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in Field Research and Technology Transfer

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CHAPTER 7

An Evaluation of RZWQM, CROPGRO, and CERES-Maize for Responses to Water Stress in the Central Great Plains of the U.S.

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INTRODUCTION

Simulation of crop production is one of the most difficult tasks in agricultural system models because of its dependence on simulations of soil water, soil nutrient, diseases, and weeds. When there is a disagreement between simulated and observed crop production, it can be difficult to identify the source of the problem(s). Discrepancies may be due to:

1. Inaccurate soil water and nutrient simulation
2. Lack of model sensitivity to plant environmental stresses
3. Unrecorded damage from natural disasters, extreme weather events, pests, diseases, and weeds
4. Variability in field measurements
5. Lack of accuracy in model parameters or processes simulation

Based on the understanding of a biological process, data availability, and experimental conditions, there can be more than one modeling approach to describe an experimental phenomenon. One approach may work better than another for certain experimental conditions. Crop modeling has not matured to a point where one model can be used for all combinations of environmental and experimental conditions.

Because plants are a central component of an agricultural production system, all models have plant growth components that are either simple or complex, and either generic or crop specific. For example, the USDA-ARS Root Zone Water Quality Model (RZWQM), which is available through the Water Resources Publications (*www.wrpllc.com*), was developed primarily for water quality applications in the 1990s. It has a generic crop growth component so that management effects on both water quality and crop yield can be simulated. Although this crop growth component does not predict detailed phenology and yield components, it does divide plant growth into seven stages: dormant seeds, germinating seeds, emerged plants, established plants, plants in vegetative growth, plants in reproductive stage, and senescent plants (Hanson, 2000; Hanson et al., 1999). Another unique feature of the generic plant growth model is that it assumes nonuniform plant population development. In other words, not all the plants in a field are at the same growth stage. Another group of agricultural system models is more focused on crop production, such as the CROPGRO and CERES family of models. These models have detailed plant growth processes and simulate each yield component. CROPGRO is for legume crops and CERES is for cereal crops (Boote et al., 1998, Ritchie et al., 1998). The CROPGRO and CERES models are distributed through the DSSAT (Decision Support System for Agrotechnology Transfer) package (*www.icasanet.org/dssat/getdssat.html*).

The objective of this chapter is to compare RZWQM, CERES, and CROPGRO for simulating crop production in the Central Great Plains of the U.S.A. The second objective is to determine how much benefit we gain from added details in crop growth and development components (e.g., CROPGRO and CERES-Maize) or soil water balance components (e.g., RZWQM). Applications of the three models for other aspects of agricultural systems are available from Ma et al. (2000), Ma et al. (2001), Singh et al. (2002), Kiniry et al. (2002), and Tsuji et al. (1998, 2002). CROPGRO has the most detail for simulating biological processes. RZWQM has the most detailed components for simulating soil water, nutrients, pesticides, and management practices (Ahuja et al. 2000). CROPGRO and CERES share the same soil water and nitrogen components (Ritchie, 1998). For the processes considered in all of the three models, methods for simulating the processes differ (e.g., photosynthesis, water uptake, and N uptake). Also, the response of plants to environmental stresses is simulated differently among the models, both in the way of quantifying stresses and in the way the processes are affected by the stresses (Ritchie et al., 1998; Boote et al., 1998; Hanson, 2000).

Data sets for corn and soybean from the USDA-ARS, Central Great Plains Research Station in Akron, CO, were used to evaluate the three models. These data were collected from 1984 to 1986 under different irrigation treatments (e.g., gradient line source, drip, and rain shelter system). Because RZWQM has a generic crop growth component and is parameterized for both corn and soybean, it was compared to CROPGRO for soybean production and CERES-Maize for corn production. All the models were run under an assumed nonlimited nitrogen condition. An evaluation for different N conditions is reported in Ma et al. (2002). The purposes of the evaluations presented in this chapter are to:

1. Compare plant responses to water stress simulated in the three models.
2. Demonstrate the applications of agricultural system models for field research.

EXPERIMENT DESCRIPTION

Maize Experiment Design

Gradient Line-Source Irrigation System

Studies were conducted during the 1984, 1985, and 1986 growing seasons at the USDA Central Great Plains Research Station, 6.4 km east of Akron, CO (40° 9′ N, 103° 9′ W, 1384 m elevation). The soil type is a Rago silt loam (fine smectitic, mesic Pachic Argiustolls). Soil texture was analyzed with the hydrometer method (Gee and Bauder, 1986) (Table 7.1). Although it is called a Rago silt loam, measured soil texture indicates that the soil is closer to a loam than a silt loam. Therefore, when using soil texture to estimate hydraulic properties, we used the measured soil texture (loam) rather than the soil mapped texture.

Corn was planted on May 14, 1984, May 3 1985, and May 1, 1986, with corresponding seeding densities of 72,400; 76,100; and 76,100 seeds/ha. Prior to each planting, the plot area was fertilized with ammonium nitrate at a rate of 168 kg N/ha. Corn (Pioneer Hybrid 3732) was grown under a line-source gradient irrigation system, with full irrigation next to the irrigation line, and linearly declining water application as distance increased away from the line. Details regarding the irrigation system can be found in Nielsen (1997). Four replications of four irrigation levels (only three levels in 1984) existed along the line-source system, with a soil water measurement site and irrigation catch gauge at each of the 16 locations (12 locations in 1984). Irrigations were initiated just prior to tasseling (stage VT, Ritchie et al., 1986) in each year. A total numbers of five irrigation events were run from July 20 to September 2, 1984; 11 from June 29 to August 22, 1985; and 10 from July 21 to August 26, 1986. Total irrigation water applied ranged from 2.3 to 10.6 cm in 1984, 7.1 to 18.9 cm in 1985, and 14.6 to 30.0 cm in 1986 (Table 7.2). Corn was harvested on October 1, 1984; September 27, 1985; and October 15, 1986.

Table 7.1 Measured Soil Texture of the Rago Silt Loam

Soil Depth (cm)	Bulk Density (g/cm^3)	Sand	Silt (%)	Clay	Drainage Limit[a] (cm^3/cm^3)		Saturated Hydraulic Conductivity (cm/hr)	
					Upper	Lower	Soil Texture[b]	Effective Porosity[c]
0–30	1.33	39.0	41.7	19.3	0.224	0.092	1.32	10.67
30–60	1.33	32.3	44.3	23.3	0.236	0.104	1.32	9.32
60–90	1.36	37.0	40.7	22.3	0.230	0.098	1.32	10.04
90–120	1.40	45.7	36.7	17.7	0.221	0.090	1.32	9.80
120–150	1.42	45.7	42.3	12.0	0.215	0.084	1.32	8.75
150–180	1.42	48.0	41.7	10.3	0.212	0.081	1.32	8.20

[a] Calculated from Ritchie et al. (1999), *Trans ASAE* 42:1609–1614, the upper limit was assumed as soil water content at 33 kPa and the lower limit as soil water content at 1500 kPa in RZWQM.
[b] Estimated from Rawls et al. (1982), *Trans ASAE* 25:1316–1320, and used for soybean field.
[c] Estimated from Ahuja et al. (1989), *Soil Sci.* 148:404–411, and used for corn field.

