EPIC Model as a Decision Support System for Irrigation Management of Crops

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Interest is growing in simulation models to better assess crop water use and production with different management practices. EPIC was validated on corn and cotton under South Texas conditions and applied to evaluate the possibility of using it as a decision support tool for irrigation management of these crops. We measured actual crop evapotranspiration (ETc) using a weighing lysimeter and determined crop yields, then validated the model. Simulated ETc using EPIC agreed with the lysimeter measured ETc. EPIC also simulated the variability in crop yields at different irrigation regimes. The simulation results with farmers' field data allowed us to use the EPIC model as a decision support tool for the crops under full and deficit irrigation conditions. While growth stage specific crop coefficients can be used for making in-season decisions in irrigation scheduling, EPIC appears to be effective in making long term and pre-season decisions for irrigation management.

Keywords: crop model, EPIC, crop evapotranspiration, irrigation management

INTRODUCTION

The traditional solution to water shortages for plants has been irrigation, which has made agriculture possible in many otherwise nonproductive areas (Kramer and Boyer, 1995). In the Wintergarden area of Texas, irrigation is also one of the major limiting factors in producing corn, cotton, and other crops, as more than 90 % of the water for urban and agricultural use in this region depends on the Edwards aquifer. As the Texas Legislature placed water restrictions on the farming industry by limiting growers to a maximum use of 6,100 m^2 ha^{-1} of water per year in the Edward aquifer region, maximization of agricultural production efficiency has become a high priority for numerous studies in the Wintergarden area of Texas. For efficient water use, the irrigation amount should not exceed the maximum amount that can be used by plants through evapotranspiration (ET), which is the sum of the amount of water returned to the atmosphere through the processes of evaporation and transpiration (Hansen et al., 1980).

ET is very difficult to measure but several methods have been developed. One of the direct measuring techniques is a method using a weighing lysimeter, which constantly weighs the soil/vegetation mass and estimates gains and losses in water (Watson and Burnett, 1995). Because direct measurement of ET can be a difficult task, a wide rage of models have been developed for use in environments that lack either sufficient radiometric, meteorological, or lysimetric data. ET models tend to be categorized into three basic types: temperature, radiation, and combination (Jenson et al., 1990; Dingman, 1984; Watson and Burnett, 1995). Temperature models (e.g., Thornthwate, 1948; Doorenbos and Pruitt, 1977) generally require only air temperature data as the sole meteorological input; Radiation models (e.g., Turc, 1962; Doorenbos and Pruitt, 1977;

Hargreaves and Samani, 1985), designed to use some component of the energy budget concept, usually require some form of radiation measurement; and combination models (e.g., Penman, 1948) combine elements from both the energy budget and mass transfer models (Jensen et al., 1990).

Interest is growing in applying simulation models for conditions of South Texas, to better assess crop water use, and production with different crop management practices. One of these simulation models is EPIC, which was developed to determine the relationship between soil erosion and soil productivity in the U.S. (Williams et al., 1984). EPIC includes physiologically based components to simulate erosion, plant growth, and related processes. Model components include weather, hydrology, erosion, nutrient cycling, soil temperature, crop growth, tillage, pesticide fate, economics, and plant environmental control. The EPIC hydrology component includes runoff, percolation, lateral subsurface flow, ET, and snow melt. EPIC comes with five ET equations from which the user has to make a single choice for a simulation exercise. The equations include: Penman (Penman, 1948), Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), Hargreaves-Samani (Hargreaves and Samani, 1985), and Baier-Robertson (Baier and Robertson, 1965).

The generic crop-growth subroutine in EPIC (Williams et al, 1989) facilitates the simulation of complex rotations and fallow-cropping systems, making the model useful for evaluating alternative crop management scenarios in South Texas. A variety of scenarios can be simulated with the model, such as evaluating crop water use. A critical step in constructing crop management scenarios with EPIC is to validate the model in the region of interest. The objective of this research was to validate and evaluate the model as a decision support tool for irrigation scheduling in South Texas.

MATERIALS AND METHODS

Field Experiment for Model Validation

Field studies for validation of EPIC crop model were conducted at the Texas A&M Agricultural Research and Extension Center in Uvalde, Texas (29° 13' 03", 99° 45' 26", 283m), in 2002, 2003, 2004, 2005, and 2006. Data were collected from two fields, one from a center-pivot-irrigated field with a low energy precision application (LEPA) system and the other from a linear-irrigated lysimeter field with a LEPA system. Crops used were corn and cotton. Their varieties and plant to harvest dates in each year are presented in Table 1. Soil type of both fields was an Uvalde silty clay soil (fine-silty, mixed, hyperthermic Aridic Calciustolls with a pH of 8.1). The experiment of the field under the center pivot was arranged in a randomized split-block design with each block replicated three times. A 90° wedge of the center pivot field was divided equally into 15° regimes, which were maintained at 100, 75, and 50 % crop evapotranspiration (ETc) values.

The lysimeter units used in this study had monolithic soil cores where soil structure and associated parameters remain unchanged (Marek et. al, 2006). The size of the monoliths is $1.5 \times 2.0 \times 2.1$ m and each lysimeter is placed in the middle of a 1 ha field. The lysimeter field was managed under full irrigation based on measured daily crop water use. For the pivot experiment, irrigation scheduling and ETc regimes were imposed according to calculations of Penman-Monteith reference ET (ETo) and multiplied by available crop coefficient (Kc):

$$ETc = Kc \times ETo \qquad [1]$$

The total amounts of irrigation for each year are presented in Table 1.

