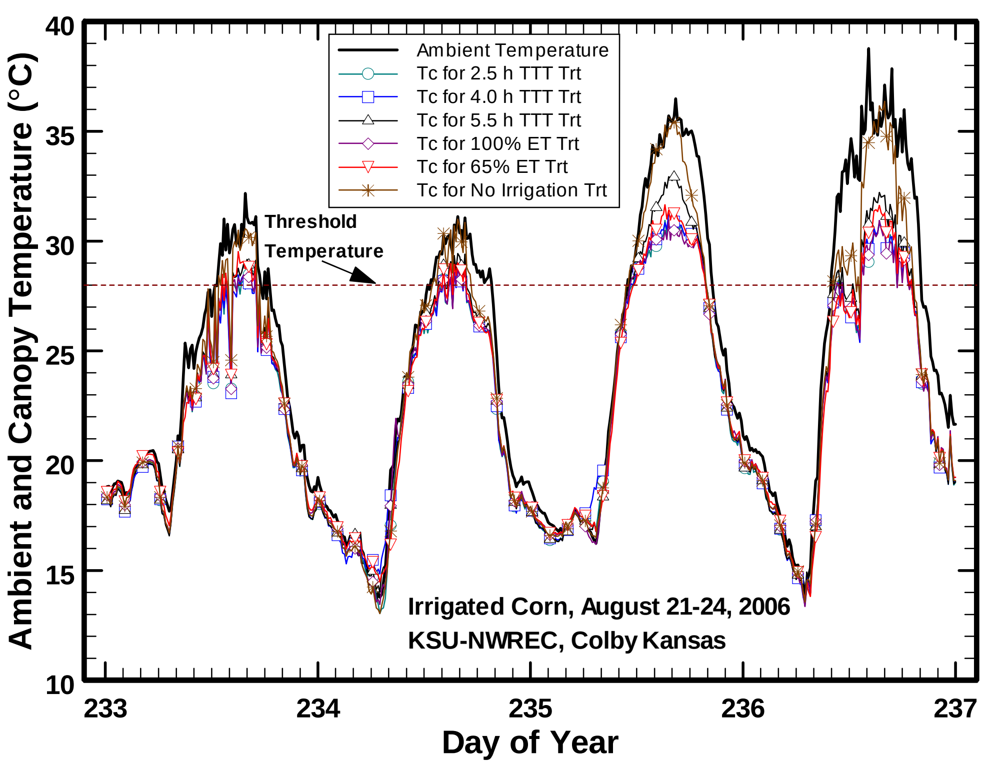

Figure 3. Ambient air temperature and canopy temperatures (T_C) for six irrigation treatments for corn during August 21 to 24, 2006, KSU Northwest Research-Extension Center, Colby Kansas. Data represents mean of four replicated plots.