Table 7.2 Irrigation Timing and Amount (cm) for the Line-Source (LS) Gradient Irrigation System in Corn Production from 1984 to 1986

Date	Irrigation Level			Date	Irrigation Level				Date	Irrigation Level			
(1984)	1	2	3	(1985)	1	2	3	4	(1986)	1	2	3	4
7/20	0.61	1.98	3.05	6/29	0.33	0.28	0.36	0.48	7/21	1.19	1.83	2.36	2.79
7/30	0.43	1.22	2.03	7/30	3.40	3.35	5.84	7.62	7/23	1.27	1.96	2.44	2.84
8/20	0.43	1.07	1.68	8/8	0.28	0.46	0.71	0.86	7/25	1.19	1.68	2.34	3.10
8/25	0.25	0.81	1.37	8/9	0.08	0.13	0.18	0.23	7/29	1.22	1.55	1.85	2.08
9/21	0.58	1.73	2.49	8/12	0.79	1.35	2.08	2.54	8/4	1.80	2.26	2.59	2.54
				8/14	0.30	0.53	0.84	1.02	8/6	1.75	2.49	3.02	3.02
				8/15	0.53	0.89	1.40	1.68	8/12	1.17	1.52	1.96	2.26
				8/17	0.28	0.48	0.74	0.91	8/19	1.32	1.88	2.62	3.33
				8/19	0.38	0.64	0.99	1.19	8/20	1.55	1.91	2.79	4.01
				8/20	0.36	0.61	0.97	1.14	8/26	2.18	3.23	3.81	4.04
				8/20	0.38	0.64	0.99	1.19					
Total	2.30	6.81	10.62		7.11	9.38	15.04	18.85		14.64	20.31	25.78	30.00

Soil water content was measured at planting and harvest and at several intermediate dates during the growing season in 1985. These measurements were made at 15, 45, 75, 105, 135, and 165 cm depths below the soil surface with a neutron probe calibrated against soil water samples taken at the time of access tube installation. Crop water use was calculated as the difference between successive soil water measurements plus precipitation and irrigation during the sampling interval. Deep percolation and runoff were assumed to be negligible.

Leaf area measurements were made periodically during the growing season by destructively sampling a 1-m row, separating leaves from the stalks, and measuring the leaf area with a leaf area meter (LI-Cor LI-3100, Lincoln, NE). An automated weather station recorded air temperature, wind run, solar radiation, rainfall, and humidity. Total annual rainfall was 47.2, 45.4, and 33.0 cm for 1984, 1985, and 1986, respectively. Total growing season rainfall (May through September) was 29.9, 31.7, and 20.5 cm for the 3 years.

Drip Irrigation System

This study was conducted only in the 1985 growing season. The plot area was fertilized prior to planting with 184 kg/ha N. Corn was planted similarly to the gradient line-source irrigation area. Corn was planted on May 9, 1985, and the final population was 74,100 plants/ha. Irrigations were applied according to four levels of the Crop Water Stress Index (CWSI) as determined by canopy temperature (Nielsen and Gardner, 1987). Irrigations were applied through drip tubing at a rate of 0.32 cm hr^{-1} when CWSI exceeded levels of 0.1 0.2, 0.4, or 0.6 (where 0.0 = no water stress, 1.0 = maximum water stress) (Table 7.3). Plants were harvested on September 27, 1985.

Soybean Experiment Design

Studies were conducted during the 1985 and 1986 growing seasons at the same station in Akron, CO. Three experiments were conducted to provide a range of available water conditions in which to evaluate water stress effects on soybean productivity. The experiments varied in the method of water application, and will be referred to as the gradient line-source irrigation experiment (LS), the rain shelter experiment (RS), and the drip irrigation experiment (Drip). Details of some cultural practices are given in Table 7.4 and irrigation amounts are shown in Table 7.5. Other details for each experiment are provided below. In all experiments the soybean variety was Pioneer Brand 9291 (late-maturity group II).

Table 7.3 Irrigation Timing and Amount (cm) for the Drip Irrigation Study for Corn Production in 1985

	Irrigation Level			
Date	1	2	3	4
7/9	—	0.48	0.48	0.48
7/10	—	2.26	2.26	2.26
7/13	—	—	—	1.55
7/14	—	—	—	1.12
7/15	—	—	1.30	—
7/16	—	1.30	2.46	1.30
7/25	—	—	0.91	0.91
8/6	—	1.07	1.07	1.07
8/8	1.57	—	1.57	1.57
8/14	—	—	1.60	1.60
8/15	0.94	0.94	—	0.94
8/16	1.47	1.47	—	1.47
8/21	—	—	2.06	2.06
8/27	2.46	2.46	2.46	2.46
8/29	—	—	2.31	2.31
8/30	—	1.19	—	—
Total	6.44	11.13	18.48	20.70

Table 7.4 Cultural Practices for Soybean Experiments

Experiment	Year	Planting Date	Harvest Date	Row Spacing (m)	Plot Dimensions (m)	Population (plants/ha)	Irrigation Method
Solid Set	1985	23 May	03 Oct	0.76	4.1 × 12.2	375,600	Overhead impact sprinklers
Solid Set	1986	20 May	25 Sep	0.76	4.1 × 12.2	262,200	Overhead impact sprinklers
Rain Shelter	1985	28 May	31 Sep	0.53	2.7 × 2.7	331,100	Flood
Rain Shelter	1986	20 May	25 Sep	0.53	2.7 × 2.7	397,600	Flood
Drip	1986	20 May	25 Sep	0.76	4.6 × 9.0	271,100	Drip

Gradient Line-Source Irrigation System

This experiment was conducted as a limited irrigation study, with irrigations applied from June 23 to August 28 in 1985, and from June 26 to August 25 in 1986. Most of the irrigations were applied in the last half of the growing season (flowering and grain-filling). Irrigations were applied with a line-source gradient irrigation system, with full irrigation next to the irrigation line, and linearly declining water application as distance increased away from the line. Details regarding the irrigation system can be found in Nielsen (1997). Four irrigation levels existed along the line-source system. These four levels were replicated twice in 1985 and four times in 1986. A soil water measurement site and irrigation catch gauge was located at the center of each plot. There were seven irrigations in 1985 and nine irrigations in 1986 (Table 7.5).

Rain Shelter and Drip Irrigated Experiments

Details for these experiments are found in Nielsen (1990). Briefly, both experiments had four levels of irrigation determined by four threshold levels of the CWSI, which was computed from

Table 7.5 Irrigation Seasonal Amounts (cm) in the Akron, Colorado Soybean Study in 1985 and 1986

