Simulating Soil Water Content, Evapotranspiration and Yield of Variably Irrigated Grain Sorghum using AquaCrop

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IRRIGATION IN THE SOUTHERN & CENTRAL HIGH PLAINS

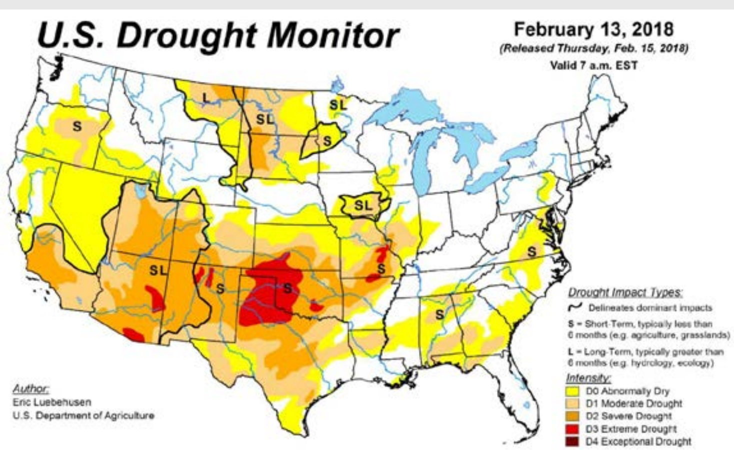
- Irrigation is crucial for sustainable agricultural production
  - Erratic growing season rainfall
  - High evaporative demand

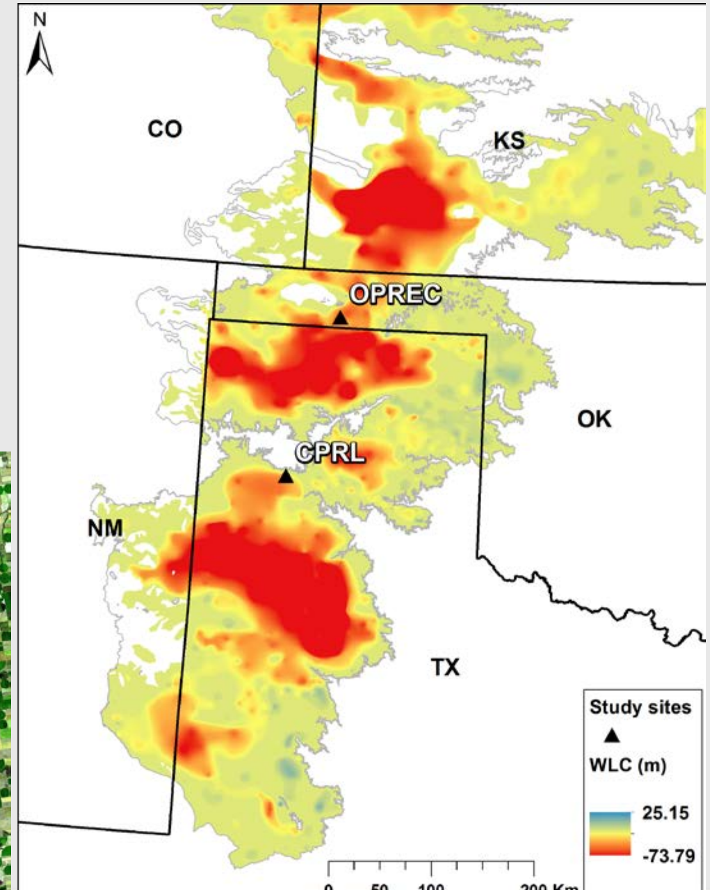
- Irrigated agriculture is a major economic driver e.g. contribute >70% production in economic value in TX (Terrell et al.,2002)

- Ogallala aquifer is the main source of irrigation water

ISSUES FACING IRRIGATION IN THE REGION

- Severe depletion of the Ogallala aquifer due to excessive withdrawals and limited recharge
- Declining water levels & well pumping capacity
- High energy costs for irrigation pumping
- Frequent Droughts





WHAT CAN BE DONE?