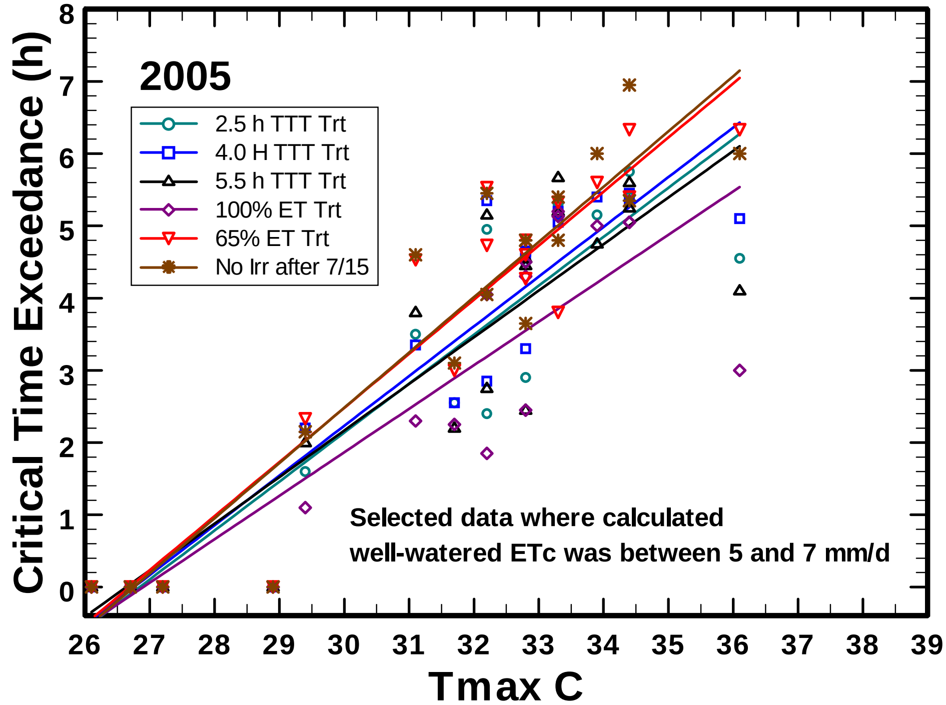

Figure 4. Critical Time Exceedance (CTE) for irrigated corn in 2005 as affected by maximum daily air temperature, KSU Northwest Research-Extension Center, Colby Kansas. Data was limited to those days where the calculated well-watered evapotranspiration for corn was between 5 and 7 mm/d.

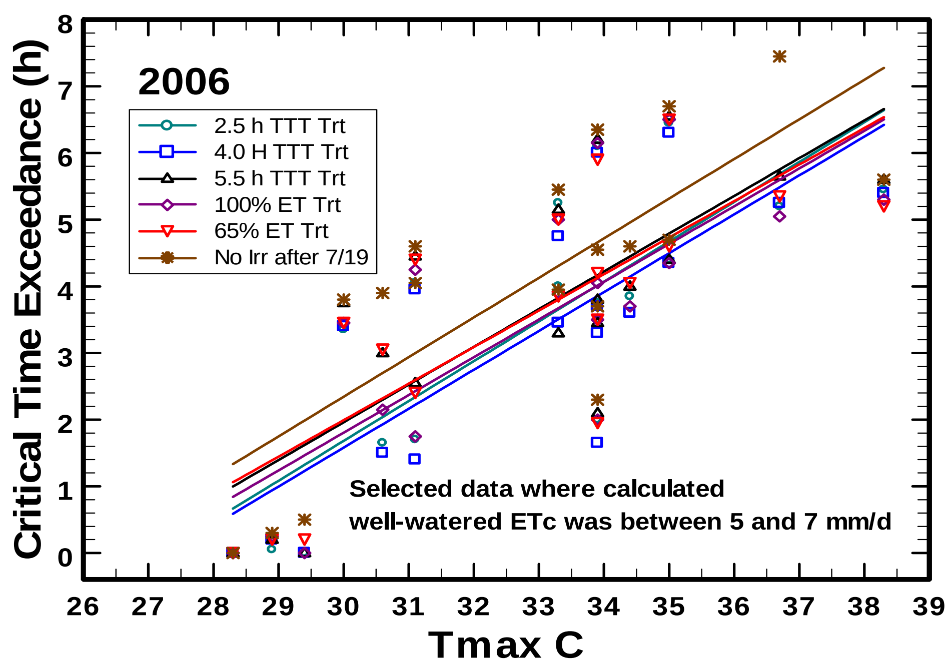

Figure 5. Critical Time Exceedance (CTE) for irrigated corn in 2006 as affected by maximum daily air temperature, KSU Northwest Research-Extension Center, Colby Kansas. Data was limited to those days where the calculated well-watered evapotranspiration for corn was between 5 and 7 mm/d.

The CTE and maximum daily air temperature data was plotted for selected days where the calculated well-watered corn ET_c was between 5 and 7 mm/d representing moderately high evaporative conditions (Figures 4 and 5). Although reduced irrigation level tended to increase the measured CTE there was a much stronger effect from maximum daily air temperature. An increase of approximately ten degrees C from the threshold temperature of 28 C resulted in an average of 7 to 8 hours of CTE.