		Irrigation Amount (cm)			
	Irrigation Time	1	2	3	4
Gradient line-source irrigation system (1985)	6/22	0.00	1.64	3.47	4.20
	8/17	0.00	0.61	1.54	3.64
	8/21	0.17	0.60	1.07	1.50
	8/23	0.10	0.05	0.90	1.27
	8/26	0.00	0.06	1.04	1.31
	8/28	0.01	0.42	0.85	1.00
	Total	0.28	3.38	8.86	12.92
Gradient line-source irrigation system (1986)	6/25	0.07	0.83	2.56	3.33
	6/27	0.07	0.83	2.56	3.33
	7/01	0.08	0.83	2.56	3.34
	7/30	0.23	0.77	1.71	2.41
	8/07	0.06	0.56	1.16	1.85
	8/11	0.04	0.35	0.71	1.13
	8/15	0.08	0.77	1.74	3.05
	8/21	0.45	1.15	2.07	3.30
	8/25	0.45	1.13	2.04	3.25
	Total	1.55	7.22	17.11	24.98
Rain shelter irrigation system (1985)	5/29	5.08	5.08	5.08	5.08
	6/24	1.69	3.39	5.08	1.69
	6/25	3.39	1.69	0.00	3.39
	7/10	5.08	5.08	5.08	5.08
	7/24	0.00	0.00	2.54	5.08
	7/30	2.54	2.54	2.54	5.08
	8/06	1.69	1.69	2.54	0.85
	8/08	0.00	0.85	0.00	1.69
	8/09	3.39	2.54	4.23	3.39
	8/12	0.85	0.85	0.85	0.85
	8/14	0.00	0.00	0.85	0.00
	8/15	1.69	1.69	0.85	2.54
	8/16	0.00	0.00	0.85	0.00
	8/20	1.69	1.69	1.69	2.54
	8/21	0.00	0.85	0.00	0.85
	8/23	2.54	1.69	3.39	1.69
	8/26	0.00	0.85	0.85	0.85
	8/27	0.00	0.85	0.00	0.85
	8/28	0.85	0.00	0.85	0.00
	8/29	1.69	0.85	0.00	0.00
	8/30	0.00	0.00	2.54	5.08
	9/05	2.54	2.54	1.69	2.54
	9/06	0.00	0.00	0.85	0.85
	Total	34.71	34.71	42.33	49.95
Rain shelter irrigation system	6/19	5.08	5.08	5.08	5.08
	7/02	5.08	5.08	5.08	5.08
	7/11	5.08	5.08	5.08	5.08
	7/15	0.00	0.00	5.08	5.08
	7/18	5.08	5.08	0.00	0.00
	7/23	0.00	0.00	5.08	5.08
	7/25	5.08	5.08	0.00	0.00
	7/29	0.00	0.00	5.08	5.08
	8/01	5.08	5.08	0.00	0.00
	8/04	0.00	0.00	0.00	5.08
	8/06	0.00	0.00	5.08	0.00
	8/11	5.08	5.08	0.00	5.08

Table 7.5 (continued) Irrigation Seasonal Amounts (cm) in the Akron, Colorado Soybean Study in 1985 and 1986

		Irrigation Amount (cm)			
	Irrigation Time	**1**	**2**	**3**	**4**
	8/14	0.00	0.00	5.08	5.08
	8/21	5.08	5.08	0.00	0.00
	8/25	0.00	0.00	5.08	0.00
	8/27	0.00	0.00	0.00	5.08
	8/28	5.08	5.08	0.00	0.00
	9/03	0.00	0.00	5.08	5.08
	9/04	0.00	5.08	0.00	0.00
	Total	45.72	50.8	50.8	55.88
Drip irrigation system (1986)	7/18	0.00	0.00	0.00	1.32
	7/21	0.00	0.00	0.00	1.17
	7/23	2.26	2.26	2.26	2.26
	7/25	0.00	3.33	3.32	0.00
	7/30	0.00	0.00	0.00	2.90
	8/01	1.96	1.96	1.96	0.00
	8/08	2.64	0.00	2.64	2.64
	8/12	0.00	4.65	0.00	0.00
	8/18	2.62	0.00	2.62	2.62
	8/26	2.54	2.54	2.54	2.54
	9/04	0.00	2.69	2.69	2.69
	9/05	2.51	0.00	0.00	0.00
	Total	14.52	17.42	18.02	18.13

Table 7.6 Calibrated Plant Model Parameter Values of RZWQM for Corn and Soybean. (Parameters with asterisk are suggested calibration parameters by the model developers.)

Parameter Name	Corn	Soybean
Minimum leaf stomatal resistance (s/m)[a]	100	100
Proportion of photosynthate lost to respiration (dimensionless)[a]	0.28	0.17
Photosynthesis rate at reproductive stage compared with vegetative stage[a]	61	69
Photosynthesis rate at seeding stage compared with vegetative stage[a]	61	69
Coefficient to convert leaf biomass to leaf area index, CONVLA (g/LAI)[a]	15.5	1.9
Plant population on which CONVLA is based (plants/ha)[a]	68,992	370,137
Maximum rooting depth (cm)[a]	300	300
Maximum plant height (cm)	210	70
Aboveground biomass at ½ maximum height (gm)	60	4
Aboveground biomass of a mature plant (gm)	152	13
Minimum time needed from planting to germination (days)	5	3
Minimum time needed from planting to emergence (days)	20	7
Minimum time needed from planting to 4-leaf stage (days)	35	22
Minimum time needed from planting to end of vegetative growth (days)	75	62
Minimum time needed from planting to physiological maturity (days)	115	92
Growth stage advanced from planting to germination (dimensionless)	0.0356	0.0356
Growth stage advanced from planting to emergence (dimensionless)	0.065	0.065
Growth stage advanced from planting to 4-leaf stage (dimensionless)	0.20	0.20
Growth stage advanced from planting to end of vegetative growth (dimensionless)	0.75	0.75
Growth stage advanced from planting to physiological maturity (dimensionless)	0.90	0.90

[a] Model developers' suggested calibration parameter.

crop canopy temperatures measured daily with an infrared thermometer. In both experiments, the irrigation treatments were laid out in a randomized complete block, with three replications in the rain shelter and five replications in the drip irrigated experiment. Irrigations were flood-applied in the rain shelter. In the drip-irrigated plots, irrigations were applied through drip irrigation tubing laid on the surface of every other interrow space. Timing and amount of each irrigation event are shown in Table 7.5.

Data Needed for the Three Models

RZWQM

RZWQM requires daily weather data for minimum and maximum daily temperature, wind run, solar radiation, relative humidity, and rainfall. These data were available from an on-site weather station. Soil texture and bulk density were determined from soil samples taken in the field (Table 7.1). The model requires a minimum input of soil water content at 33 kPa suction, which is estimated from Ritchie et al. (1999) by assuming that it is the drained upper limit. Saturated soil hydraulic conductivity was calculated from effective porosity (Ahuja et al., 1989) for the corn fields or soil texture mean values (Rawls et al., 1982; 1998) for the soybean fields. RZWQM uses the Brooks–Corey equations to describe the soil water retention curve, and the required parameters were estimated from soil texture classes (Rawls et al., 1982) and scaling with respect to bulk density and 33 kPa water content (Ahuja et al., 2000). Corn growth parameters were based on Farahani et al. (1999), with slight modification (Ma et al. 2002). Soybean parameters were based on model testing in Ohio (Landa et al., 1999), Missouri (Ghidey et al., 1999), and Iowa (Jaynes and Miller, 1999). Initial soil water content in the profile was assumed to be at field capacity, and the models were run from January 1 to December 31 every year.

CERES-Maize and CROPGRO-Soybean

Researchers used the versions included in the Decision Support System for Agrotechnology Transfer (DSSAT) family models (version 3.5) (Hoogenboom et al., 1999; Tsuji et al., 1994). CERES-Maize and CROPGRO-Soybean use the same soil water balance component, which requires weather data of minimum and maximum daily temperature, solar radiation, and rainfall. Measured soil texture and bulk density were used (Table 7.1). Drained upper and lower limits were calculated as suggested by Ritchie et al. (1999). Required corn and soybean growth parameters were calibrated as suggested in the DSSAT manual (Boote, 1999, Hoogenboom et al., 1994). Initial soil water content in the profile was assumed to be at field capacity and the models were run from January 1 to December 31 every year.