- Irrigation efficiency improvements ✓
- Shifting to crops with less water demand ✓
- Investigate strategies that optimize crop water use
  - ➢ Deficit irrigation: levels of water stress, timing & duration of stress
  - ➢ Planting dates
  - ➢ Planting densities

RESEARCH OPTIONS

- **Field experiments:** Time, labor & cost constraints
- **Crop models:** ✓ : **However, applicability and performance should be assessed.**

STUDY OBJECTIVE

- To calibrate and evaluate the performance of the AquaCrop model for simulating soil water content (SWC) , evapotranspiration (ET) and grain yield for sorghum in the region

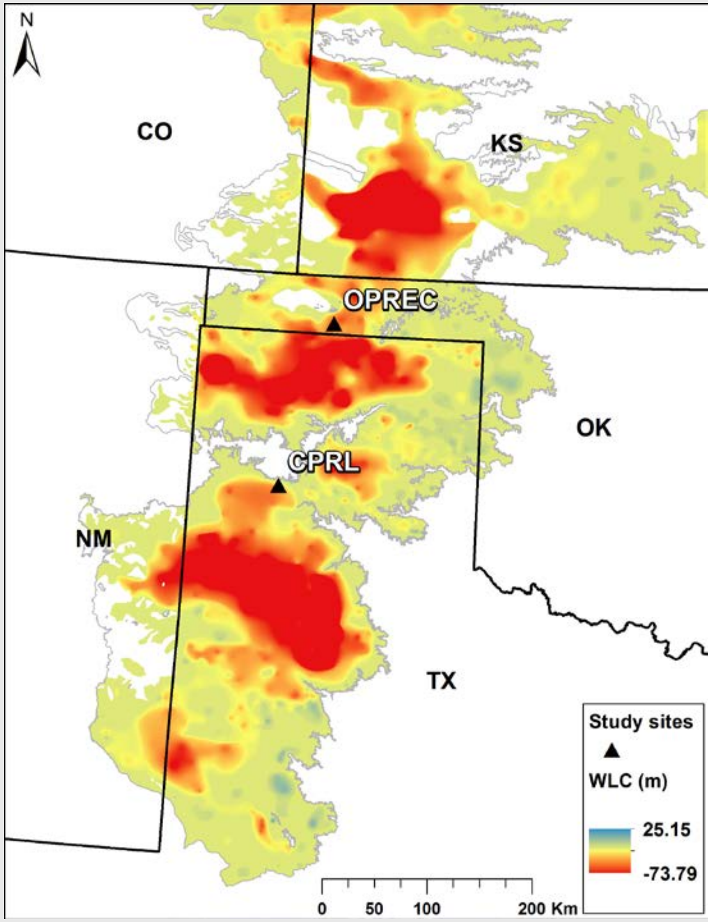
METHODOLOGY: Study sites

❑ USDA-ARS Conservation and Production Research Laboratory (CPRL) at Bushland, TX

- Characterized by semi-arid climate
- High wind velocities
- Long-term average annual rainfall: 470 mm
- Pullman clay soil: FC ≈ 0.33 m^3m^{-3}, WP ≈ 0.18 m^3m^{-3}

❑ Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK

- Similar climate
- Long-term average annual rainfall: 440 mm
- Gruver clay loam soil: : FC ≈ 0.39 m^3m^{-3}, WP ≈ 0.20 m^3m^{-3}



AGRONOMY: CPRL

- Fields were irrigated using a linear move system
- ET, SWC & grain yield measurements were done in 9 m^2 - lysimeters
- SWC measured using a field calibrated neutron probe

Growing season/ Irrigation treatment	1993/ Full	1993/ 50%	1998/ Dryland	2005/ Full 1	2005/ Full 2	2007/ Dryland
Variety	DK-56	DK-56	PIO-8699	DK-39Y	DK-39Y	DK-39Y
Planting Date	27 May	27 May	24 Jun	22 Jun	22 Jun	6 Jun
Planting Density (plants/ha)	200,000	200,000	119,000	160,000	160,000	96,370
Harvest Date	4 Oct	4 Oct	4 Oct	7 Nov	7 Nov	3 Oct
Seasonal Rainfall, (mm)	263	263	230	165	165	192
Irrigation (mm)	380	174	0	219	218	0
Seasonal ET_o (mm)	780	780	855	843	843	713