Relationship of CTE to Calculated and Measured Corn Water Use

The CTE was also related to the calculated well-watered ET_c for corn with CTE increasing as ET_c increased (Figure 6 and 7). These results indicate that CTE is driven strongly by weather conditions such as temperature, solar radiation, wind and humidity. Once again, differences in irrigation treatment were less important in the resultant CTE than was weather. Wide differences in irrigation treatments resulted in less than one hour average difference in CTE values during 2005 and 2006.

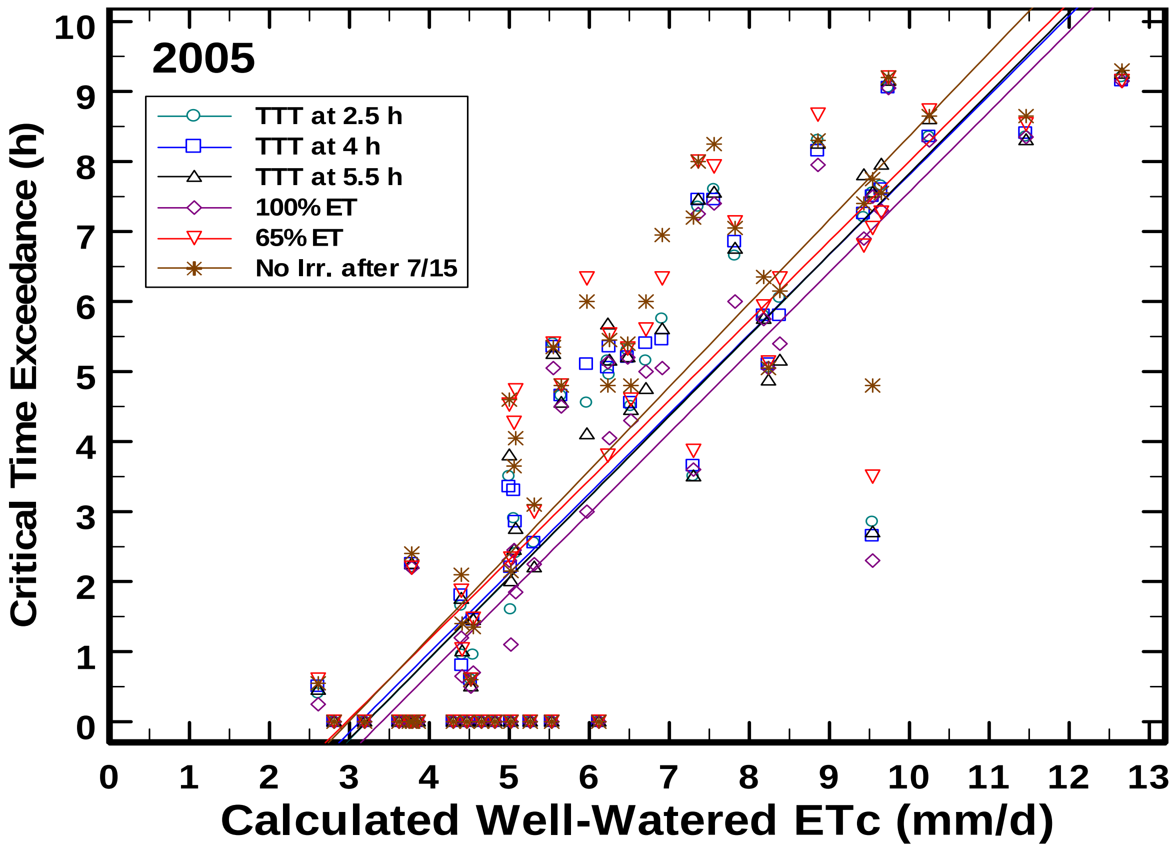

Figure 6. Relationship of measured CTE and calculated well-watered corn ETc for 2005, KSU Northwest Research-Extension Center, Colby Kansas.

The seasonal average CTE was also linearly related to the ratio of measured seasonal corn water use obtained from the soil water balance to the seasonal calculated well-watered ET_c (Figure 8). In this case, the seasonal CTE value is negatively related indicating that as the relative ET_c decreases due to water stress, then the CTE will increase.