APPLICATIONS OF RZWQM AND CERES-MAIZE FOR CORN

Calibration of RZWQM and CERES-Maize

Calibration of RZWQM for Corn

Calibration of RZWQM followed the methods suggested by Hanson et al. (1999) and Rojas et al. (2000). Data from the 1985 line-source irrigation system were used for calibration because of its frequent soil water measurements. As suggested by Boote (1999), the authors selected data from the highest irrigation level (or least stress) as the calibration dataset (level 4 in Table 7.2), although all irrigation levels were not irrigated for full crop water use. In addition, they assumed that corn was not under N stress. Goodness-of-fit for the model calibration was based on a comparison of measured and simulated soil water content, estimated evapotranspiration (ET), leaf area index (LAI), plant height, plant biomass, and harvest grain yield. Root mean square errors (RMSE) were also calculated as an indication for model accuracy.

Table 7.1 lists the measured soil texture, bulk density, and estimated 33 kPa soil water contents from Ritchie et al. (1999). Estimated 33-kPa soil water contents were very close to the 33 kPa value of 0.233 cm^3 cm^{-3} given by Rawls et al. (1982) for a loam soil. In addition, the RMSE indicated that soil water contents were better predicted with saturated soil hydraulic conductivity estimated from effective porosity (Ahuja et al., 1989). Plant growth parameters were calibrated from previous work in Colorado (Farahani et al. 1999), and calibrated values are listed in Table 7.6. Minimum leaf stomatal resistance was set from 250 s/m to 100 s/m based on literature reports (Fiscus et al., 1991, Bennett et al., 1987). Aboveground biomass for a mature plant changed from 70 to 152 g, based on experimental measurements. Maximum rooting depth extended from 180 cm to 300 cm to accelerate root growth without changing other model parameters. Maximum plant heights were 210 cm instead of the 250 cm as calibrated by Farahani et al. (1999). Minimum days from planting to physical maturity was set to 115 in the model under optimal growth conditions, which was reasonable compared to observed actual life spans of 127 to 158 days under semiarid Colorado conditions.

Predicted soil water content and soil water storage are shown in Figure 7.1 with RMSE of 0.023 cm^3 cm^{-3} and 2.82 cm, respectively. In general, RZWQM over predicted soil water contents, but, as shown in Ma et al. (2002), soil water contents were more accurately predicted if the calibrated 33 kPa soil water contents were used. Predicted ET from June 13 to September 25, 1985 was 51.4 cm, which is very close to the estimated ET of 50.6 cm, based on soil moisture contents (changes in soil water storage + rainfall + irrigation water). The model simulated a 0.7 cm of surface runoff and a 0.4-cm deep percolation in 1985.

LAI was adequately simulated whereas plant height was underpredicted in the early growth stage and aboveground biomass was overpredicted in later growth stage (Figure 7.2). Simulated corn grain yield was 9813 kg/ha, which was similar to measured yield of 9854 kg/ha. At the observed silking date of July 26, 1985, when reproductive growth was initiated, RZWQM also simulated 20% of the plant population in the field entering reproductive growth. During model calibration, we put more weight on ET, LAI, and grain yield. We tolerated small errors in plant height and biomass simulations as long as they were within reasonable ranges of measured values. In addition, we tried to use as many default values as possible and used the same values in both RZWQM and CERES-Maize models without in-depth calibration so that bias on model calibration was minimized. Alternatively, we could have calibrated the 33 kPa soil water contents in both models, but we would end up with different calibrated 33 kPa soil water contents in the two models for the same soil.

Calibration of CERES-Maize for Corn

CERES-Maize was calibrated using the same irrigation treatment (line-source, irrigation level 4 in Table 7.2) in 1985 as RZWQM. The same soil hydraulic properties were used in the CERES-Maize model. CERES-Maize requires the drained upper and lower limits (Table 7.1). The model produced the same results with saturated hydraulic conductivity estimated from either Ahuja et al. (1989) or Rawls et al. (1982). Figure 7.3 shows simulated soil water storage and soil moisture contents. Simulated soil water contents are more scattered compared to that of RZWQM with RMSE of 0.036 cm^3 cm^{-3}; however, RMSE for CERES-Maize simulated water storage was 2.39 cm, which was better than that from RZWQM. Simulated ET from June 13 to September 25, 1985 was 48.0 cm, which is slightly lower than the observed 50.6 cm. CERES-Maize also simulated a 3.1 cm runoff and 2.0-cm deep percolation of water in 1985, which were higher than we would expect under the semiarid Colorado conditions with minimum irrigation, but neither were measured in the field plots.

Six cultivar-related parameters can be defined by the model user and the values used for this experiment are listed in Table 7.7. Species-specific parameters were not calibrated as suggested by the model developers. As shown in Figure 7.4, CERES-Maize provided reasonable simulations of

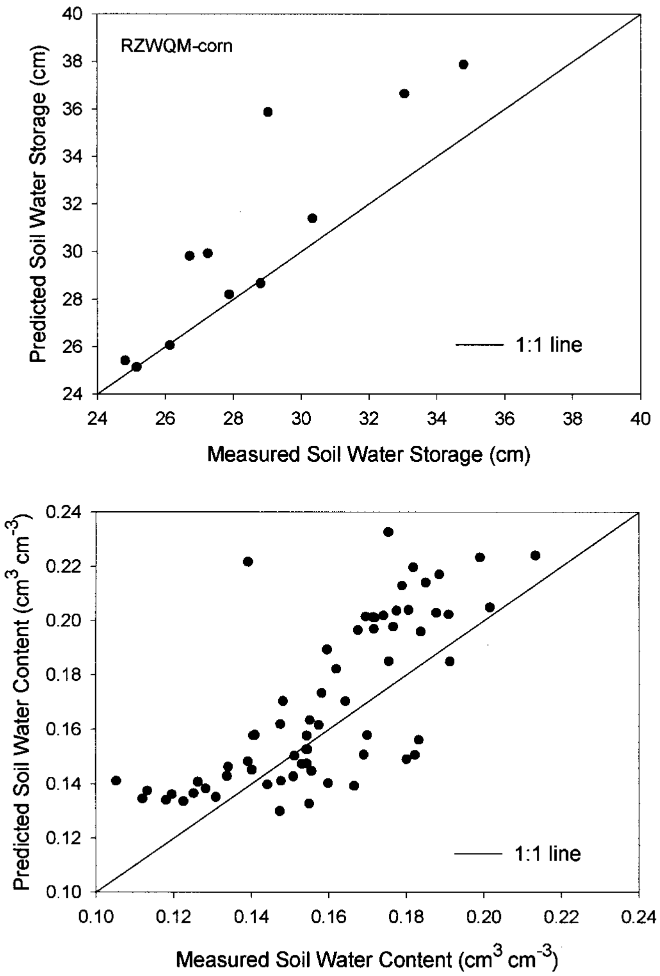

Figure 7.1 Predicted soil water storage and soil water contents with RZWQM-corn for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

LAI and aboveground biomass, with a slight overprediction of biomass at later growth stages. Plant height was not simulated in CERES. Leaf number was overpredicted, although the phylochron interval (PHINT) was increased from 38.9 to 50. Growth stages were adequately simulated (Figure 7.5). Simulated corn yield was 9882 kg/ha compared to observed yield of 9854 kg/ha.