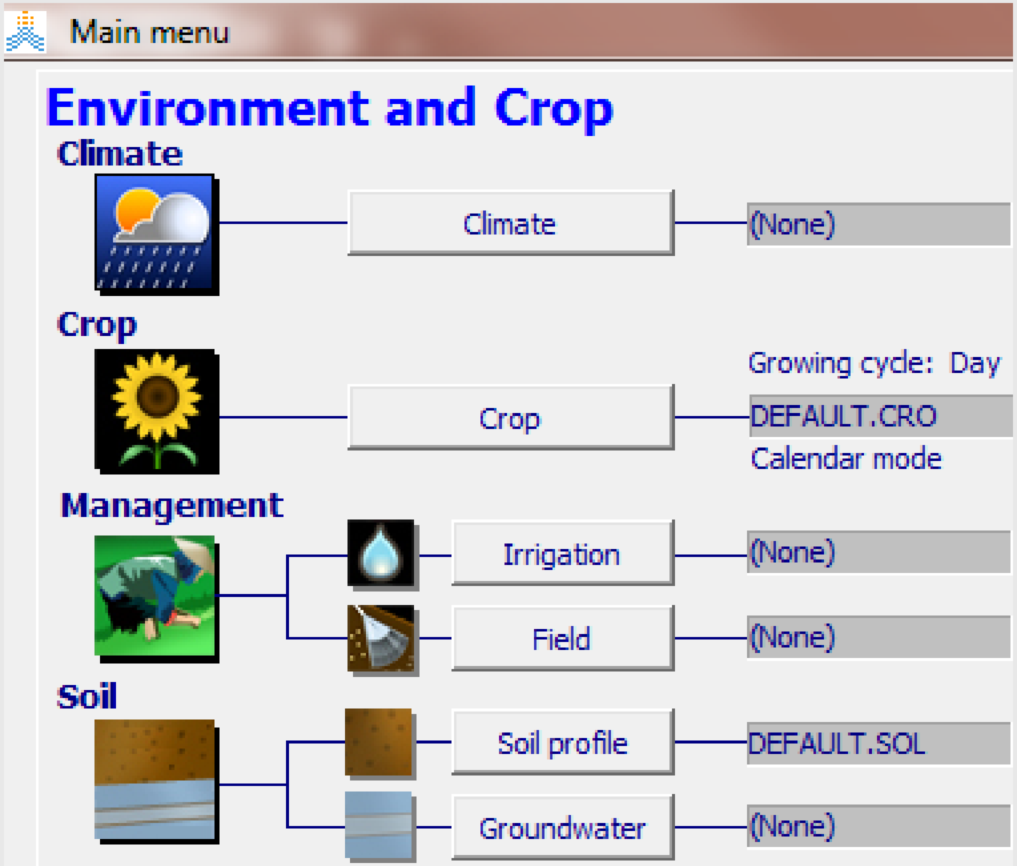
AGRONOMY: OPREC

- 3 irrigation treatments, replicated 3 times
- Irrigated using a subsurface irrigation system
- Only data for grain yield was available for model evaluation

Irrigation Treatment	2014/ Full	2014/ 75%	2014/ 50%	2015/ Full	2015/ 75%	2015/ 50%	2016/ Full	2016/ 75%	2016/ 50%
Variety	PIO-84G62	PIO-84G62	PIO-84G62	PIO-84G62	PIO-84G62	PIO-84G62	SP-73B12	SP-73B12	SP-73B12
Planting Date	6 Jun	6 Jun	6 Jun	1 Jun	1 Jun	1 Jun	8 Jun	8 Jun	8 Jun
Planting Density (plants/ha)	154,440	154,440	154,440	154,440	154,440	154,440	154,440	154,440	154,440
Harvest Date	15 Oct	15 Oct	15 Oct	15 Oct	15 Oct	15 Oct	29 Oct	29 Oct	29 Oct
Seasonal Rainfall (mm)	270	270	270	296	296	296	229	229	229
Irrigation (mm)	384	288	193	320	237	160	293	222	151
Seasonal ET_o (mm)	891	891	891	800	800	800	886	886	886