Model Validation and Application

Parameters for the model validation were ETc and crop yields. In-field and simulated ET were calculated under unstressed crop conditions. Modified Penman-Monteith (Allen et al., 1998) ETo method in conjunction with crop coefficients developed at Bushland, TX (2002-03), and Uvalde, TX (2004), were used to calculate in-field ETc. EPIC makes users select one ET equation from five options. After preliminary test runs of the EPIC model, the Hargreaves-Samani (Hargreaves and Samani, 1985) ETo method was selected to simulate ETc in this study.

The model was applied to simulate the crop yields of 2006 from farmers' fields in South Texas (Fig. 1). Information regarding the fields and their cropping practices is presented in Table 2. In addition, the model was used to simulate the yields of each crop with various irrigation scenarios. These were 229, 306, 381, 457, 533, and 610 mm of irrigation, respectively.

Weather data used in the simulations were collected with a standard Campbell Scientific meteorological station (Campbell Scientific Inc., Logan, UT) at each location. Simple linear regression using PROC REG (SAS version 9.1, Cary, NC) was used to compare yields of simulated and measured data.

Table 1. Summary of cropping practices at Texas A&M Agricultural Research and Extension Center in Uvalde, Texas.

Crop	Variety†	Year	Plant-maturity (M/D)	Irrigation (mm)§		Rainfall (mm)
				Lysimeter	IFC	
Corn	30G54	2002	3/25-6/20	358.1	422.4	99.6
	30G54	2003	3/18-6/24	370.8	417.8	136.7
	30G54	2004	3/10-6/24	293.6	231.1	232.4
Cotton	ST4892	2003	4/02-8/11	N/A	253.5	318.3
	ST4892	2004	4/01-8/16	N/A	257.6	274.1
	ST4892	2005	4/07-8/07	N/A	337.3	140.7
	DP555	2007	4/16-9/07	76.2	N/A	575.8

† 30G54 from Pioneer (Johnston, IA 50121); ST4892 from Stoneville (Monsanto, St. Louis, MO 63167); and DP555 from Delta and Pine (Scott, MS 38772).
§ Total amounts of irrigation based on crop evapotranspiration using lysimeter-measured and in-field-calculated (IFC).

Fig. 1. Geological location of farms (open circle with a dot) used in crop simulation.

Table 2. Summarized information of farmer's fields and their cropping practices in 2006 used in crop simulation.

Crop	Farm's name	County	Soil type	plant to harvest (M/D)	N-P§ (kg ha^{-1})	Irrigation (mm)
Corn	Boyle, Duane	Medina	Knippa clay 0-1%	3/11-7/22	163-19	622
	Clary, Austin†	Medina	Montell clay 0-1%	3/03-8/01	101-90	427
	Crawford, Jimmy	Uvalde	Uvalde silty clay loam 0-1%	3/03-7/30	168-56	610
	Parker, Jimmy	Uvalde	Uvalde silty clay loam 0-1%	3/08-8/10	168-45	495
	Shirmer, Ernie	Bexar	Brayton clay 0-1%	3/10-8/26	163-46	533
Cotton	Panther City	Zavala	Uvalde silty clay loam 0-1%	4/10-8/29	103-0	425
	Clary, Kenneth†	Uvalde	Montell clay 0-1% Knippa clay 0-1%	3/30-8/29	56-0	406
	Gillerland, Weldon	Uvalde	Knippa clay 0-1%	4/04-8/29	50-129	464
	Stoy, Steve	Uvalde	Knippa clay 0-1%	3/21-8/29	123-45	419
	Tech Farm	Frio	Duval loamy fine sand 0-5%	4/05-9/02	123-0	533

§ Nitrogen-Phosphate applied.
† Two fields were used from these farms.

RESULTS AND DISCUSSION

Model Validation

Lysimeter-measured crop water use under unstressed crop conditions was previously compared to two different methods of irrigation calculation: 1) in-field-calculation with Penman-Monteith formula and 2) EPIC Hargreaves-Samani. This was performed as a preliminary validation of the EPIC model. No statistical difference was found between the ETc values of lysimeter-measured and the two different methods of irrigation calculation (data not shown). However, cumulative ETc varied during the growing seasons among the three methods of measurements (Fig. 2). In-season differences among ETc methods varied possibly due to inexact simulation growth curves or growth stage specific crop coefficients; however, the variations were within an acceptable range.

The EPIC model simulated the variability in grain corn yields with different irrigation regimes, with r^2 value of 0.69 and root mean square error (RMSE) of 0.50 Mg ha^{-1} (Fig. 3A). The regression line was close to the 1:1 line. For the three years, measured yields ranged from 4.71 to 7.62 Mg ha^{-1} while simulated yields ranged from 4.68 to 7.56 Mg ha^{-1}. The upper 95 % confidence interval of the means ranged from 6.08 to 8.14 Mg ha^{-1} while the lower 95 % confident interval ranged from 4.50 to 6.67 Mg ha^{-1}. For cotton, EPIC simulated the variability in lint yields, with r^2 value of 0.74 and RMSE of 0.70 Mg ha^{-1} (Fig. 3B). The regression line was close to the 1:1 line. For the three years, measured yields ranged from 1.82 to 2.67 Mg ha^{-1} while simulated yields ranged from 1.35 to 2.46 Mg ha^{-1}. The upper 95 % confidence interval of the means ranged from 1.81 to 2.86 Mg ha^{-1} while the lower 95 % confident interval ranged from 1.23 to 2.18 Mg ha^{-1}. Previously, Williams et al. (1989) reported that EPIC could accurately simulate crop responses to irrigation at locations in the western USA. Our validation results also demonstrate that the EPIC model can be used as a decision support tool for irrigation management of corn and cotton in South Texas.

