Assessing Maize Crop Water Stress Using an Aerodynamic Temperature Approach

Colorado State University

GRADUATE STUDENT SHOWCASE

CELEBRATING RESEARCH AND CREATIVITY

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Introduction

- The sustainability of food production, in regards to water resources, relies on two important factors: Knowing the amounts of irrigation water needed to be applied to the crop root zone and the timing that such irrigation events should be scheduled;
- Crop water stress index (CWSI) method (Idso et al. 1977; Ehrler et al. 1978; Jackson et al. 1981) is a powerful variable that allows the assessment of when irrigation should be triggered based on empirical thresholds of canopy stress levels;
- Research papers have been indicating that improvements on CWSI estimation might be achieved when surface energy balance and remote sensing variables are incorporated into the calculation of CWSI (Osroosh et al., 2015; O'Shaughnessy et al., 2010, Zarco-Tejada et al., 2013);
- Sensible heat flux is one of the components of the energy balance, alongside with the available energy. Costa-Filho (2019) developed models for sensible heat flux estimation based on estimating the surface aerodynamic temperature (T_o) that incorporates surface characteristics such as canopy cover (f_c) and surface temperature (T_s) and weather data (air temperature and wind speed direction); Chavez et al. (2005) developed a similar model for T_o based on leaf area index (LAI), wind speed (u), air temperature (T_a), and T_s;
- The goal of this study is to evaluate CWSI estimation for maize based on the aerodynamic temperature approaches to model sensible heat flux.

Methodology

$$CWSI = 1 - \frac{ET_a}{ET_c} \simeq \frac{H}{R_n - G}$$ **CWSI model based on the surface energy balance approach**

NOTE 1: ET_a is evapotranspiration rate for field conditions, ET_c is the evapotranspiration rate for non-stressed canopy, H is sensible heat flux, R_n is net radiation and G is soil heat flux. R_n – G is the available energy. All surface heat fluxes are in W/m².

$$H = \rho_a \cdot Cp_a \cdot \left(\frac{T_o - T_a}{r_{ah}}\right)$$ **Single source sensible heat flux model in W/m²**

$$T_o = 0.534 \cdot T_s + 0.39 \cdot T_a + 0.224 \cdot LAI - 0.192 \cdot u + 1.67$$ **T_o model by Chavez et al. (2005)**

$$T_o = 1.025 \cdot f_c + 0.407 \cdot T_a + 0.631 \cdot T_s + 0.498 \cdot r_p$$ **T_o model by Costa-Filho (2019)**

NOTE 2: T_o is given in ºC on both models. The variable r_p is the turbulent-mixing row resistance (s/m), developed by Costa-Filho (2019). The variables ρ_a, Cp_a, and r_{ah} are the air density (kg/m³), specific heat of air (~ 1005 J/kg/K), and aerodynamic resistance (s/m), respectively.

- The experiment site was located at the Limited Irrigation Research Farm (LIRF) managed by the United States Department of Agriculture - Agricultural Research Service (USDA-ARS) near Greeley, Colorado, USA; latitude N 40.4463˚, longitude W 104.6371˚, and elevation of 1,432 m (Fig. 1). Data analyzed were collected in 2018 from August to September from different instrumentation types (table 1);
- The canopy underwent water stress due to low frequency irrigation water application. Only two major irrigation events were scheduled for the water stressed treatment plot. Field 02 was the low-frequency irrigation plot. (Fig. 1);
- The field 02 dimensions were 190 m x 110 m. The maize variety was Dekalb 51-20 (drought tolerant) with irrigation supplied by subsurface drip. The drip irrigation emitters were 0.30 m apart and buried 0.23 m deep on 0.76 m distance between rows. Plant density was 87,500 plants per hectare. Tillage was accomplished by strip tilling prior to planting, which occurred on DOY 130. Nitrogen fertilizer was applied as urea ammonium nitrate (UAN) at 32% concentration rate. Nitrogen was applied on DOY 197 and 226 at a rate of 72 and 50 kilograms per hectare, respectively;

