EVALUATION OF MEASURED AND SIMULATED COTTON WATER USE AND YIELD UNDER FULL AND DEFICIT IRRIGATION

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Abstract

The AquaCrop model simulates crop growth, water use, yield, and water use efficiency of several crops including cotton. The model is intended to be useful for irrigation planning and management, and it attempts to balance simplicity and accuracy so that it can be applied in locations where weather and soil data are limited. However, past research suggests that AquaCrop simulations are less robust when crops are irrigated at deficit levels and consequently under water stress. Our objective was to evaluate the accuracy with which AquaCrop simulates soil water balance, soil water content, above ground biomass and yield of irrigated cotton (*Gossypium hirsutum*) at two irrigation levels. Soil water use, biomass, and lint-seed yield of cotton in the Texas High Plains, USA, were evaluated during the 2000 to 2001 growing seasons under full and deficit sprinkler irrigation. The fields were equipped with large weighing lysimeters to evaluate soil water use. The capability of the model to accurately predict soil water use within the profile and throughout the growing season as well as the conversion of transpiration to aboveground biomass and seed lint yield production are emphasized.

Introduction

The FAO crop model AquaCrop is a canopy-level and engineering type of model focused on simulating the attainable crop biomass and harvestable yield of several crops including cotton in response to the available water (Raes et al., 2009: Steduto et al., 2009). Developed to replace the former FAO I&D Paper 33, the model is intended to be useful for irrigation planning and management, and it attempts to balance simplicity and accuracy so that it can be applied in locations where weather and soil input data are limited. However, past research suggests that AquaCrop simulations are less robust when crops are irrigated at deficit levels and consequently under water stress.

Methods

Our objective was to evaluate the accuracy with which AquaCrop simulates soil water content and balance, above ground biomass and seed-lint yield of irrigated cotton (*Gossypium hirsutum,* cv. Paymaster 2145) at two irrigation levels. Soil water use, biomass, and lint-seed yield of irrigated cotton grown in 2000 – 2001 at the USDA-ARS Laboratory, Bushland, Texas, (Howell et al., 2004) were evaluated under full (100%) and deficit (50%) irrigation. The soil was a Pullman clay loam with slow permeability. The fields were equipped with large weighing lysimeters (3.0 m × 3.0 m × 2.4 m deep) to measure and calculate daily crop water use (ET – evapotranspiration) using the soil water balance equation. Fields were irrigated by a lateral-move system with low pressure nozzles on 5-ft centers. Leaf area and aboveground biomass were measured throughout the season; lint yield was measured at harvest.

Soil hydraulic data for parameterization of the AquaCrop model were estimated from published data for Pullman soil. A maximum crop water use coefficient of K_c=1.2 was used, as given by Howell et al. (2006). Initial model runs used these data plus AquaCrop "default" values (Raes et al., 2011). The readily evaporable water (REW) was set to 11 mm following measurements in bare soil (J.A. Tolk, personal communication). Values of canopy growth rate (CGC), soil water evaporation coefficient (K_{ex}) and Stage 2 decline factor (DF) for soil water evaporation were set to "default" values for cotton given in the AquaCrop manual (Raes et al., 2011). Secondary model runs attempted to improve major inaccuracies by altering the canopy growth rate (CGC), REW, K_{ex} and DF parameter values.. Model output was tested with measured data for fully irrigated cotton in 2000.

Results

In the first step of the model parameterization we adjusted initial conditions for specific soil layers to closely estimate soil water content throughout the cotton vegetative season. For example, the initial water content for the 0-150 cm soil profile was adjusted so that at 31 days after planting (DAP) model estimated water storage (489 mm) approximated neutron probe measured water storage (513 mm) under full irrigation.

Initial simulations revealed that ET was overestimated during the rapid vegetative growth part of the growing season (40 to 65 DAP) because of overly rapid simulated canopy development using a canopy growth coefficient of 10.5 % increase per day adopted from Farahani et al. (2009). Decreasing this value to 7.5 % per day better reproduced ET throughout the season (Fig.1), although ET was still overestimated greatly in the first 30 DAP. In the study area, initial cotton development is slow because of cooler climatic conditions compared with other cotton-growing regions around the world. All simulations were run in calendar days. Other work, not reported here, has revealed some differences in model output when running in growing degree days.