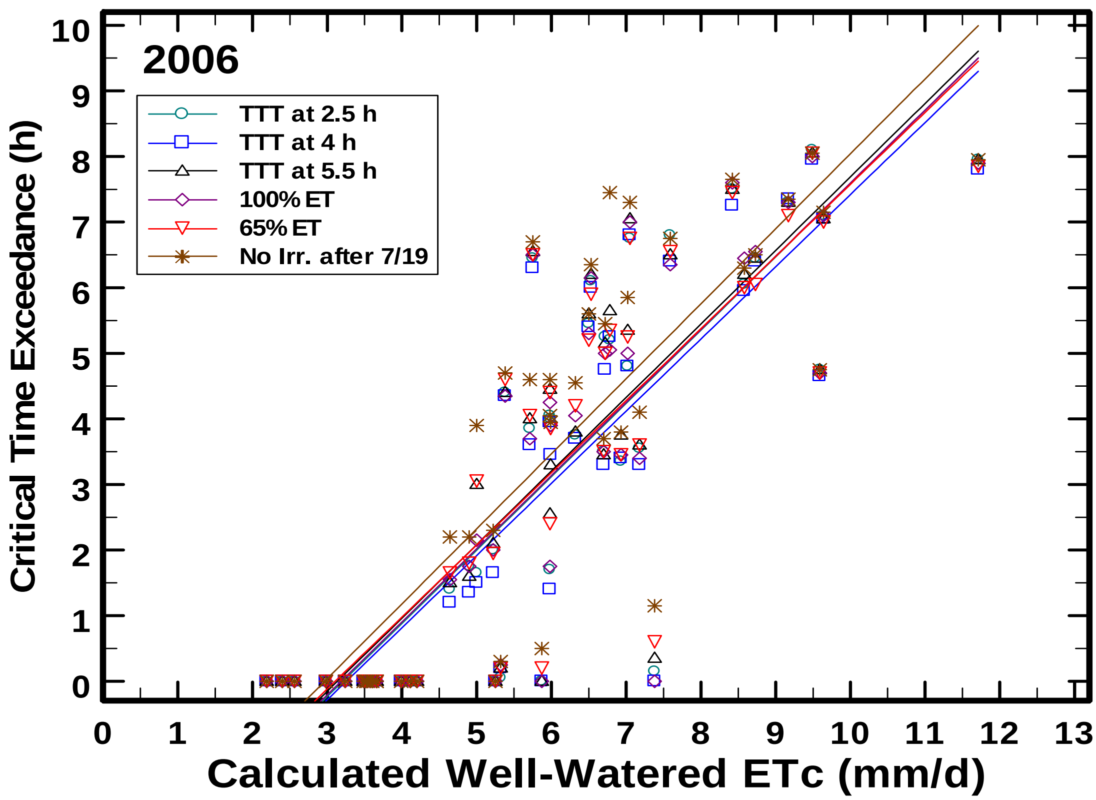

Figure 7. Relationship of measured CTE and calculated well-watered corn ETc for 2006, KSU Northwest Research-Extension Center, Colby Kansas.