Model Application to Corn

The crop model simulated the variability in grain corn yield from different farmers' fields at different irrigation regimes, with r^2 value of 0.67 and RMSE of 0.66 Mg ha^{-1} (Fig. 4). Reported yields ranged from 3.28 to 7.07 Mg ha^{-1} while simulated yields ranged from 3.83 to 6.86 Mg ha^{-1}. Since we are confident of reproducing the yield variation of corn using EPIC for the farmers' fields, the model was applied to simulate yield responses with various irrigation scenarios.

Grain yield as a function of irrigation + rainfall linearly increased until 800 mm and reached a plateau after that (Fig. 5A). With this result, we assume that the amount of water necessary to achieve 5 to 5.5 Mg ha^{-1} for corn is ~ 800 mm. In addition, yield versus crop evapotranspiration shows that grain yield linearly increased up to ~ 700 mm, which is considered to be a saturated crop evapotranspiration for corn in this region (Fig. 5B). Values of water use efficiency (WUE) versus grain yield linearly increased as grain yield increased until ~ 5 Mg ha^{-1} (Fig. 6A). WUE calculated with water input generally maintained a plateau after 5 Mg ha^{-1}. Our result shows that there is a positive correlation between WUE and grain corn yield up to a certain range of yield, which was ~ 5 Mg ha^{-1}. When the WUE values were plotted against values of ETc and water input, WUE sporadically increased as ETc or water input increased until ~ 700 mm (Fig. 6B). WUE versus water input decreased with a slow linear phase after ~800 mm. Therefore, it is considered that there is a negative correlation between WUE and water input after ~ 800 mm, which was determined to be the amount of water input needed to achieve the range of the highest grain corn yield in this study.

Model Application to Cotton

The crop model simulated the variability in lint yield, with r^2 value of 0.11 and RMSE of 0.22 Mg ha^{-1} (Fig. 7). The reported yields ranged from 1.40 to 1.61 Mg ha^{-1} while the simulated yields ranged from 1.18 to 1.74 Mg ha^{-1}. While present data were not statistically significant due to a narrow range of reported lint yields, simulated yields were arithmetically in general agreement with the reported yields. Assuming that EPIC can reproduce the cotton yield variation for the farmers' fields, the model was applied to simulate yield responses with various irrigation scenarios.

Lint yield as a function of irrigation + rainfall linearly increased until 700 mm and reached a plateau after that (Fig. 8A). With this result, we assume that the amount of water necessary to achieve 1.8 to 2.0 Mg ha^{-1} for cotton is ~ 700 mm. Likewise, the yield versus the amounts of crop evapotranspiration (ETc) shows that lint yield linearly increased up to ~ 600 mm, which is considered to be a saturated crop evapotranspiration for cotton in South Texas (Fig. 8B). Values of water use efficiency (WUE) calculated with water input versus lint yield linearly increased as the lint yield increased until ~ 1.7 Mg ha^{-1} and maintained a plateau after that (Fig. 9A). Meanwhile, WUE calculated with ETc versus lint yield increased with a slow linear phase until ~ 1.5 Mg ha^{-1} and maintained a plateau after that. Likewise for corn, the result shows that there is a positive correlation between WUE and cotton lint yield. When the WUE values were plotted against values of ETc and water input, WUE sporadically increased as ETc or water input increased until ~ 600 mm (Fig. 9B). WUE versus water input decreased with a slow linear phase after ~ 700 mm. This result shows that there is a negative correlation between WUE and water input after ~ 700 mm. This value corresponded to the amount of water input necessary to achieve the range of the highest cotton lint yield.

CONCLUSIONS

We validated and evaluated the EPIC crop model to use as a decision support tool for management of corn and cotton under various irrigation conditions in South Texas. The validation results of corn and cotton show reasonable agreement between simulation and measurement in terms of crop water use and crop yield. The simulation results with farmers' field data demonstrate that the EPIC model can be used as a decision support tool for the crops under full and deficit irrigation conditions in South Texas. EPIC specifically appears to be effective in long term and pre-season decision makings for irrigation management of crops. Using growth stage specific crop coefficients and/or the EPIC simulation model indicate the possibility of being effective tools in irrigation scheduling.