Evaluation of RZWQM and CERES-Maize

After calibration, both models were used to predict corn production for other field experiments, including the irrigation levels in 1985 that differed from the dataset used for calibration, irrigation studies in 1984 and 1986 under line source irrigation system, and drip irrigation in 1985. Because RZWQM does not simulate leaf number and CERES-Maize does not simulate plant height, both models are only used to evaluate field results in terms of common simulated variables, such as yield, biomass, LAI, phenology, and ET. CERES-Maize correctly predicted corn growth stage in 1984 except for a slight delay of stages 3, 5, and 6 (Figure 7.5). RZWQM predicted a 15% plant population entering the reproductive growth stage at the observed silking date of August 6, 1984. No phenology data were available for 1986. ET data were only available for 1985. Both models showed the capability to accurately predict ET (Figure 7.6), although ET for CERES-Maize did

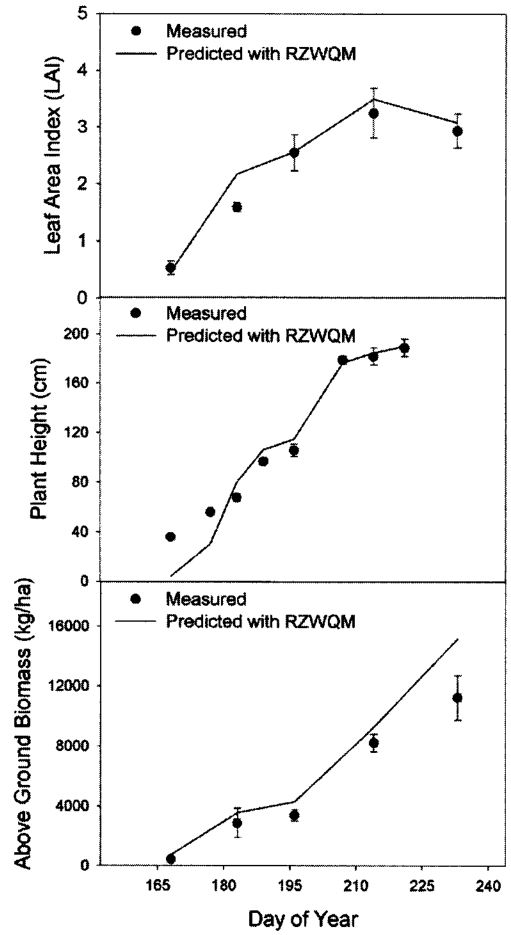

Figure 7.2 Simulated leaf area index (LAI), plant height, and biomass with RZWQM-corn for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

not respond well to the irrigation water levels. For the 1985 gradient line-source irrigation system where soil water measurements were available, RZWQM simulations of soil water content were more accurate (Figure 7.7) than CERES-Maize simulations, based on RMSE.

RZWQM predicted the yield responses to irrigation water better than CERES-Maize, especially for the year of 1985 (Figure 7.8). Although RZWQM underestimated corn yield for the 1985 drip irrigation and 1986 line source irrigation experiments, the model correctly predicted relative increases in yield with irrigation water. CERES-Maize overpredicted corn yield in all years and did not respond to irrigation water treatments. It is interesting to note that when we calibrate CERES-Maize model using the lowest irrigation level in 1985 (level 1), the plotted data points will shift to the right with almost the same scattering pattern as shown in Figure 7.8, the 1:1 line will go through the middle of the scattered data points, and no obvious bias will be observed. RMSE of simulated yields was 1381 kg/ha for RZWQM and 3609 kg/ha for CERES-Maize (Figure 7.8).

Both models provided good predictions of LAI for 1985 with comparable RMSE of 0.3 for RZWQM and 0.32 for CERES-Maize (Figure 7.9); however, both models overpredicted LAI for the 1984 growing season, with slightly better prediction from CERES-Maize model. Similarly, aboveground biomass was better predicted for the various irrigation levels in 1985 by both models than in 1984 (Figure 7.10). RMSE of simulated biomass for RZWQM was lower than that of CERES-Maize for the 1984 growing season.

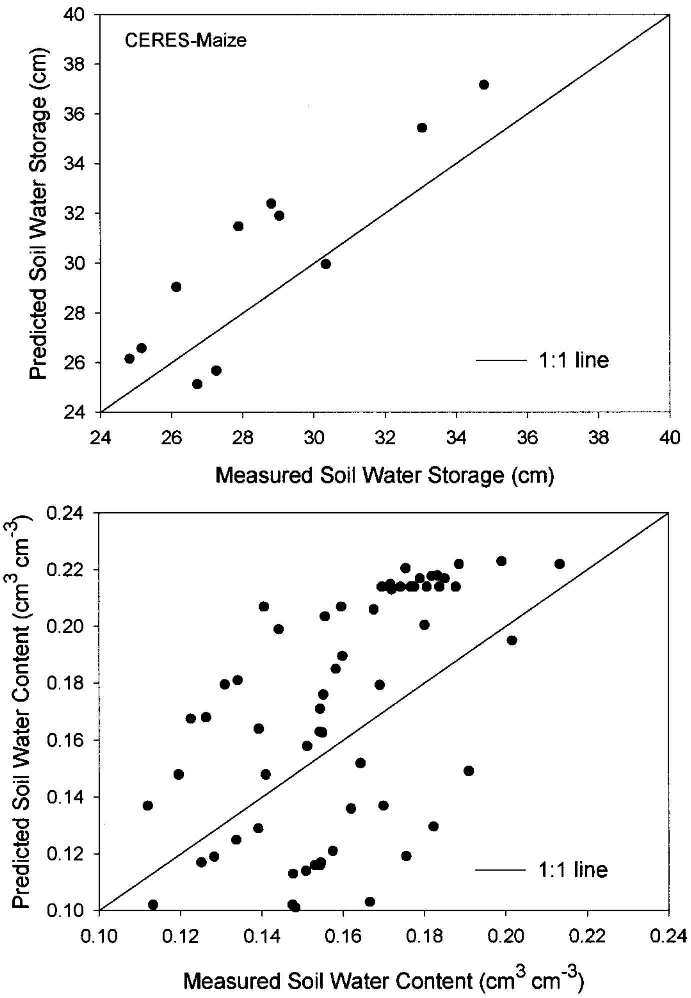

Figure 7.3 Predicted soil water storage and soil water contents with CERES-Maize for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

Table 7.7 Cultivar-Specific Parameters Used in the CERES-Maize Model and Their Calibrated Values

Symbol	Description	Calibrated Values
P1	Thermal time from seedling emergence to the end of the juvenile phase during which the plant is not responsive to changes in photoperiod (thermal days above 8°C)	245
P2	Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (days)	0.8
P5	Thermal time from silking to physiological maturity (thermal days above 8°C)	680
G2	Maximum possible number of kernels per plant	860
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day)	9.5
PHINT	Phylochron interval between successive leaf tip appearances (thermal days)	50

To evaluate how both RZWQM and CERES-Maize simulated soil water stress, the measured CWSI for the drip irrigation system from canopy temperature (Nielsen and Gardner, 1987) was compared with the water stress factor calculated by the models. RZWQM predicts a water stress factor of (1-EWP), where EWP is the ratio of actual transpiration to potential transpiration (Hanson,

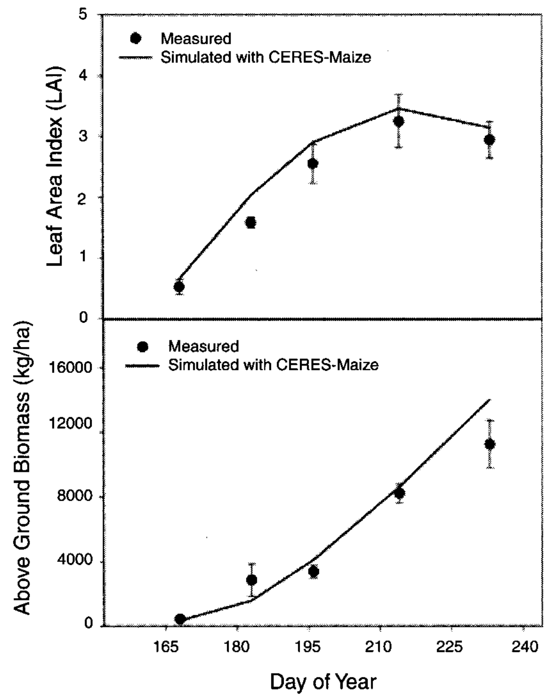

Figure 7.4 Simulated leaf area index (LAI) and biomass with CERES-Maize for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