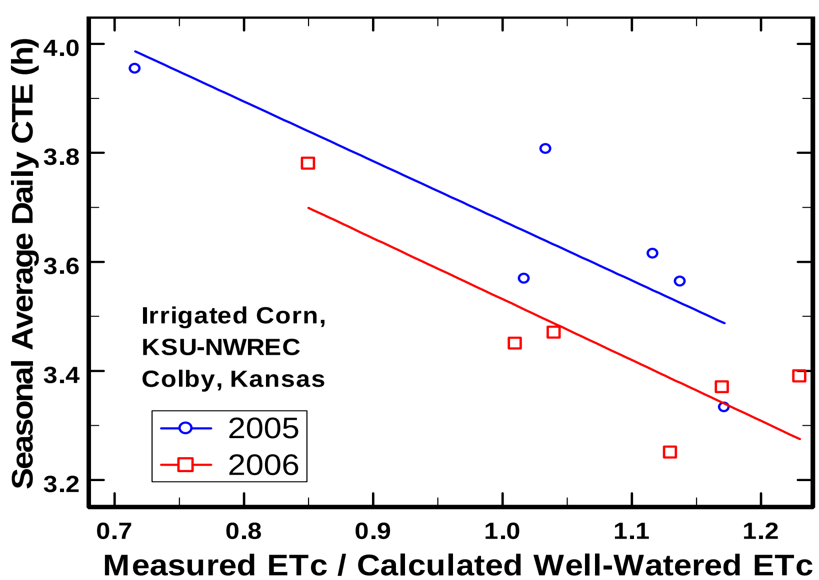

Figure 8. Seasonal average daily CTE as related to the relative corn ET_c (ratio of measured corn water use to calculated well-watered ET_c) for 2005 and 2006 at KSU Northwest Research-Extension Center, Colby, Kansas.

Relationship of CTE to Plant Available Soil Water

The CTE was also found to be related to plant available soil water (PASW) in the 2.4 m soil profile but once again weather conditions were a larger factor in the resultant CTE (Figure 9). Plant available soil water was measured on August 21, 2006 which was followed by two moderate weather days and two hot days. An increase in PASW from approximately 37 to 60% resulted in a decrease in CTE from 4.0 to 1.7 h for the two moderate days (TMax = 30.8 C) but only a decrease of in CTE from 7.4 to 6 h on the hot days (TMax = 36.4 C). The weather conditions resulted in a difference in CTE of nearly 4 hours.

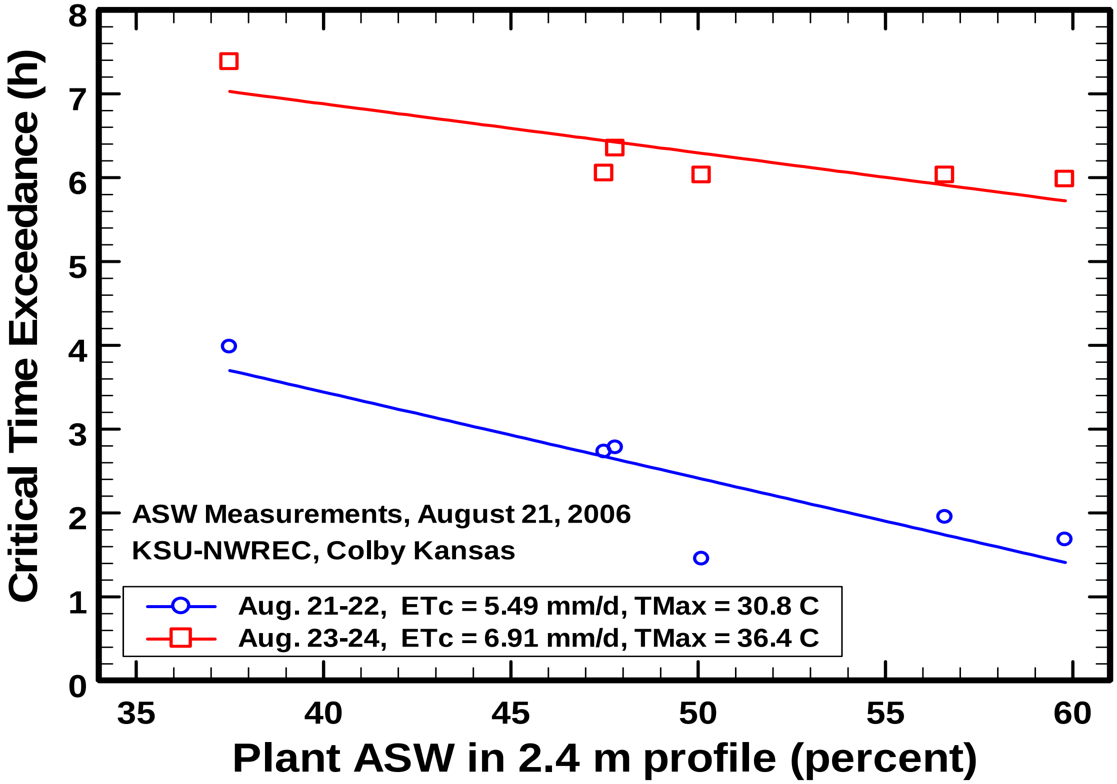

Figure 9. The CTE as affected by plant available soil water in the 2.4 m soil profile for a short four day period having very different weather conditions, KSU Northwest Research-Extension Center, Colby, Kansas.

