Assessment of the AquaCrop model for simulating soil water content, evapotranspiration and yield of grain sorghum

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Introduction

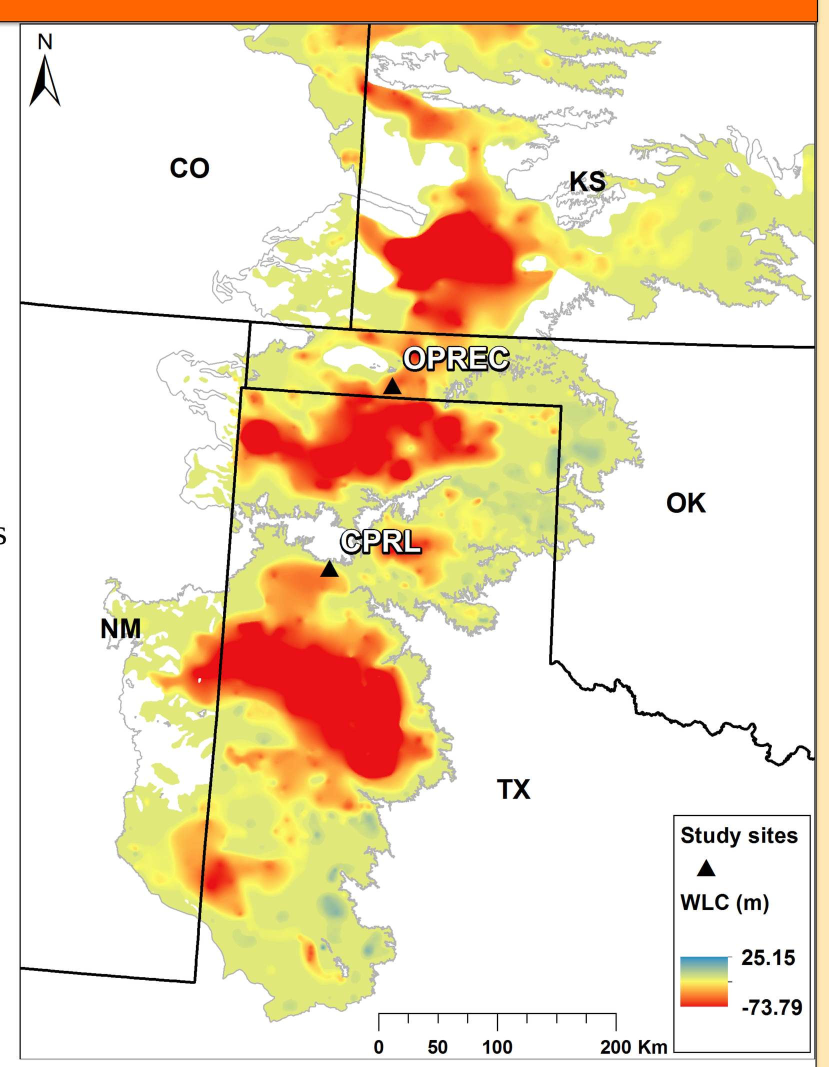
Diminishing water resources threatens irrigated agriculture in the Southern High Plains (SHP) region. Both surface and groundwater resources have declined due to persistent droughts and severe groundwater abstractions. This occurrence has resulted in loud calls by various sectors in the region to find ways that ensure efficient utilization and conservation of water resources, especially for irrigation. A number of options have been proposed to achieve this goals, including adoption of deficit irrigation, as well as shifting to crops that have high water use efficiency, such as grain sorghum.
To this end, the use of crop models to simulate crop production has become important in the evaluation and formulation of deficit irrigation strategies in the arid and semi-arid regions. However, performance and applicability of these crop models generally differ across regions, due to environmental differences as well as management factors. In this study, the performance of the AquaCrop model to simulate soil water content (SWC), evapotranspiration (ET) and yield was assessed for grain sorghum grown under different irrigation regimes and dryland conditions at two locations in the SHP.

Objectives

i. To calibrate the AquaCrop model for grain sorghum in the SHP
ii. To evaluate the performance of the AquaCrop model in simulating SWC, ET and grain yield

Methods

Study area
The data used in this study were collected from field research plots at two locations in the SHP; the USDA-ARS Conservation and Production Research Laboratory (CPRL) at Bushland, TX and the Oklahoma Panhandle Research & Extension Center (OPREC) near Goodwell, OK. The map to the right shows the location of study sites and highlight the water level changes of the Ogallala aquifer from predevelopment (about 1950) to 2011.