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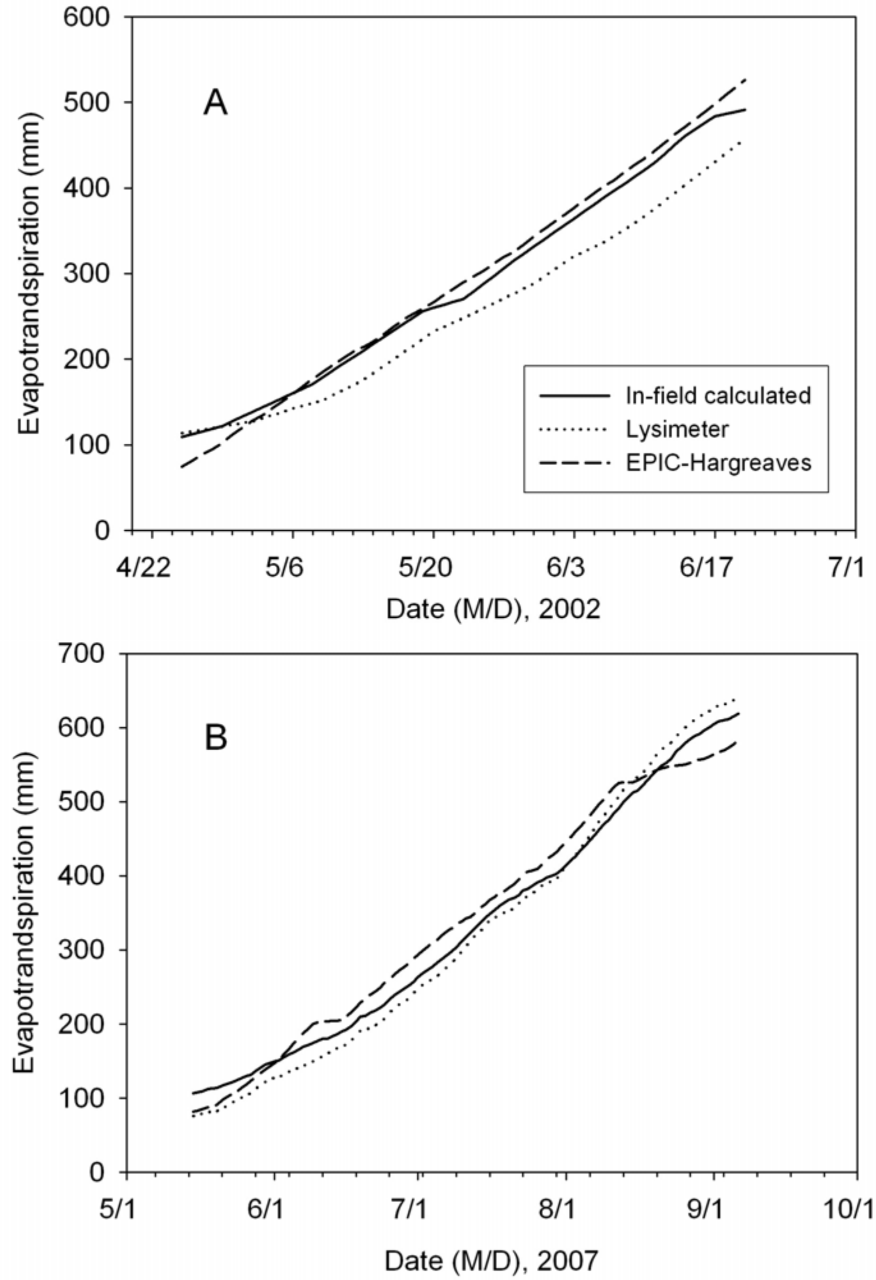


Fig. 2. Lysimeter-measured crop evapotranspiration (ETc) vs. two methods of estimating ETc (in-field-calculated and EPIC-simulated using Hargreaves-Samani) for corn (A) and cotton (B) in Uvalde, Texas.