Subsequent simulations using the AquaCrop "default" values of REW, K_{ex} and DF for cotton revealed that stored soil water was underestimated later in the season. This underestimation was particularly severe for deficit irrigation, causing more than 50% underestimation of yield (Fig. 2 and Fig. 3).

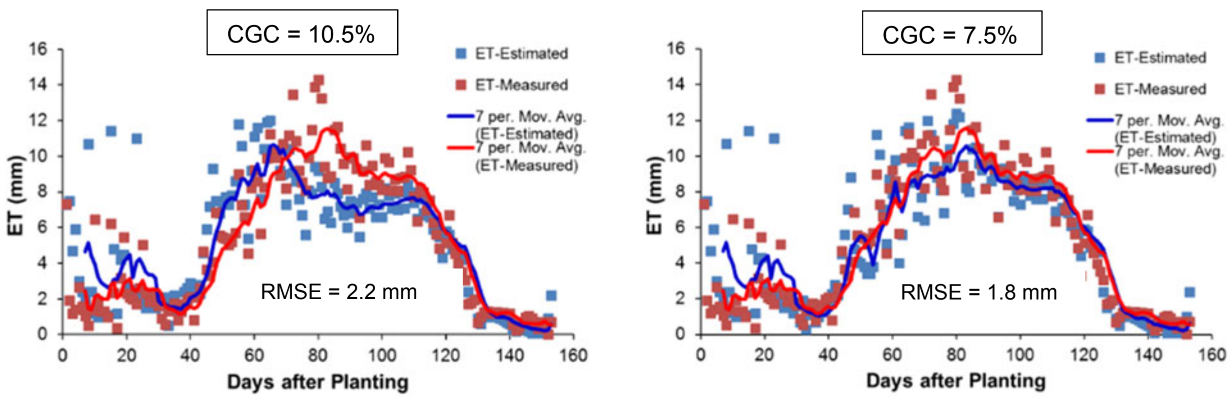

Figure 1. Measured and estimated daily water use (ET-evapotranspiration) during the growing season of fully irrigated cotton using different crop canopy coefficients (CGC), 2000. RMSE – Root Mean Square Error.

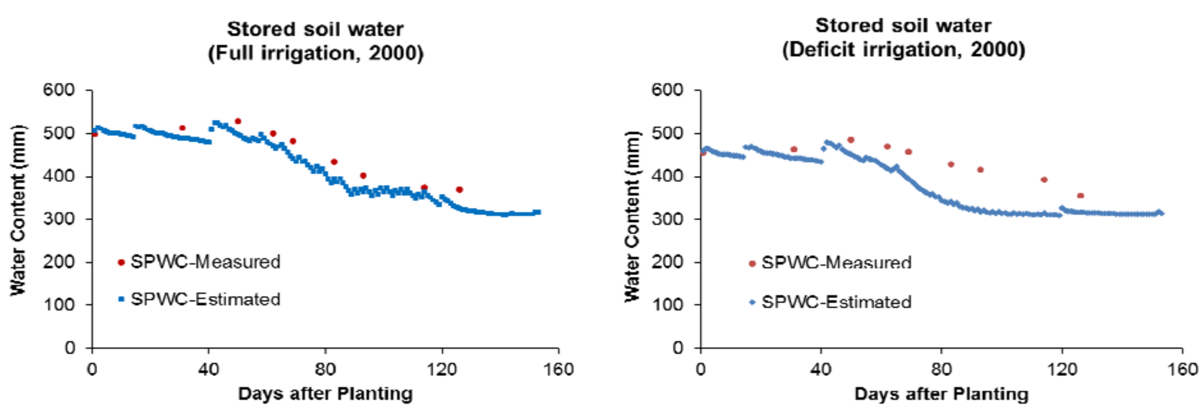

Figure 2. Measured and estimated water content in the 0-150 cm soil profile (REW=11 mm, K_{ex}=1.10 and DF=4). SPWC – Soil Profile Water Content.