The AquaCrop model
AquaCrop simulates the yield response of herbaceous Crops to water. It simulates biomass (B) production as a function of cumulative transpiration (T_r), which is estimated as a product of the normalized water productivity (WP*) and the ratio of T_r and reference evapotranspiration (ET_o).

$$B = WP^* \times \sum \frac{T_r}{ET_o}$$

The crop harvestable yield (Y) is then estimated as a product of B and the harvest index (HI).

$$Y = B \times HI$$

The required data include climatic data, as well as Data on crop, soil, field and irrigation management.

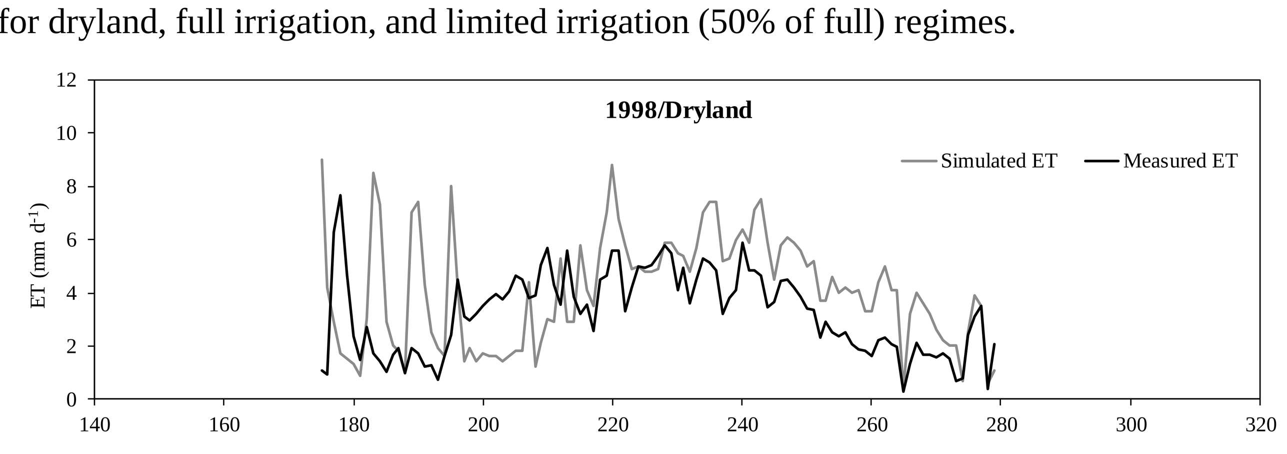
Performance indicators
Simulated values were compared with measured values over several growing seasons. Evaluating the performance of ET and SWC simulation was conducted for the CPRL site only due to data availability. For yield, assessment included all data from the two sites. The Prediction Error (P_e), Root Mean Square Error (RMSE) and the Nash-Sutcliffe Efficiency (NSE) were used to evaluate the performance of the model:

$$P_e = \frac{(S_i - M_i)}{M_i} \times 100 \qquad RMSE = \sqrt{\sum_{i=1}^{n} 1/(N)\,(M_i - S_i)^2} \qquad NSE = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - \bar{M})^2}$$