AQUACROP MODEL

- Simulates the yield response of herbaceous crops to water



$$B = WP^* \times \sum\left(\frac{T_r}{ET_o}\right)$$

B – biomass; T_r – transpiration

WP*- normalized water productivity; ET_o - reference evapotranspiration

$$Y = B \times HI$$

Y- yield; HI- harvest index

VALIDATION: Performance Indicators

Prediction error, $P_e = \frac{(S_i - M_i)}{M_i} \times 100$

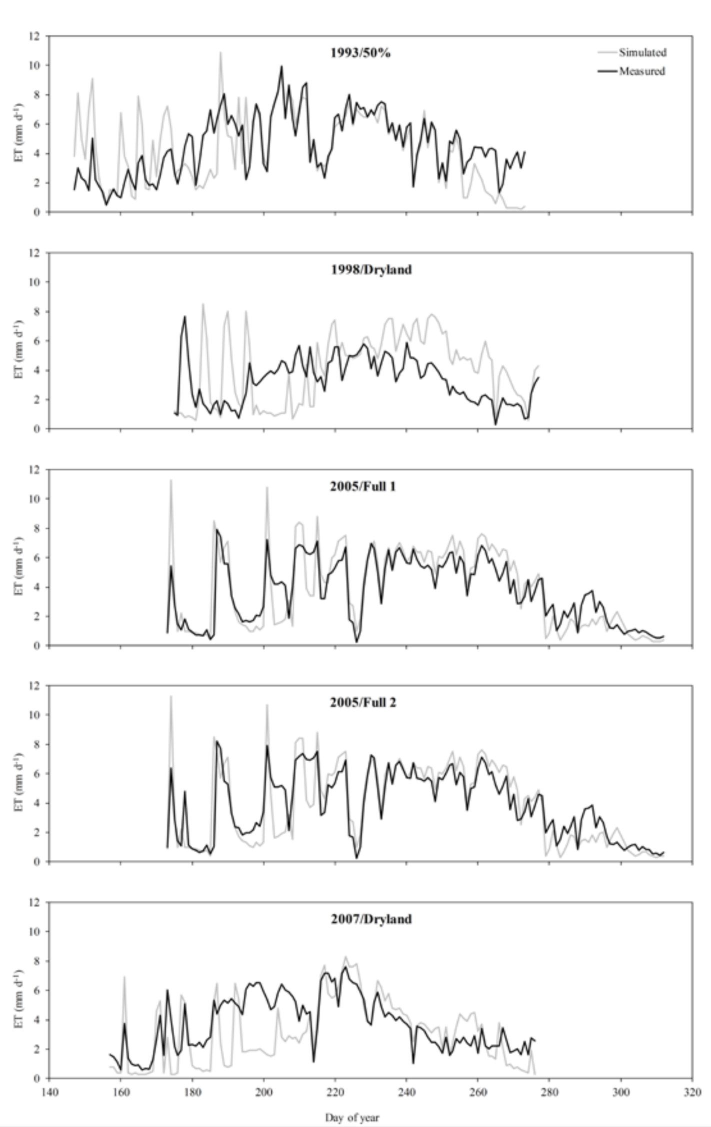
Root Mean Square Error, $RMSE = \sqrt{\sum_{i=1}^{n} 1/(N)\,(M_i - S_i)^2}$

Nash-Sutcliffe Efficiency, $NSE = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - \bar{M})^2}$

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

- **P_e & *RMSE* close to zero, and 0 >NSE ≤ 1 indicate better model performance**