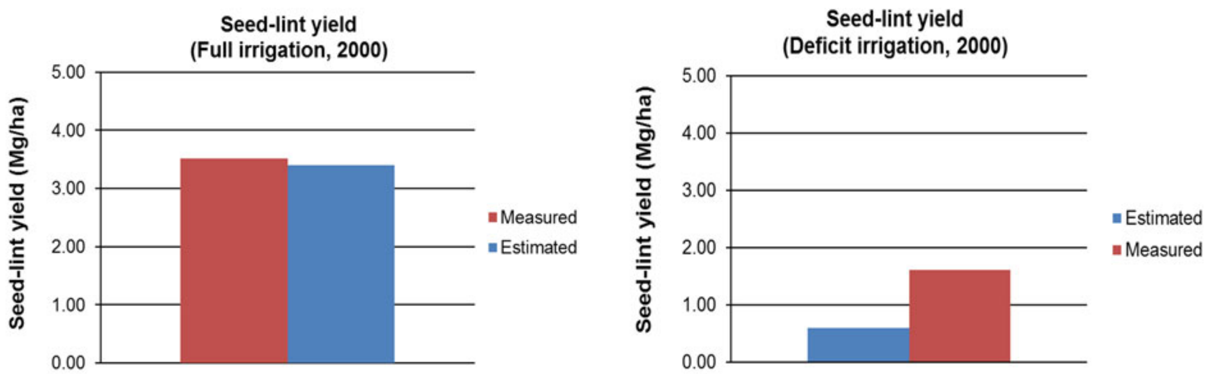

Figure 3. Measured and estimated seed-lint yield of fully and deficiently irrigated cotton (REW=11 mm, K_{ex}=1.10 and DF=4)

Underestimated soil profile stored water for both full and deficit irrigation was a result of overestimated soil water evaporation (*E*) during the early vegetative stage (Fig.4). Hence, we tried to adjust the thickness of soil layers to decrease simulated *E* during vegetative development as shown by Evett and Lascano (1993). However we found that soil layer thickness changes input into AquaCrop were not used by the model, and thus the resultant *E* could not be decreased in that way.

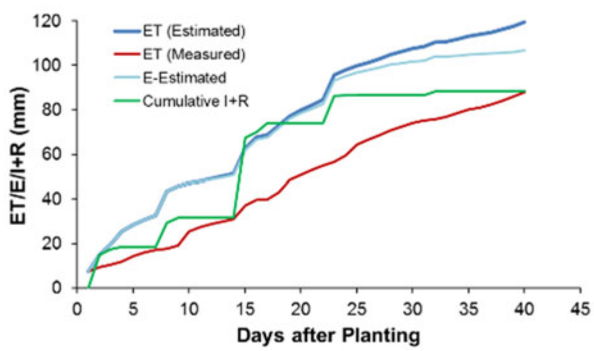

Figure 4. Cumulative ET, Evaporation (E) and Irrigation plus Rainfall (I+R) during initial development of fully irrigated cotton, 2000.

Additional runs attempted to decrease simulated *E* by adjusting three model parameters: REW, K_{ex} and DF (Figs.5 and 6).

Adopting an iterative approach, the overall results for fully irrigated cotton were best with settings of REW=3 mm, K_{ex}=1.00 and DF=4 even though the model still overestimated *E* loss at early (vegetative) growth stages concomitant with an underestimation of ET around peak flower to end of growing season. Daily ET for the cotton vegetative season was simulated with an RMSE of 1.4 mm. Fully irrigated cotton seed-lint yield was overestimated by 11% or 0.39 Mg ha^{-1} compared with the measured value (Fig.7).

The performance of the parameterized model was evaluated by simulating soil water, water use, growth parameters and seed-lint yield for deficit irrigation of cotton in 2000 with the same optimized crop and soil parameters used for fully-irrigated cotton. AquaCrop simulated daily ET for the vegetative season with an RMSE of 1.8 mm. Accumulated ET was overestimated for about 90 days after planting and ET was greatly underestimated around first open boll (~100 DAP) and later in the growing season. Simulated cotton seed-lint yield for deficit irrigation was 12% or 0.19 Mg ha^{-1} less than the measured value (Fig.8).