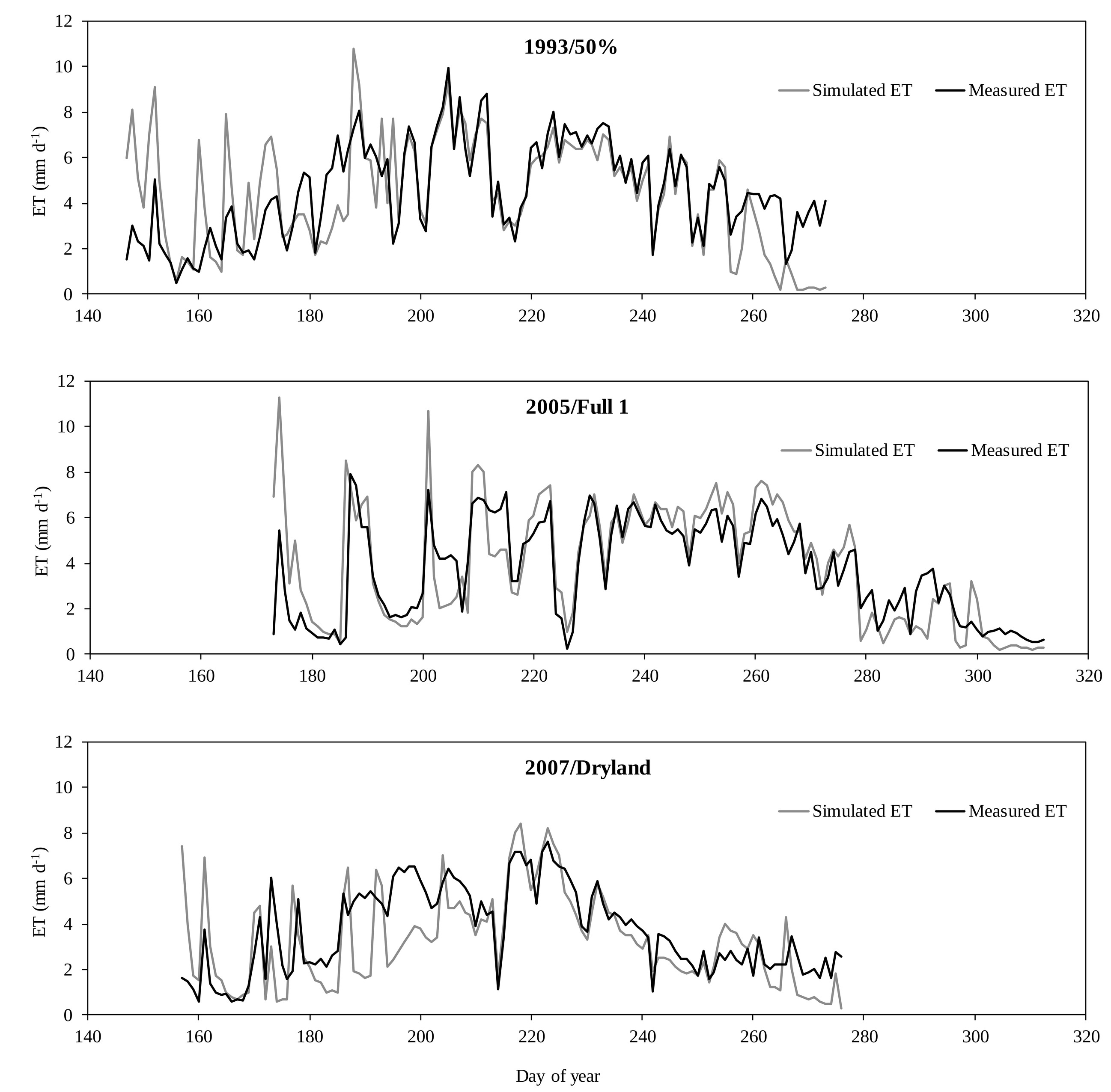
where M_i and S_i are the measured and simulated values, N is the number of measurements, and $\bar{M}$ is the mean value of M_i.

Results: ET

- The AquaCrop model tended to overestimate daily ET, especially in the early stages of the growing season. The following graphs demonstrate simulated (AquaCrop) and measured (weighing lysimeter) daily ET values for dryland, full irrigation, and limited irrigation (50% of full) regimes.

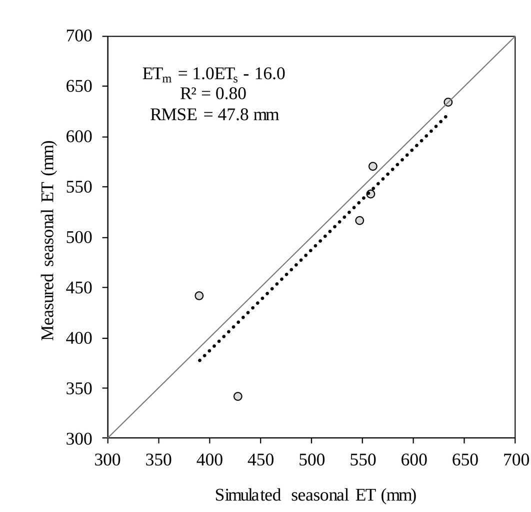


Results: ET (continued)