RESULTS: DAILY ET

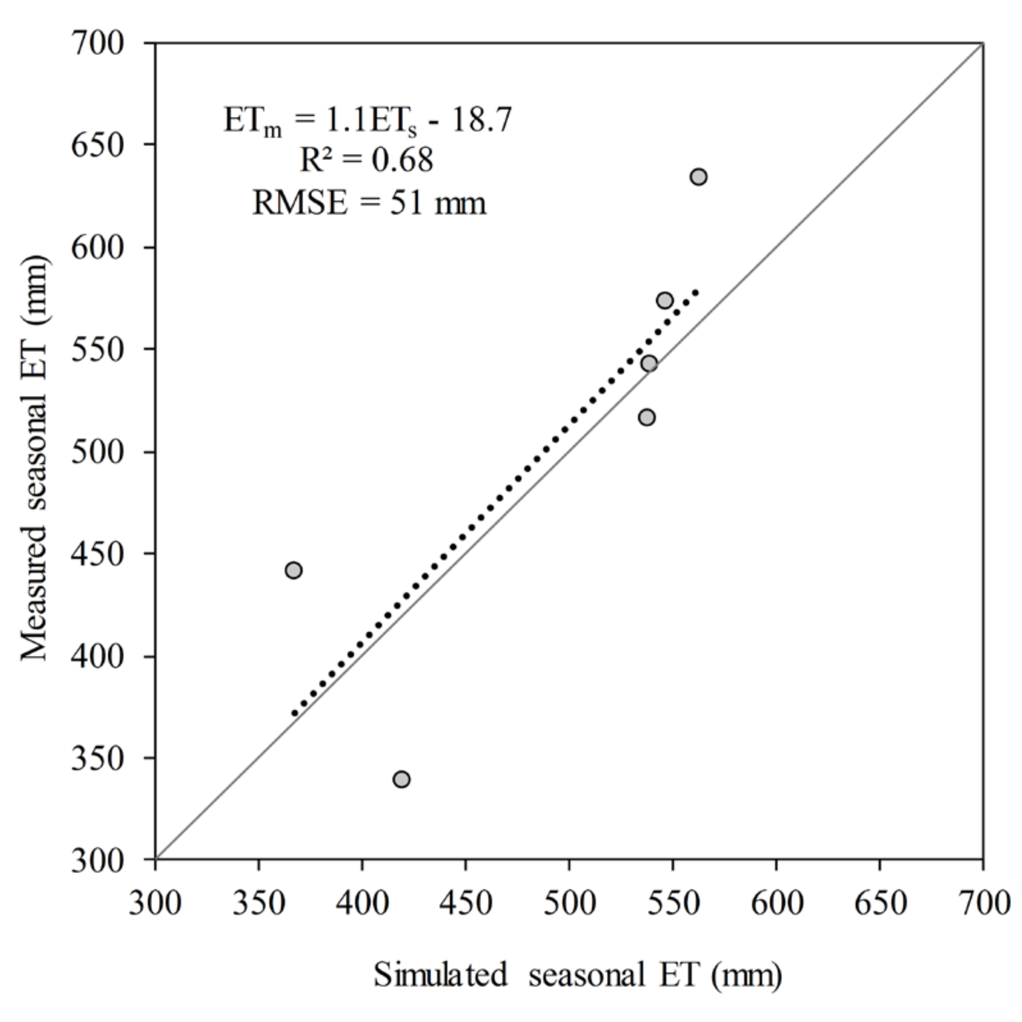


- Overestimation early in the growing season
- Better results in irrigated treatments than in dryland conditions

RMSE:

- 1993/50% = **1.9** mm d^{-1}
- 2005/Full = **1.5** mm d^{-1}
- 1998/Dryland = **2.6** mm d^{-1}
- 2007/Dryland = **1.9** mm d^{-1}