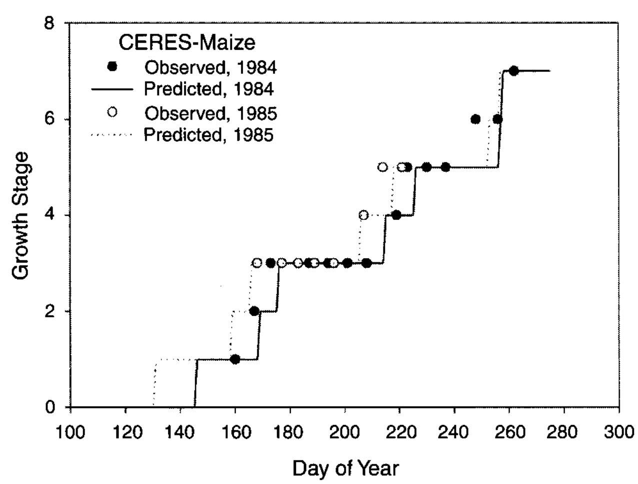

Figure 7.5 Simulated growth stage with CERES-Maize for 1984 and 1985 growing season under the gradient line-source irrigation system.

2000), and the water stress factor in CERES-Maize is calculated as (1-SWDF1), where SWDF1 is the ratio of potential uptake to potential transpiration (Ritchie, 1998). As shown in Figures 7.11 and 7.12, simulated water stress levels decreased with the amount of irrigation water applied in both models, although simulated water stress was better correlated to CWSI in RZWQM than in

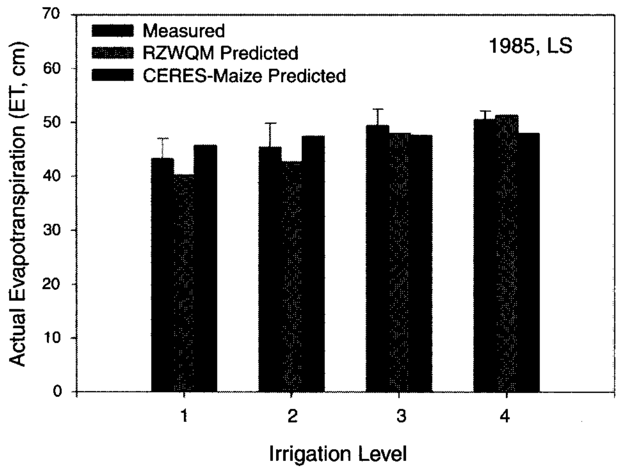

Figure 7.6 Simulated evapotranspiration (ET) (June 13 to September 25) with RZWQM-corn and CERES-Maize during 1985 growing season under the gradient line-source irrigation system (LS). See Table 7.2 for irrigation treatments.

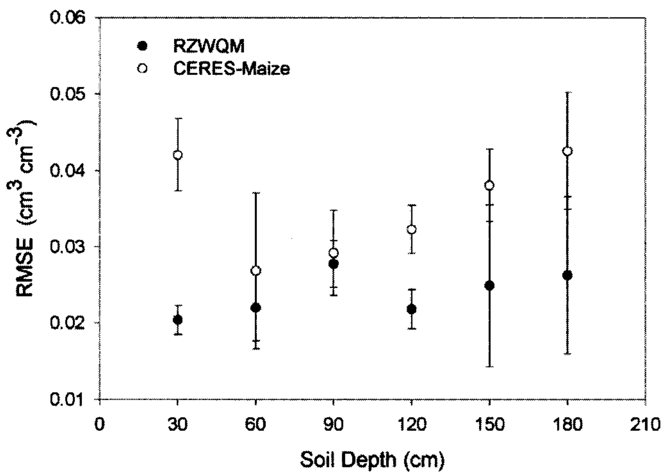

Figure 7.7 Root mean square errors (RMSE) of predicted soil water contents in various layers of the soil profile for the 1985 gradient line-source irrigation system of corn production. RMSE was averaged across treatments for each year and each irrigation system. The bars are one standard error around the means. RMSE of each soil layer is plotted at the lower soil boundary of the soil layer.

CERES-Maize. RZWQM simulated little stress from July 13 to August 11, 1985 where CWSI indicated considerable stresses. CERES-Maize did not predict water stresses from July 16 to September 12, 1985. Thus, for this application, RZWQM simulated water stresses better than CERES-Maize, which explains the better yield prediction by RZWQM.

APPLICATIONS OF RZWQM AND CROPGRO FOR SOYBEAN

Calibration of RZWQM and CROPGRO-Soybean

Calibration of RZWQM for Soybean

Researchers also used the highest irrigation levels (level 4 in Table 7.5) of the 1985 gradient line source irrigation system to calibrate the RZWQM and CROPGRO models for soybean. Soil texture

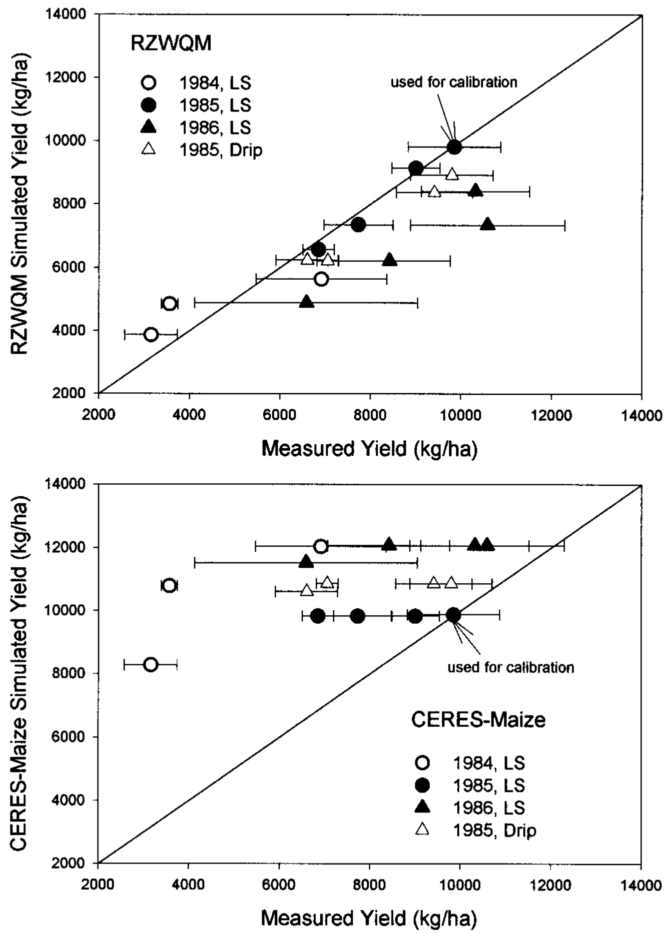

Figure 7.8 Predicted corn grain yields with RZWQM-corn and CERES-Maize. LS: line source irrigation system; Drip: drip irrigation system.

and 33 kPa soil water contents in Table 7.1 were used and soil hydraulic properties were based on soil texture class (Rawls et al. 1982). Although both corn and soybean fields were classified as Rago silt loam, different saturated soil hydraulic conductivities for corn and soybean were used because saturated hydraulic conductivity varies spatially in the field and depends on management practices (Benjamin, 1993; Lal, 1999; Rodriguez et al., 1999, van Es et al., 1999). In addition, another similar soil series named Weld (fine smectitic, mesic Aridic Argiustolls) was mixed with Rago in some fields. The Weld series has a clay loam layer at 15 to 30 cm soil depth. Therefore, both corn and soybean in RZWQM used the same soil properties except that a lower saturated hydraulic conductivity was used for soybean field, which provided better soil water content simulations.