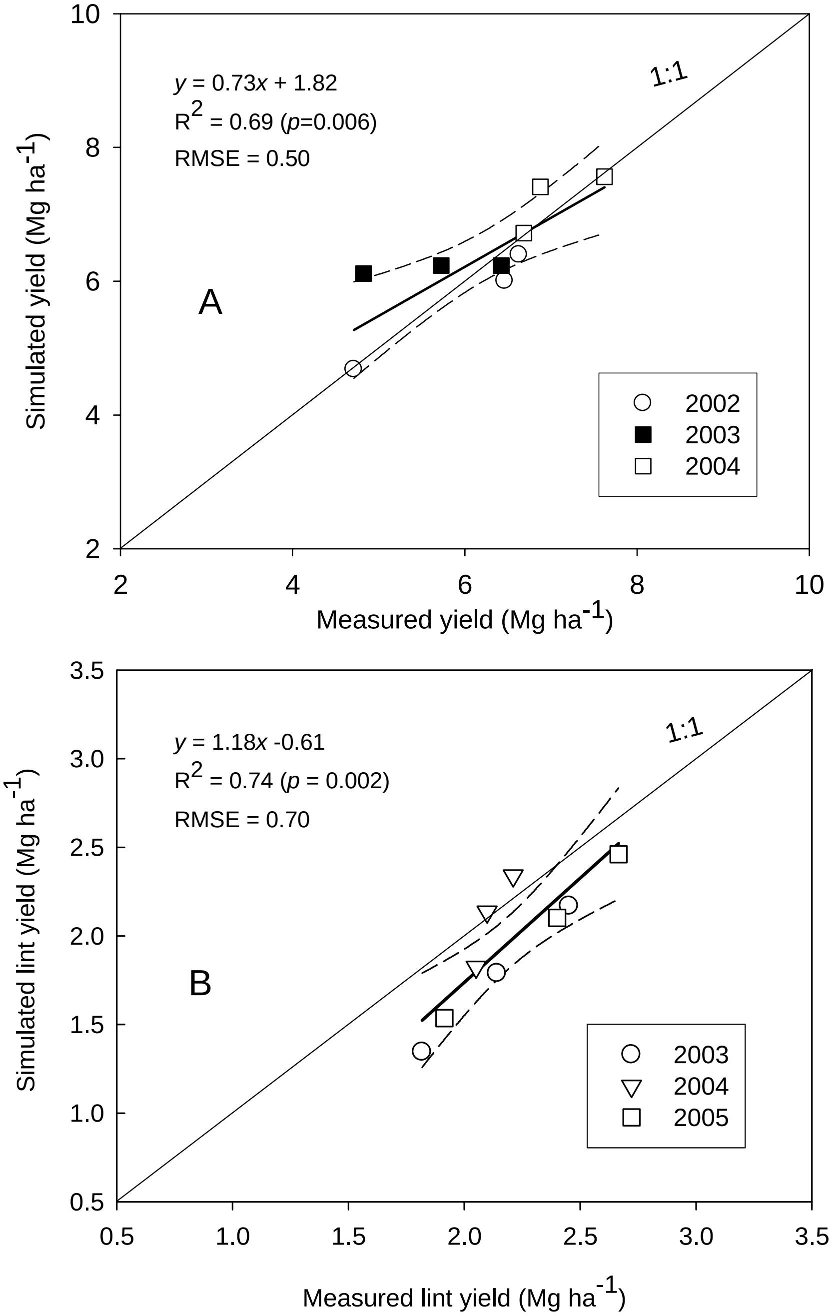


Fig. 3. Measured vs. simulated corn grain yields (A) and cotton lint yields (B) at the field of Texas A&M Agricultural Research and Extension Center in Uvalde, Texas. Dashed lines are 95% confidence interval for the mean of the simulated values.

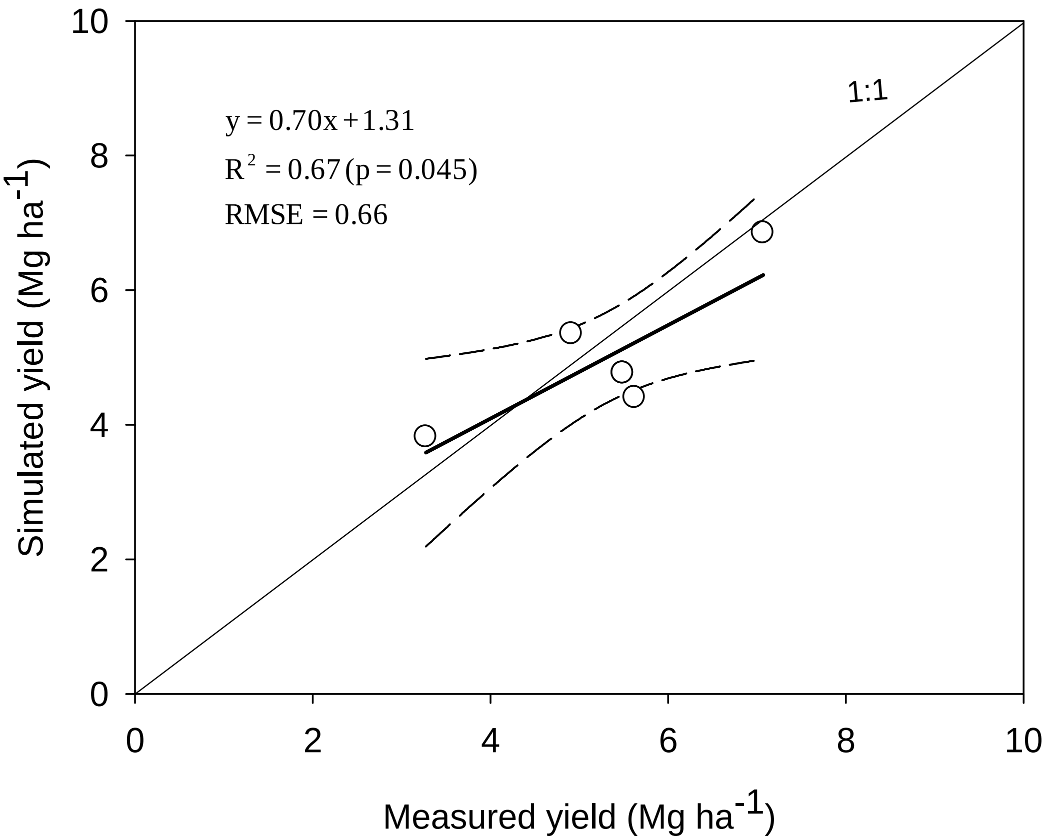
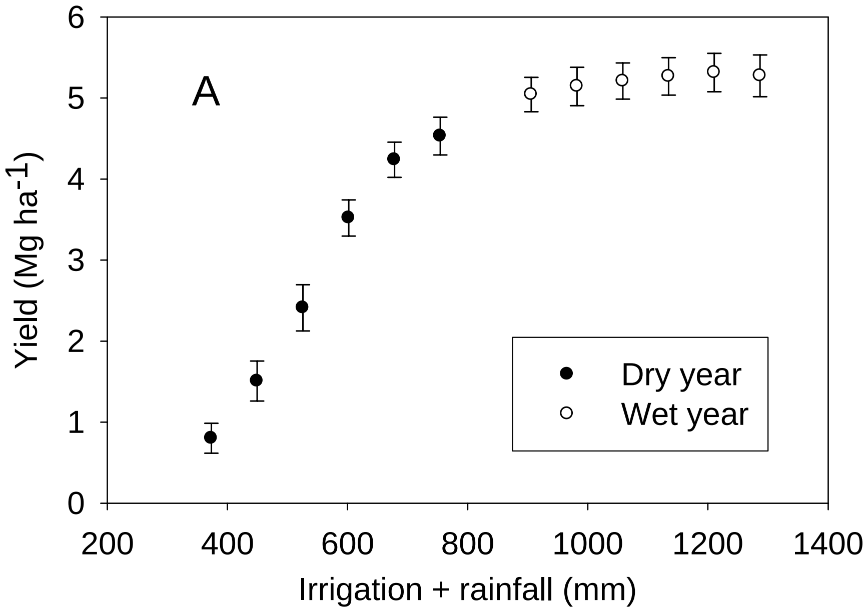


Fig. 4. Measured vs. simulated corn grain yields using farmer's field data, which were obtained from three counties of South Texas (Bexar, Medina, and Uvalde) in 2006. Dashed lines are 95% confidence interval for the mean of the simulated values.