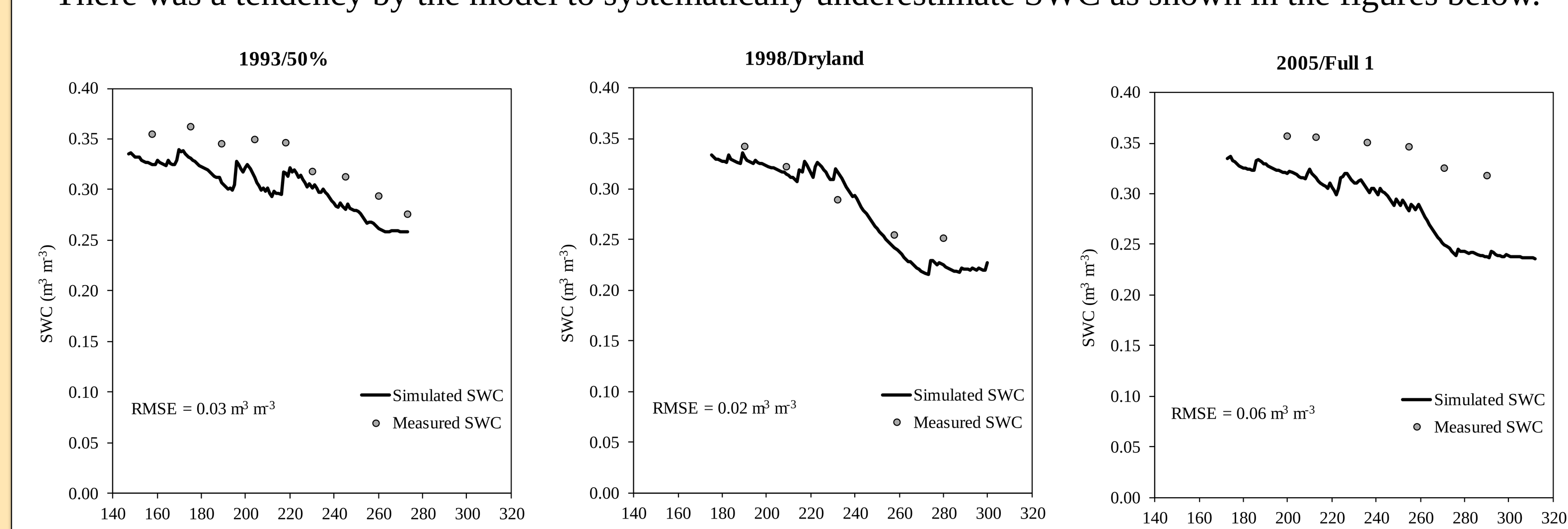
The RMSE for daily ET was determined as 1.5 mm d^{-1} for both full irrigation treatments,1.9 mm d^{-1} for the limited irrigation (50%) treatment, and 2.3 and 1.6 mm d^{-1} for the 1998 and 2007 dryland treatments, respectively. While daily ET is of great importance in irrigation scheduling, long-term planning relies more on seasonal ET. The RMSE and NSE for seasonal ET of all simulations was 47.8 mm and 0.66, respectively. The simulated seasonal ET in the irrigated treatments closely approximated the measured values. However, P_e was larger under dryland conditions as presented in the table and graph below.

Site Name	Growing season	Irrigation treatment	Seasonal ET (mm) Measured	Seasonal ET (mm) Simulated	P_e (%)
CPRL	1993	50%	569.8	560.5	-2
	1998	Dryland	341.4	428.1	25
	2005	Full 1	515.8	547.4	6
	2005	Full 2	541.9	559.2	3
	2007	Dryland	441.2	390.8	-11