Figure 7.13 shows simulated soil water storage and soil water contents for the calibrated data set. In general, the model simulated good soil water storage and no biased soil water content with RMSEs of 1.28 cm and 0.027 cm^3/cm^3, respectively. RZWQM adequately simulated ET from July 10 to September 9, 1985, at 37.4 cm versus 39.0 cm estimated from the soil water balance (Figure 7.14); however, better agreement between the simulated (40.1 cm) and estimated ET (40.5 cm) was obtained from July 10 to September 25, 1985. Therefore, goodness of model simulations also depends on the accuracy of estimated ET that has directly inherited errors from the measured soil water contents. RZWQM also simulated 2.0 cm of runoff and 0.7 cm of deep seepage in 1985, which were assumed to be zero when estimating ET from the soil water balance;

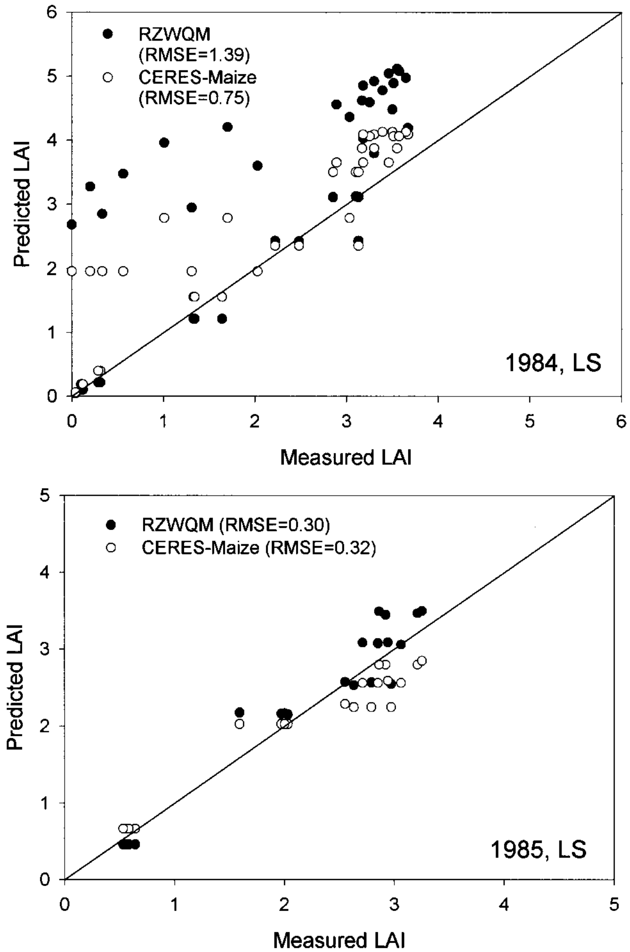

Figure 7.9 Predicted leaf area index with RZWQM-corn and CERES-Maize for 1984 and 1985 growing season under the gradient line-source irrigation system.

however, surface runoff would be considerably reduced if a higher saturated hydraulic conductivity were used (Ahuja et al. 1989). Therefore, depending on which criterion was selected for model calibration, a different saturated soil hydraulic conductivity might be used for soybean simulation in this study. In addition, it may not be valid to use a constant soil hydraulic conductivity for all the years and for all management practices because of its dependency on soil dynamics (van Es et al. 1999).

Calibrated plant parameters were based on parameters derived from RZWQM applications for soybean in the midwest of the U.S. (Table 7.6) (Hanson et al., 1999; Landa et al., 1999; Ghidey et al., 1999; Jaynes and Miller, 1999). For this experiment, the minimum leaf stomatal resistance was modified to a value of 100 s/m, based on the study of Nielsen (1990), and aboveground biomass of a mature plant was set at 13 g, based on experimental measurements. The rest of the parameters in Table 7.6 were either default or calibrated values. Although plant phenology is not the focus of RZWQM, the model also showed that 84% of plants reached maturity on September 16, 1985 at the field observed date for the R8 stage; however, the model simulated the initial reproductive growth on July 30, 1985, which was delayed according to the observed R1 stage date of July 19, 1985. The delay may have been a result of the indeterminate variety used in this study, where there was no definite flowering period. The model overpredicted LAI in the later development phases

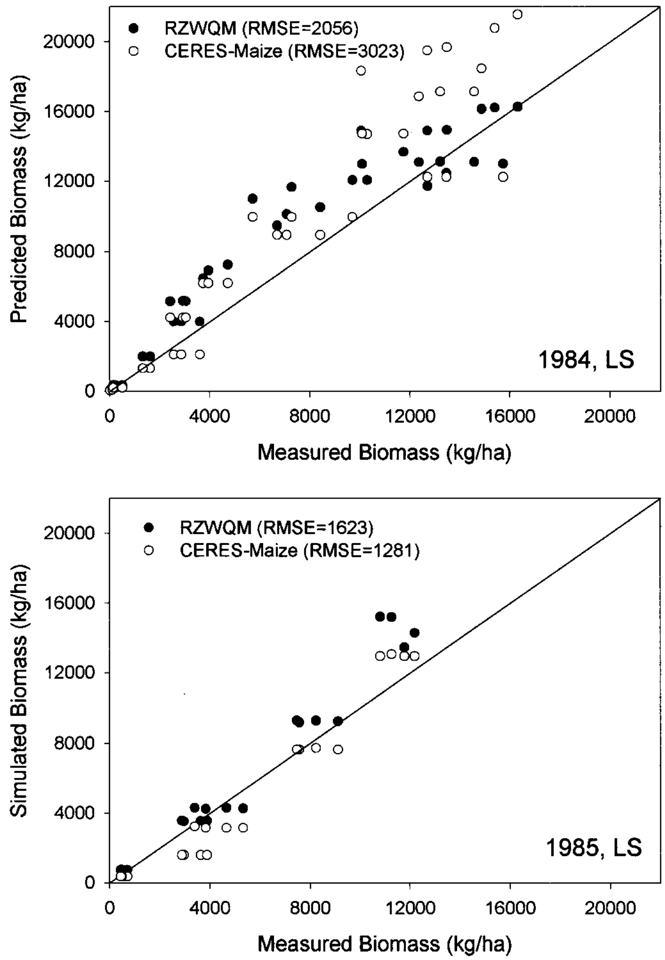

Figure 7.10 Predicted biomass with RZWQM-corn and CERES-Maize for 1984 and 1985 growing seasons under the gradient line-source irrigation system.

and plant height during the middle of the growing season (Figure 7.15). RZWQM also underpredicted plant height during the early growth phases. Aboveground biomass was adequately simulated, however. Simulated grain yield was 2686 kg/ha compared to a measured yield of 2678 kg/ha (Figure 7.16).