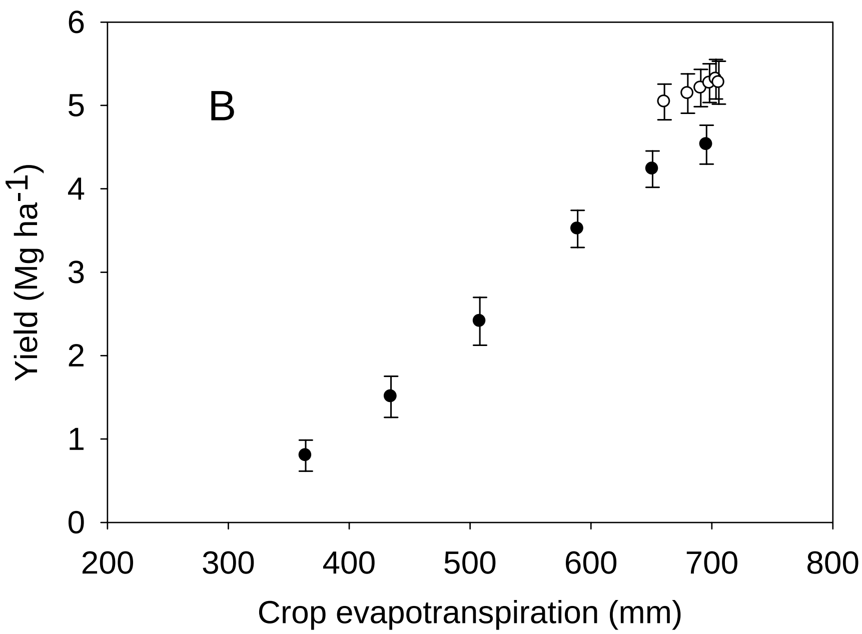


Fig. 5. Corn yield responses as a function of irrigation + rainfall (A) and crop evapotranspiration (B). Dry and wet year were chosen from 20 yr weather data (1987-2006) for each of 6 farmers' field data. Vertical bars represent standard errors at 95% confidence interval for the mean of each data point (n=6).

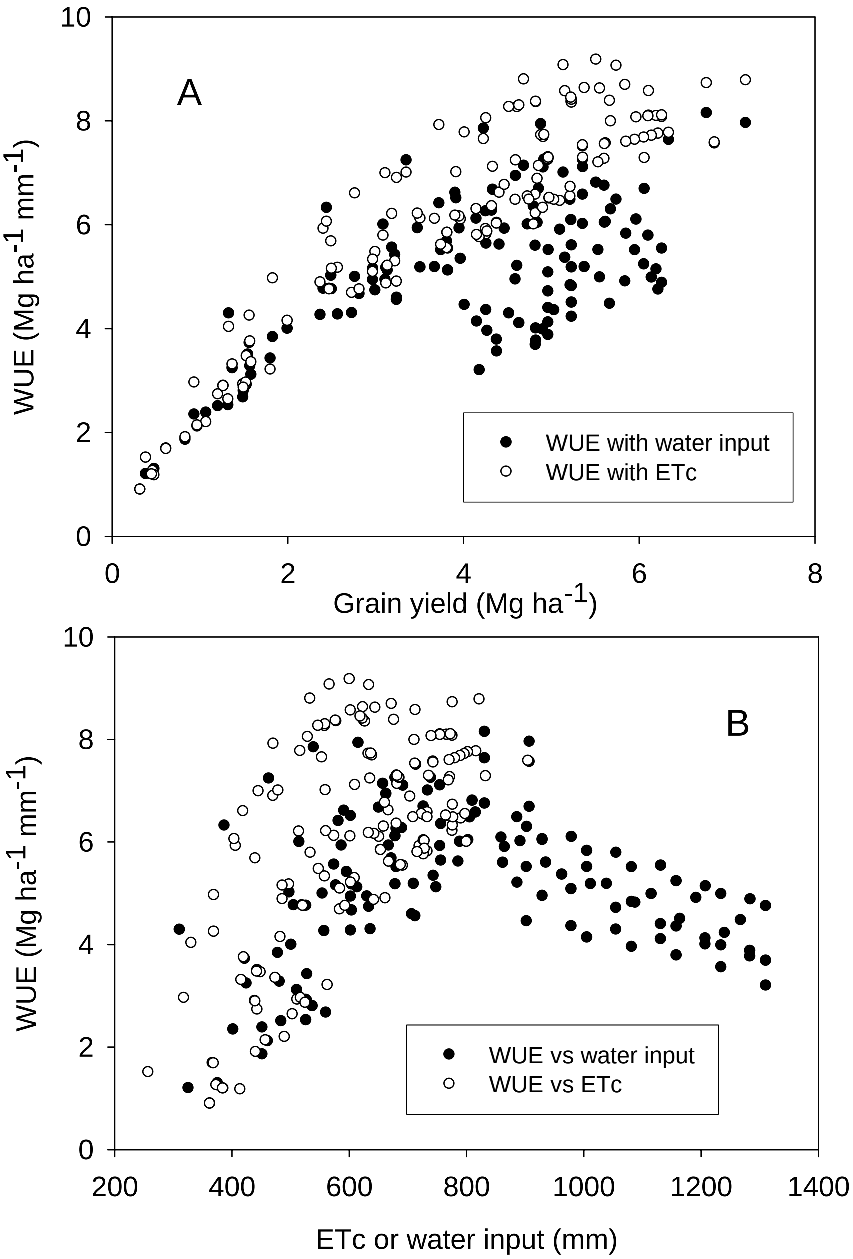


Fig. 6. Water use efficiency (WUE) vs. corn grain yield (A) and WUE vs. water input or crop evapotranspiration (B).