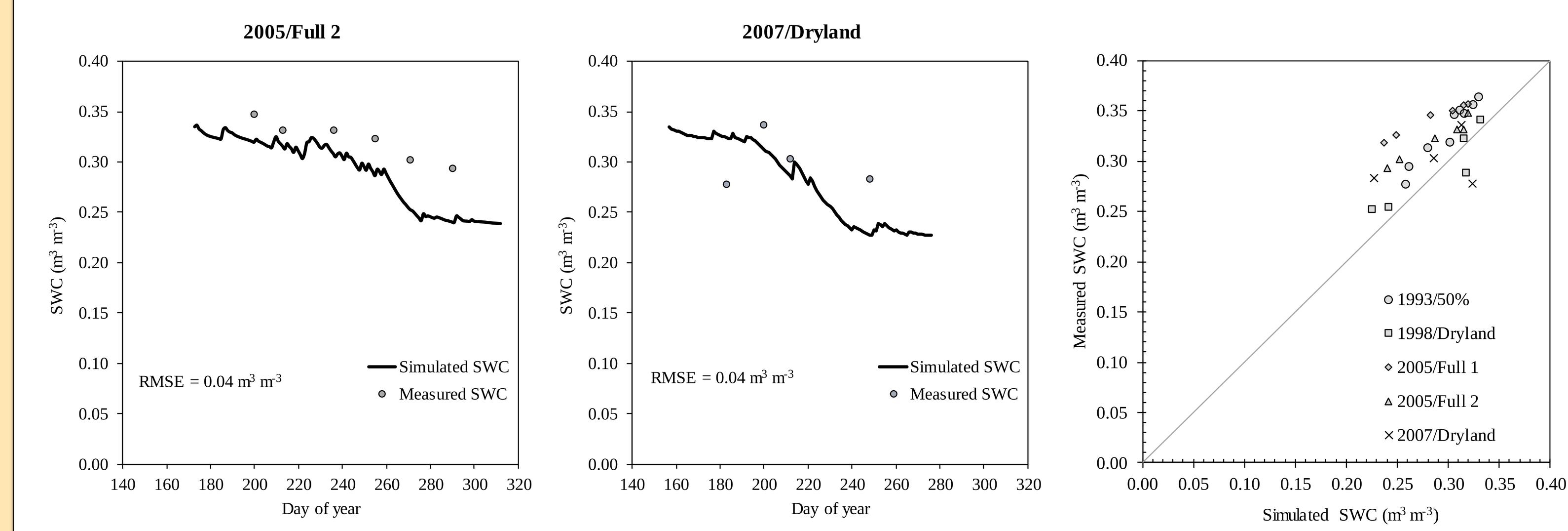


Results: SWC

- Simulated SWC values were compared against field measurements using a neutron probe. Both parameters represent the average values for the entire root zone considered in the AquaCrop.
- The P_e for SWC determined at different days of the growing season ranged from -25 to -5% in fully irrigated, -11 to -5% in limited irrigated and -20 to 17% in dryland treatments.
- The RMSEs were 0.02 and 0.04 $m^3\,m^{-3}$ for the two full irrigation treatments in 2005, 0.03 $m^3\,m^{-3}$ for the limited irrigation (50%), and 0.02 and 0.04 $m^3\,m^{-3}$ for the 1998 and 2007 dryland treatments, respectively.
- There was a tendency by the model to systematically underestimate SWC as shown in the figures below.



Results: SWC (continued)



- High R^2 values (0.94 to 0.98), were attained for measured and simulated SWC values in full and limited irrigation treatments.
- The dryland treatment for the 1998 season had a relatively high R^2 (0.84) but dryland treatment in 2007 had the lowest R^2 (0.11).

Results: Yield

The measured and simulated yield values as well as the prediction errors are presented in the table below.

Site Name	Growing season	Irrigation treatment	Yield ($Mg\,ha^{-1}$) Measured	Yield ($Mg\,ha^{-1}$) Simulated	P_e (%)
CPRL	1993	Full	8.68	8.78	1.1
	1993	50%	8.26	8.25	0.0
	1998	Dryland	4.65	4.36	-6.3
	2005	Full 1	7.03	6.39	-9.2
	2005	Full 2	7.02	6.38	-9.1
	2007	Dryland	5.31	5.24	-1.2
OPREC	2014	Full	9.66	9.68	0.2
	2014	75%	9.44	10.00	6.0
	2014	50%	7.70	9.40	22.1
	2015	Full	10.32	10.31	-0.1
	2015	75%	10.30	10.34	0.4
	2015	50%	10.29	10.54	2.5
	2016	Full	8.88	9.06	2.0
	2016	75%	9.26	9.47	2.3
	2016	50%	8.51	7.44	-12.6

Overall, the RMSE and NSE were 0.6 $Mg\,ha^{-1}$ and 0.87 respectively. The NSE value obtained in this study indicate that the model performance in simulating grain yield was acceptable.

Conclusions

- The model produced better results for ET and SWC under irrigated as compared to dryland conditions.
- The model performed well in simulating the overall grain yield under all conditions.
- The study recommends improvements of the water stress functions in the model algorithm to better simulate severe water stress under limited irrigation treatments and dryland conditions.
- Overall, the study concluded that AquaCrop model can be used as an important tool for irrigation water management and planning in the Southern High Plains region.

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