RESULTS: SEASONAL ET



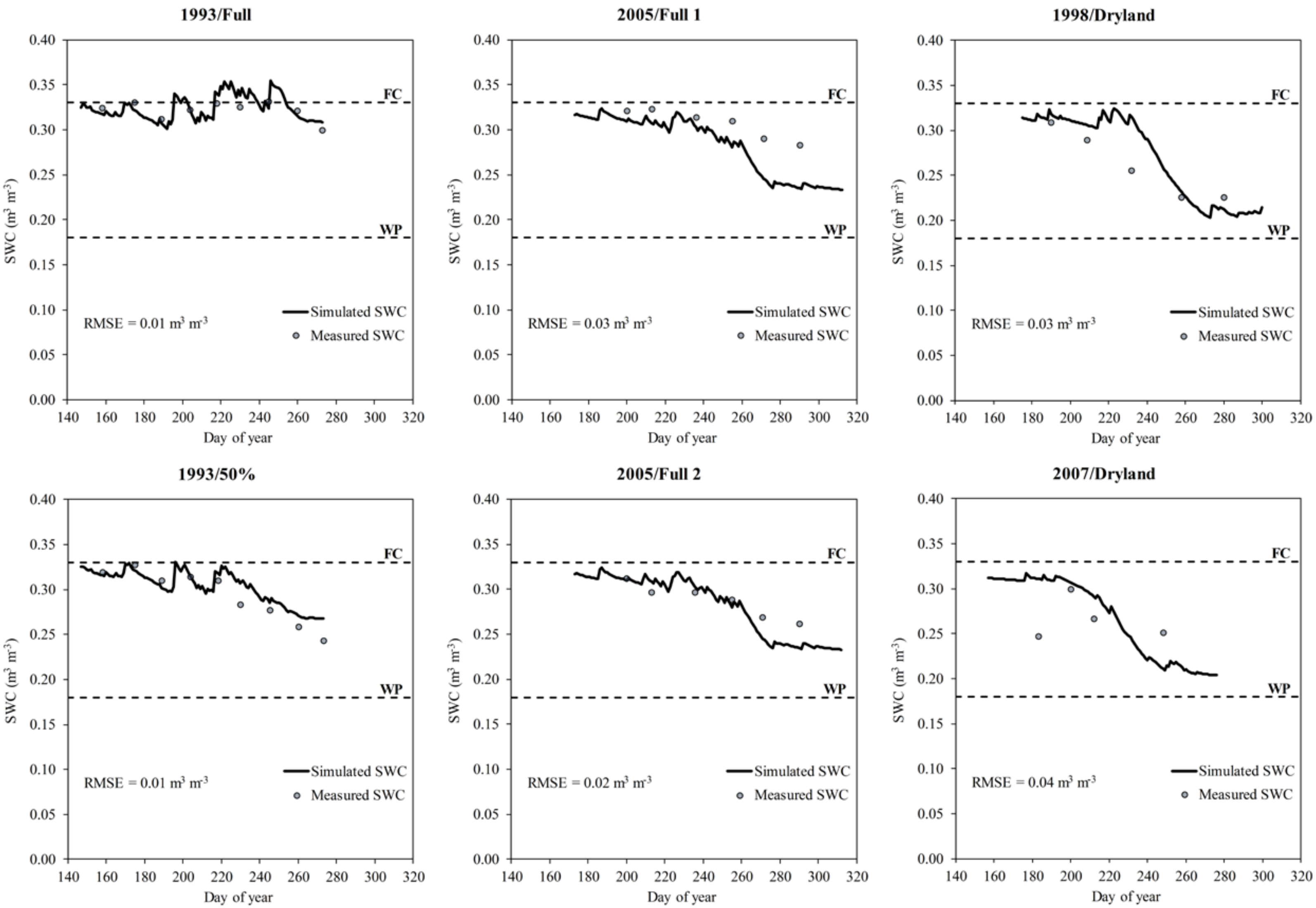
➢ Better results in irrigated than in dryland treatments

Irrigation Trt	Seasonal ET (mm)		P_e (%)
	Measured	Simulated	
1993/Full	634	564	-11
1993/50%	570	547	-5
1998/Dryland	341	420	24
2005/Full 1	516	539	4
2005/Full 2	542	539	-1
2007/Dryland	441	368	-17