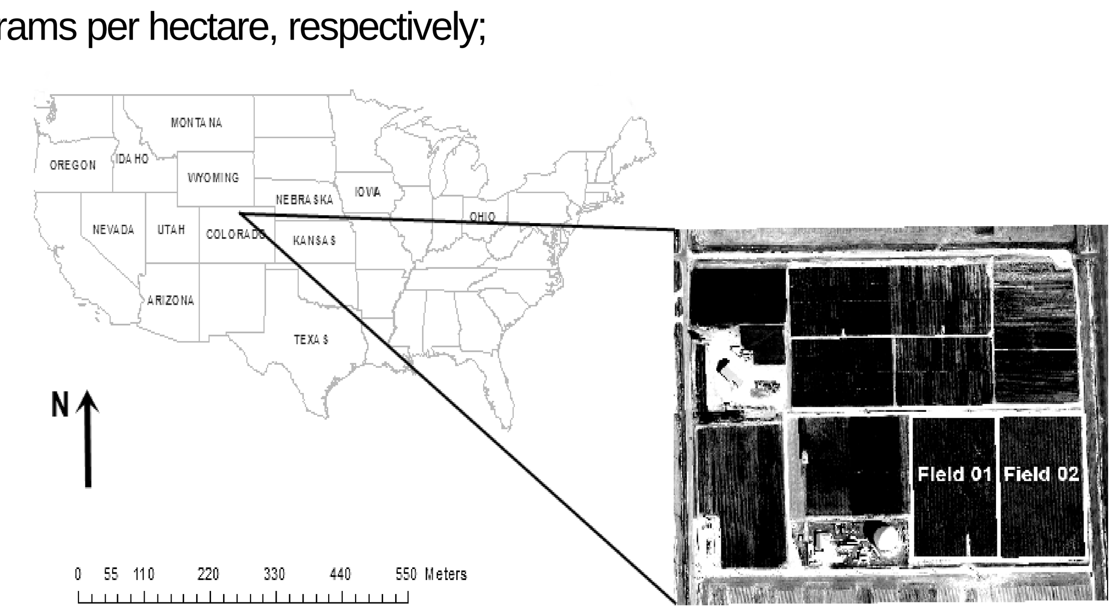

Figure 1 – USDA Limited Irrigation Research Field (LIRF) fields.

Table 1 – Summary of instrumentation for measuring data for CWSI assessment.

Sensor Type	Model type	Manufacturer Information	Quantity	Measured data | Variables calculated
Soil water content	5TE	Decagon Devices Inc., Pullman, WA, USA	4	Volumetric water content
Multispectral radiometer	MSR5	Cropscan Inc., Rochester, MN, USA	1	RED, NIR | NDVI, f_c, OSAVI, LAI
Infra-red thermometer	SI-111	Apogee Instruments, Logan, UT, USA	2	T_s
Hygrometer	HMP45C	Vaisala, Vantaa, FI	5	T_a and RH
Cup anemometer	03101-L	RM Young Company, Traverse City, MI, USA	5	u | r_p
Net radiometer	NR-Lite	Kipp and Zonen, Delft, NL	1	R_n
Net radiometer	CNR01	Kipp and Zonen, Delft, NL	1	R_n
Soil heat flux plate	HFT3-L	Radiation and Energy Balance Inc., Bellvue, WA, USA	4	G
Temperature probe	T107	Campbell Scientific Inc., Logan, UT, USA	8	Soil temperature

- Two stations located at 1/4 north and 1/2 length of the field were set up to collect the data for assessing CWSI; Around noon (11 am to 3 pm) hourly estimated CWSI was compared to CWSI based on measured R_n, G, and H;
- Measured R_n data were collected at 3.2 m above ground surface (AGS). Soil heat flux data were measured based on the soil heat flux plate method. Measured sensible heat flux through the Bowen ratio method was obtained from the aerodynamic tower installed at the north section of field 2. The heights of measurement for air temperature and humidity were of 2.60 and 4.20 m AGS, respectively;
- Modeled R_n and G were based on the radiation budget approach and the model developed by Bastiaanssen (1998), respectively;
- Statistical assessment of modeled CWSI was done by comparing results from Chavez et al. (2005) and Costa-Filho (2019) based on Mean Bias Error (MBE) and Root Mean Square Error (RMSE);

Results and discussion

- Data from 2018 indicated that estimated CWSI based on Costa-Filho (2019) sensible heat flux model provided smaller errors than the model developed by Chavez et al. (2005). Both model results underestimated CWI (MBE < 0), but Costa-Filho (2019) CWSI results had smaller RMSE (0.08 < 0.27), which indicates an improvement of about 30 %, on average, on CWSI estimation (table 3);
- Both empirical aerodynamic surface models analyzed were developed for maize crops. However, Chavez et al. (2005) model was fitted using data from Aimes, Iowa. Costa-Filho (2019) fitted the aerodynamic temperature model based on data from Greeley, Colorado. The differences in performance, when estimating CWSI, could be due to the limitations of Chavez et al. (2005) to better estimate sensible heat flux for semi-arid climate conditions;
- CWSI estimation based on empirical aerodynamic temperature approaches for sensible heat are dependent on the conditions from which the models were derived. Recalibration of empirical models for surface aerodynamic temperature is recommended when climate conditions between areas may not be assumed similar (Gonzalez-Lugo et al., 2009);