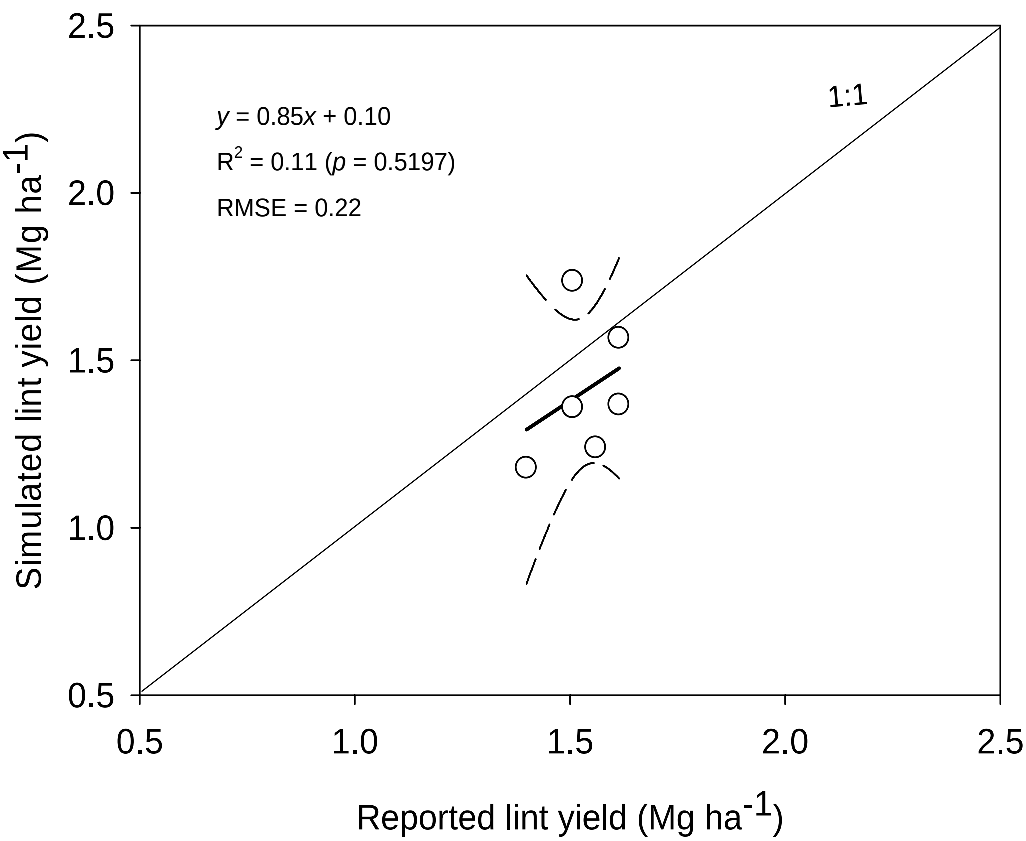


Fig. 7. Simulated vs. reported cotton lint yields using farmer's field data, which were obtained from three counties of South Texas (Bexar, Medina, and Uvalde) in 2006. Dashed lines are 95% confidence interval for the mean of the simulated values.