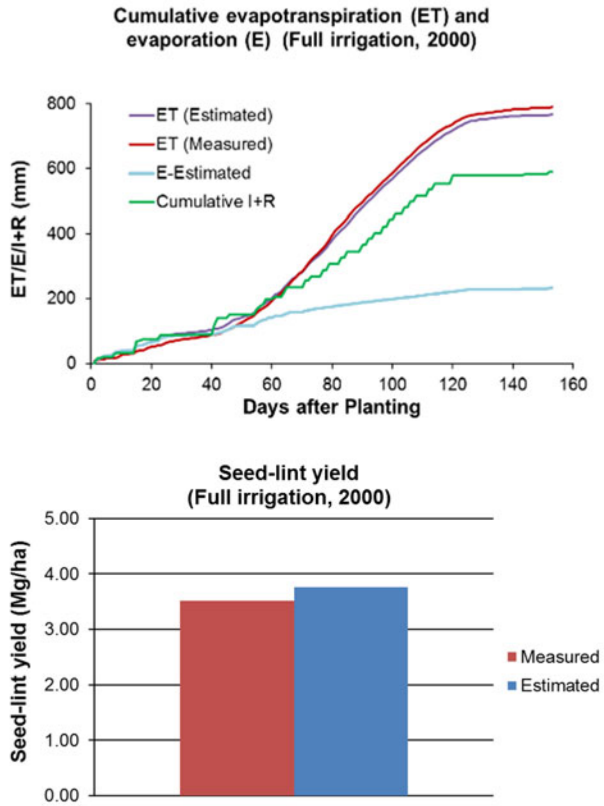

Figure 5. Measured and estimated evapotranspiration and cotton seed-lint yield with model settings of REW=8 mm, K_{ex}=1.00 and DF= 6

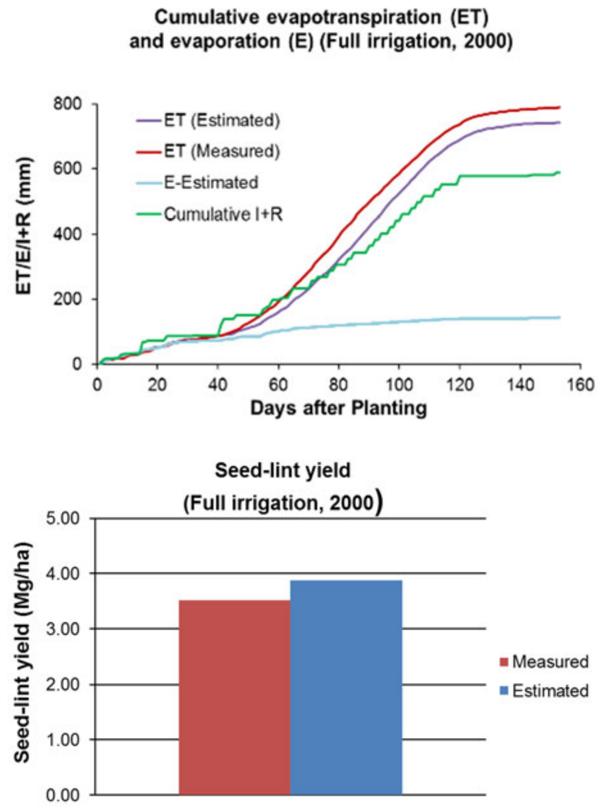

Figure 6. Measured and estimated evapotranspiration and cotton seed-lint yield with model settings of REW=1 mm, K_{ex}=0.95 and DF=8