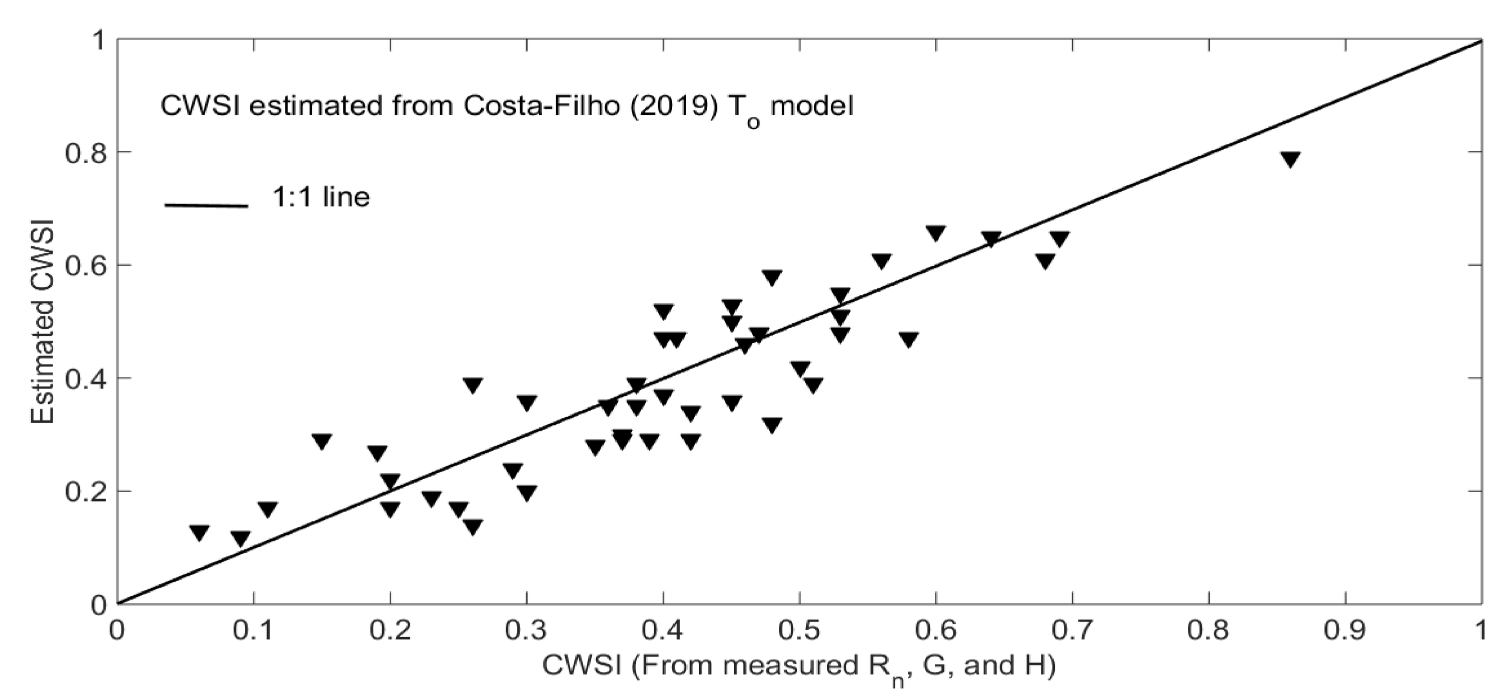

Figure 2 – Estimated CWSI based on Costa-Filho (2019) T_o model vs. CWSI from measured surface heat fluxes in 2018.

Table 2 – Descriptive statistics of CWSI approaches.

Approach Type	Variable	Sample size	Sample Mean	Sample Standard Deviation	Standard Error	Max. value	Min. value
Chavez et al. (2005) T_o model	CWSI	48	0.16	0.11	0.02	0.38	0.00
Costa-Filho (2019) T_o model	CWSI	48	0.39	0.16	0.02	0.79	0.12
Measured R_n, G, and H	CWSI	48	0.40	0.16	0.02	0.86	0.06

Table 3 – Statistical analysis assessment for CWSI estimation based on the T_o models analyzed.

CWSI approach	Sample size (n)	MBE	RMSE
Chavez et al. (2005) T_o model	48	-0.24	0.27
Costa-Filho (2019) T_o model	48	-0.01	0.08

Future directions

- Estimating CWSI based on the development of semi-empirical models for T_o. It might reduce the recalibration process for locations under different climate regimes.

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