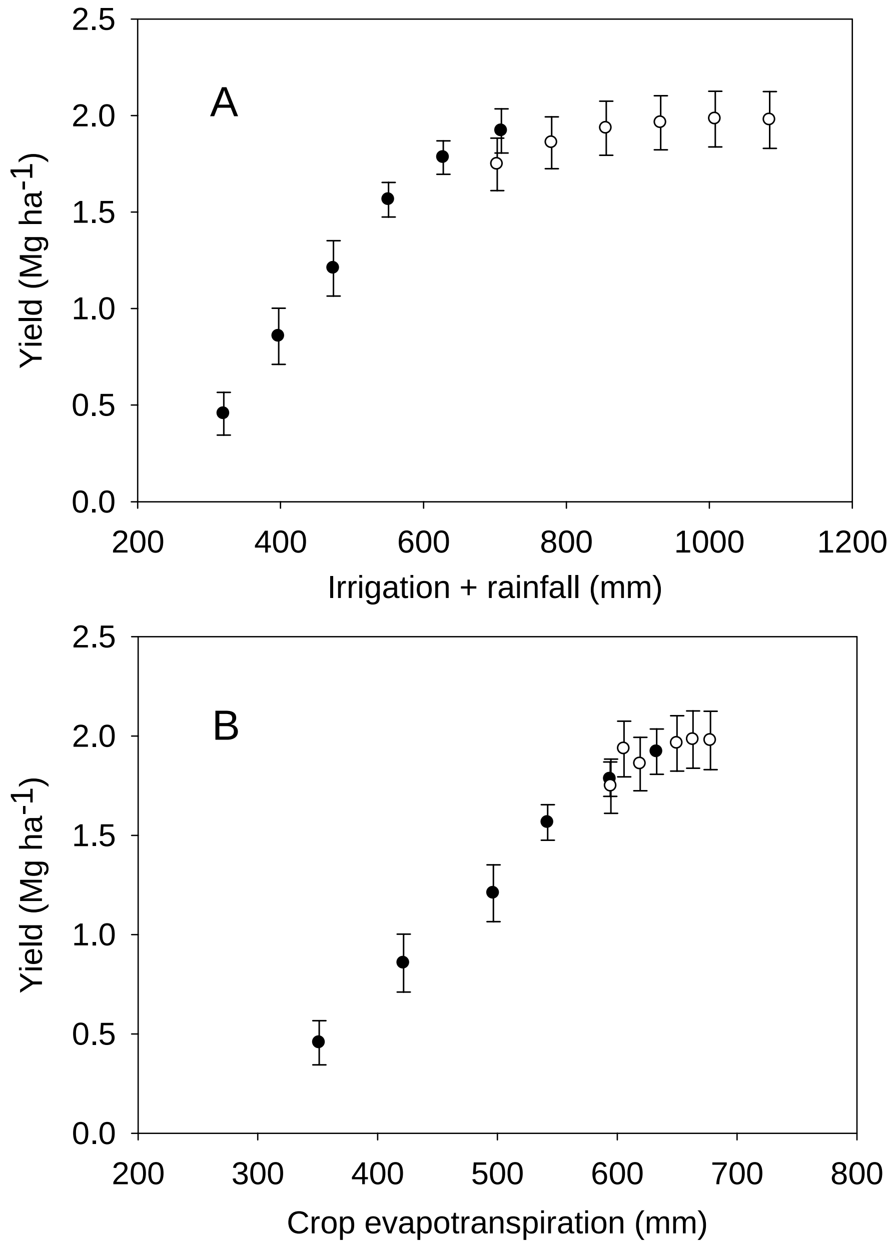


Fig. 8. Cotton lint yield responses as a function of irrigation + rainfall (A) and crop evapotranspiration (B). Dry and wet year were chosen from 20 yr weather data (1987-2006) for each of 6 farmers' field data. Vertical bars represent standard errors at 95% confidence interval for the mean of each data point (n=6).

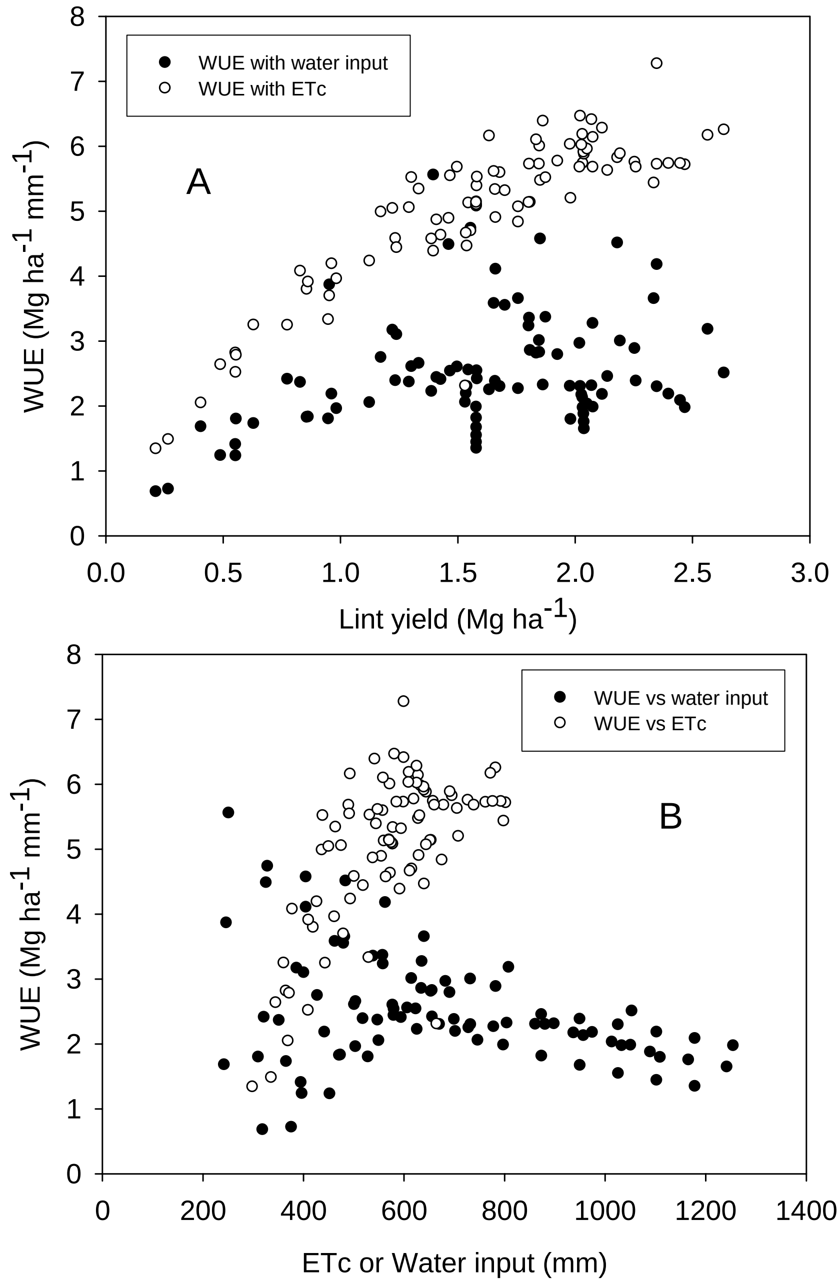


Fig. 9. Water use efficiency (WUE) vs. cotton lint yield (A) and WUE vs. water input or crop evapotranspiration (B).