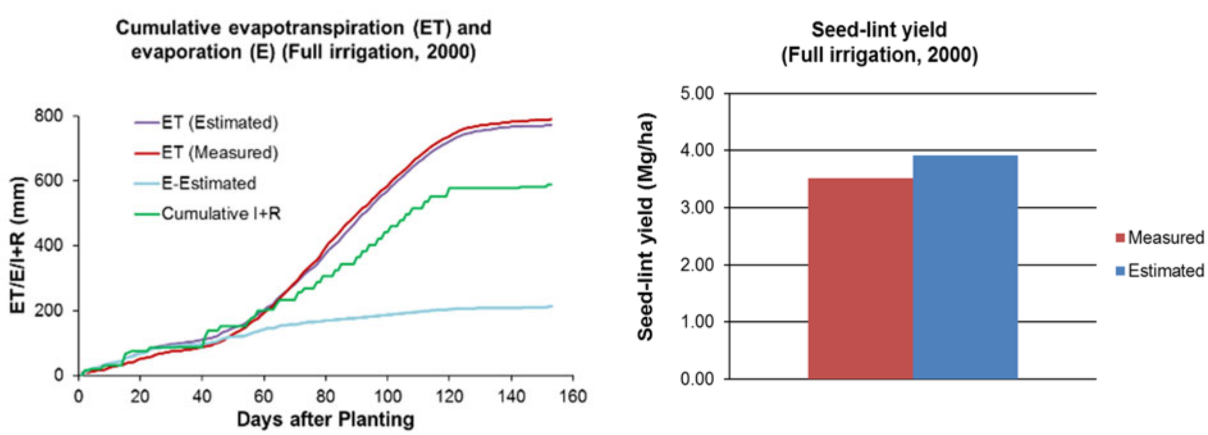

Figure 7. Measured and estimated evapotranspiration and seed-lint yield of fully irrigated cotton in 2000 with model settings of REW=3 mm, K_{ex}=1.00 and DF=4

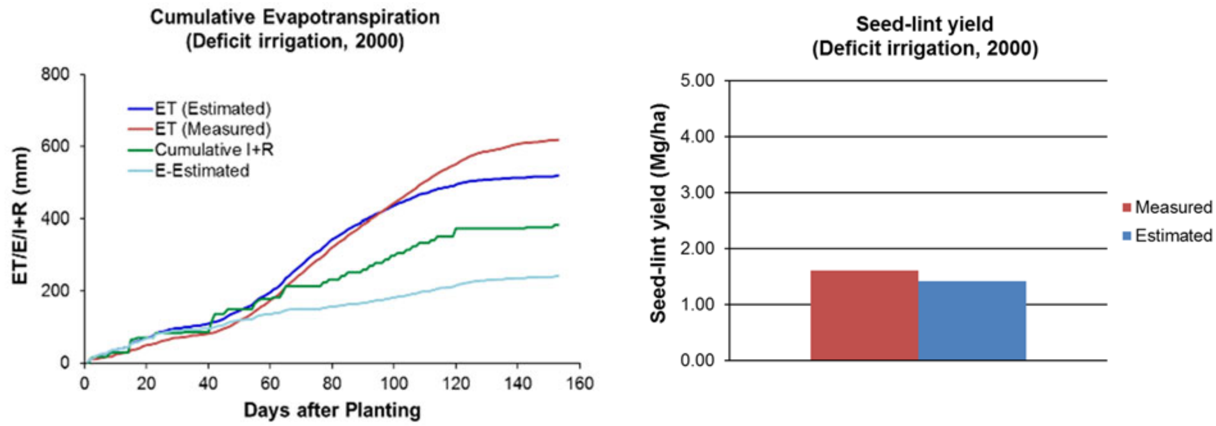

Figure 8. Measured and estimated evapotranspiration and seed-lint yield of deficiently irrigated cotton in 2000 with model settings of REW=3 mm, K_e=1.00 and DF=4

Summary

Our findings on parameterization and test of the parameterized AquaCrop model to estimate water use, growth parameters and yield for full and deficit irrigation of cotton included:

- AquaCrop overestimated soil water evaporation during the first 30 days after planting for both irrigation regimes (full or deficit), which reduced the stored soil water available for subsequent growth and yield formation.
- Modeled soil water evaporation was insensitive to the layer thickness set by the user, which was not a realistic outcome. Moreover, the model output indicated that user-set layer thicknesses were not used in the simulations.
- Unrealistically small values of REW, K_{ex} and DF were required to reduce overestimation of soil water evaporation during early in the season.
- Overall, the best results with fully irrigated cotton were obtained with REW=3 mm, K_{ex}=1.00 and DF=4, although the model still greatly overestimated evaporative loss in the first 30 days after planting and underestimated ET at peak flower to first open boll and later.
- The parameterized AquaCrop model overestimated cumulative ET of deficit-irrigated cotton in 2000 for about 90 days after planting and greatly underestimated ET around first open boll and later in the growing season. Simulated cotton seed-lint yield was 12% less than the measured value.
- Getting simulated ET right early in the growing season is important towards estimating cumulative biomass of cotton during the growing season and consequently cotton seed-lint yield. Changes are needed in the AquaCrop model to realistically simulate early-season evaporative loss from the soil and crop.

Acknowledgements

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