Conclusions

The Temperature-Time Threshold or BIOTIC method of irrigation scheduling can be used to effectively irrigate corn in the U.S. Central Great Plains. Although there were no significant differences in corn yield as affected by irrigation treatments there were numerically higher grain yields for those treatments which received more irrigation. A TTT of 2.5 hours appeared to correspond reasonably well to a 100% ET_c replacement treatment for both grain yield and irrigation amount. Similarly, a 5.5 hour TTT treatment corresponded reasonably well to a 65% ET_c replacement treatment. Water use efficiency tended to be slightly greater with the TTT treatments than with the ET-based treatments but was not statistically significant.

The CTE for a given day was more strongly related to the prevailing weather conditions than it was to differences in irrigation levels or plant available soil water.

References

Burke, J.J. 1996. Personal communication to S. R. Evett from the USDA-ARS Crop Stress Research Laboratory, Lubbock, Texas.

Evett, S.R., T. A. Howell, A. D. Schneider, D. R. Upchurch and D. F. Wanjura. 1996. Canopy temperature based automatic irrigation control. Proc. International Conf. Evapotranspiration and Irrigation Scheduling, San Antonio, Texas, November 1996. pp 207-213.

Evett, S.R., T. A. Howell, A. D. Schneider, D. F. Wanjura, and D. R. Upchurch. 2002 Automatic drip irrigation control regulates water use efficiency. International Water and Irrigation, 22(2):32-37.

Jensen, M. E. 1969. Scheduling irrigation using computers. J. of Soil and Water Conservation 24(8):193-195.

Jensen, M. E., C. E. Franzoy, and D. C. N. Robb. 1970. Scheduling irrigations using climate-crop-soil data. ASCE, J. of Irrigation and Drainage 96(IRI):25-38.

Jensen, M. E., B. J. Pratt and J. L. Wright. 1971. Estimating soil and moisture depletion from climate, crop and soil data. Transactions of ASAE, 14(5):954-959.

Kincaid, D. E. and D. F. Heerman. 1974. Scheduling irrigation using a programmable calculator. USDA Publication ARS-NC-12, February, 1974. 55 pp.

Lamm, F. R., and D. H. Rogers. 1983. Scheduling irrigation using computed evapotranspiration. Presented at the 1983 Mid-central regional meeting of the American Society of Agricultural Engineers. Available as ASAE Paper No. MCR 83-109, ASAE, St. Joseph, Michigan. 22 pp.

Lamm, F. R. and D. H. Rogers. 1985. Corn yield response to different irrigation regimes. Presented at the 1985 Mid-central regional meeting of the American Society of Agricultural Engineers. Available as ASAE Paper No. MCR 85-131, ASAE, St. Joseph, Michigan. 12 pp.

Lamm, F. R., D. A. Pacey, and H. L. Manges. 1987. Spreadsheet templates for the calculation of Penman reference evapotranspiration. Presented at the 1987 Mid-central regional meeting of the American Society of Agricultural Engineers. Available as ASAE Paper No. MCR 87-106, ASAE, St. Joseph, Michigan. 21 pp.

Upchurch, D. R., D. F. Wanjura, J. J. Burke, and J. R. Mahan. 1996. Biologically-Identified Optimal Temperature Interactive Console (BIOTIC) for managing irrigation. U.S. Patent No. 5539637.

Wanjura, D. F. and D. R. Upchurch. 2000. Canopy temperature characterizations of corn and cotton water status. Trans ASAE 43(4):867-875.

Wanjura, D. F., D. R. Upchurch, G. Sassenrath-Cole, and W. R. DeTar. 1995b. Calculating time thresholds for irrigation scheduling. In: Proc. 1995 Beltwide Cotton Conferences, Jan 4-7, San Antonio, Texas. pp. 449-452.

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