RMSE = 51 mm

NSE = 0.63

RESULTS: SWC



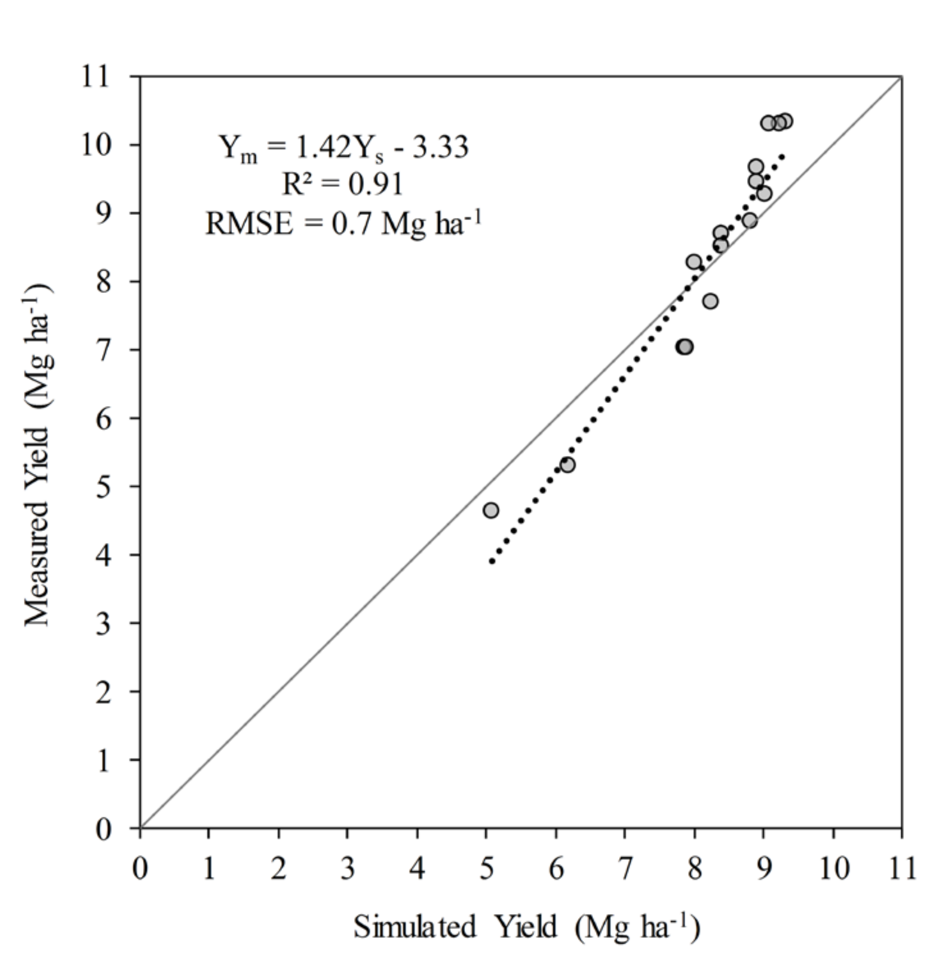
P_e (%)

Full: -17 - 4

Limited: -3 - 10

Dryland: -16 - 25

RESULTS: GRAIN YIELD



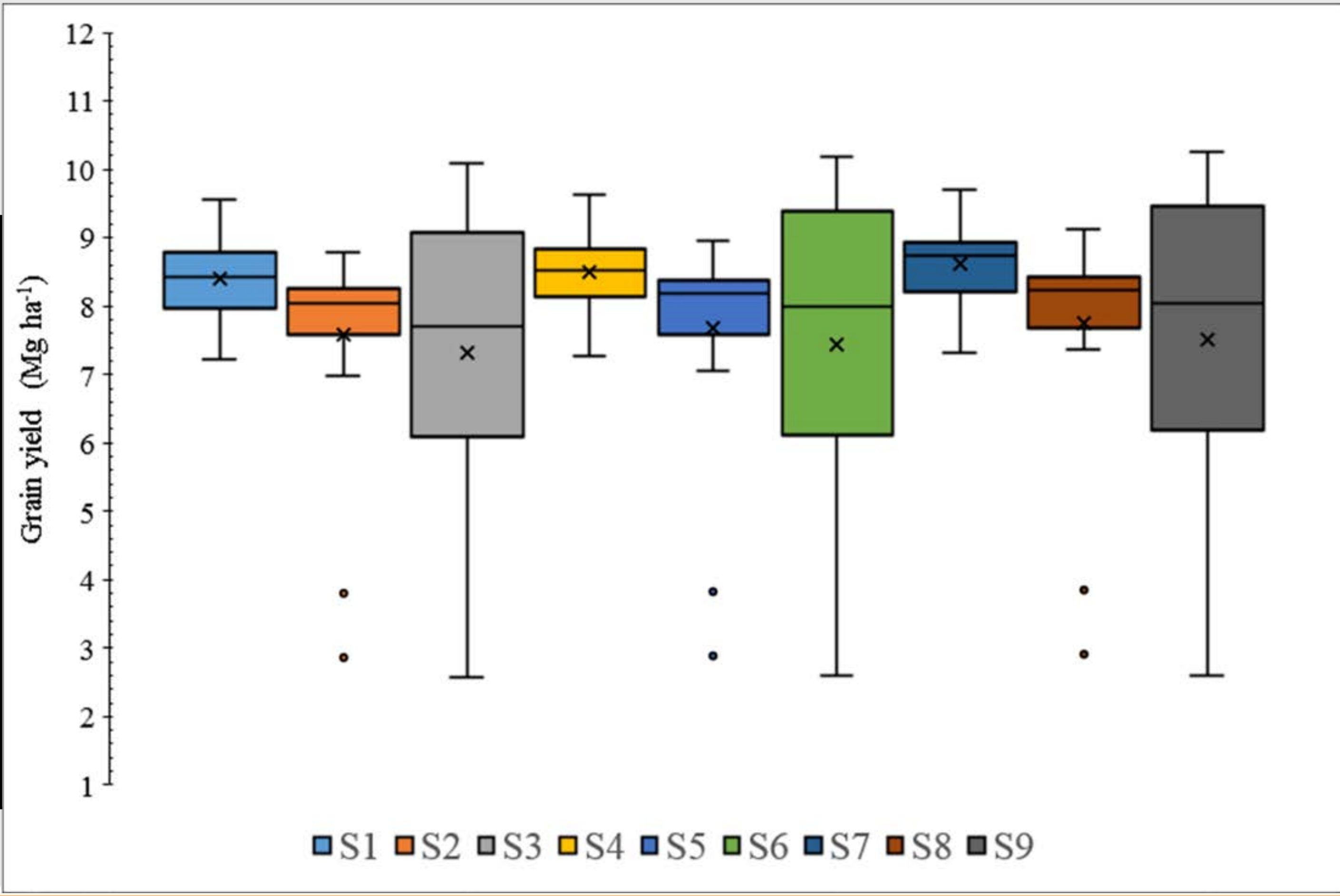
Irrigation Treatment	Grain Yield (Mg ha^{-1}) Measured	Simulated	P_e (%)
1993/Full	8.68	8.41	-3
1993/50%	8.26	8.01	-3
1998/Dryland	4.65	5.09	9
2005/Full 1	7.03	7.85	12
2005/Full 2	7.02	7.88	12
2007/Dryland	5.31	6.19	17
2014/Full	9.66	8.92	-8
2014/75%	9.44	8.91	-6
2014/50%	7.70	8.24	7
2015/Full	10.32	9.31	-10
2015/75%	10.30	9.23	-10
2015/50%	10.29	9.08	-12
2016/Full	8.88	8.80	-1
2016/75%	9.26	9.01	-3
2016/50%	8.51	8.39	-1

RMSE = 0.70 Mg ha^{-1} **NSE = 0.83**

RESULTS: MODEL APPLICATION

- Evaluated the effect of different planting dates and planting densities on yield under no stress conditions.

	Planting Date	Planting Density (seeds/ha)
1	25-May	135,908
2	10-Jun	
3	25-Jun	
4	25-May	160,618
5	10-Jun	
6	25-Jun	
7	25-May	185,329
8	10-Jun	
9	25-Jun	



SUMMARY & 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.

- Overall, the study concluded that AquaCrop model can be used as an important tool for irrigation water management and planning in the Southern & Central High Plains region.

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Thank You!

INPUT PARAMETERS

Parameter	Units	Value
Base temperature	°C	8
Cut-off temperature	°C	30
Canopy cover per seedling at 90% emergence	cm^2	3
Canopy growth coefficient	% day^{-1}	14.5
Canopy decline coefficient	% GDD^{-1}	0.986
Sowing to emergence	GDD	121
Sowing to maximum canopy cover	GDD	921
Maximum canopy cover	%	90
Maximum basal coefficient (Kcb)	Unitless	1.07
Sowing to flowering	GDD	1040
Length of flowering	GDD	305
Sowing to max rooting depth	GDD	1315
Sowing to senescence	GDD	1420
Sowing to maturity	°C	1773
Normalized Crop Water Productivity, WP*	$g\ m^{-2}$	33.7
Canopy expansion function		
P-upper	fraction of TAW	0.15
P-lower	fraction of TAW	0.70
Stomatal closure function		
P-upper	unitless	0.75
Shape	unitless	3
Early canopy senescence function		
P-upper	unitless	0.7
Shape	unitless	3