Calibration of CROPGRO-Soybean

The wettest treatment in 1985 line-source irrigation system was used to calibrate CROPGRO-Soybean. The soil properties shown in Table 7.1 were used without modification. Generally the model underpredicted soil water contents (Figure 7.17), which cannot be improved except by changing the upper and lower drained limits. The model provided the same results using saturated hydraulic conductivities from either method in Table 7.1. Experimentally, we observed more soil water storage in the soil profile during the soybean growing season than during the maize season (Figures 7.1, 7.3, 7.13, and 7.17). CROPGRO-Soybean simulated an ET of 31.1 cm from July 10 to September 9, 1985, which is lower than the estimated ET of 39.0 cm. The model also simulated 3.2 cm of surface runoff and 3.0 cm deep percolation. RMSEs for simulated soil water storage was 5.5 cm and for soil water contents was 0.038 cm^3/cm^3.

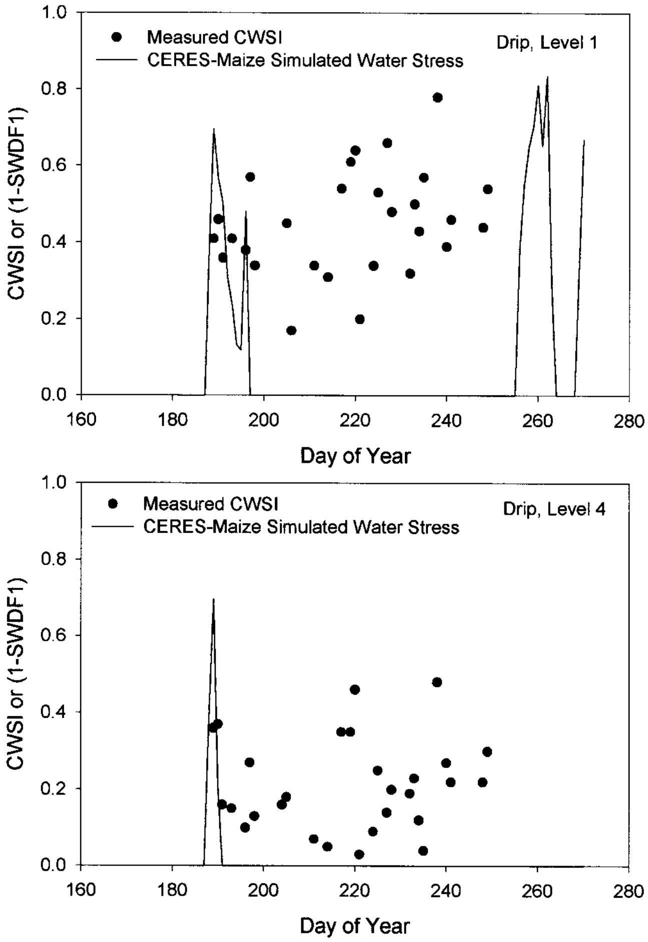

Figure 7.12 Measured crop water stress index (CWSI) and simulated water stress in CERES-Maize (1-SWDF1) for corn under the drip irrigation system in 1985. SWDF1 is the ratio of potential uptake to potential transpiration.

ulated ET responded correctly to irrigation water amounts. CROPGRO showed the most accurate simulation of ET for the drip irrigation system (Figure 7.14), although CROPGRO-simulated ET did not respond to amount of irrigation for the rain shelter irrigation system. Overall RMSEs of simulated ET among all the treatments and years were comparable, 7.3 cm for CROPGRO and 7.8 for RZWQM.

RZWQM simulated more accurate soil water contents for the 0 to 30, 30 to 60, and 60 to 90 cm soil profile for the 1985 and 1986 line-source irrigation system than CROPGRO (Figure 7.19); however, CROPGRO predicted equal or better soil water contents beyond the 90 cm soil profile except for the 120 to 150 cm layer in 1985. For the rain shelter system, CROPGRO also provided better predictions of soil water contents in soil profiles below 90 cm. RZWQM simulated more accurate soil water contents for the 30 to 60 cm soil layer. Goodness of model prediction for the 0 to 30 and 60 to 90 cm soil layers depended on the year of study. RZWQM simulated better soil water contents in 1986, whereas CROPGRO predicted better soil water contents in 1985. Overall, the differences between the two models were insignificant for the rain shelter system. For the drip system, RZWQM was better for the 0 to 30 and 30 to 60 cm soil layers, whereas CROPGRO was insignificantly better beyond 60 cm soil depth. Both models predicted soil water contents better for the rain shelter irrigation system than for the other two irrigation systems in terms of RMSE (Figure 7.19).

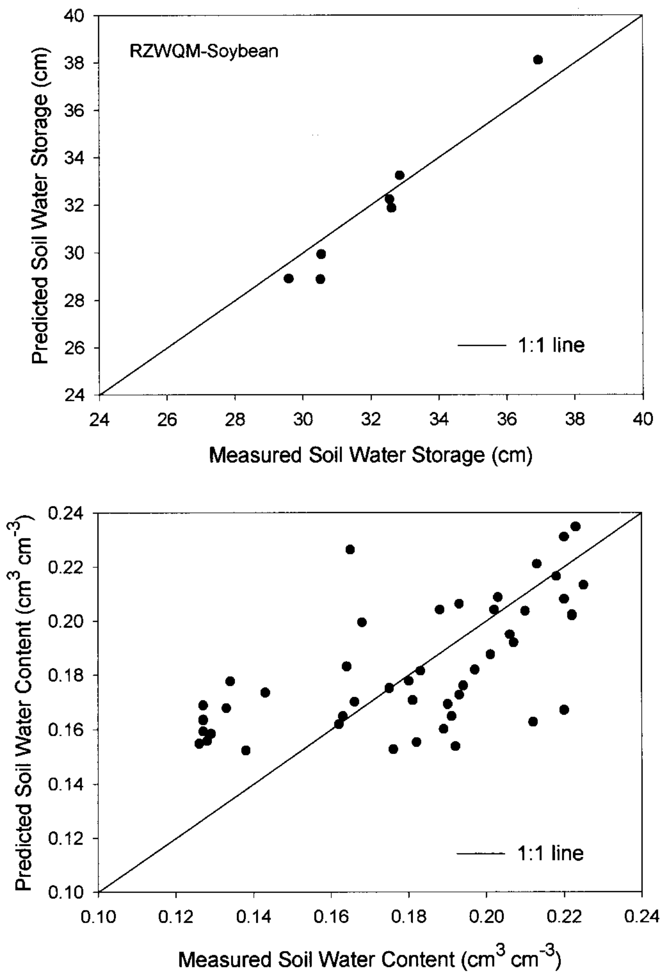

Figure 7.13 Predicted soil water storage and soil water contents with RZWQM-soybean for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

RZWQM accurately predicted good yields for all the treatments except for the 1986 drip system. CROPGRO, on the other hand, predicted yields most accurately for the 1986 drip system (Figure 7.16). RZWQM responded to irrigation water better under the rain shelter system than CROPGRO. RMSEs of simulated yields were 295 kg/ha for CROPGRO and 432 kg/ha for RZWQM. Both models adequately predicted plant canopy height for 1985, but underpredicted canopy height for 1986. Maximum canopy height was overpredicted by 30 to 100% by both models, suggesting that the models failed to account for drought effects on plant height in 1986 after model calibration in a relatively wet year of 1985.

Simulated water stresses were compared with the CWSI values as determined by Nielsen (1990). For the drip irrigation system, both RZWQM and CROPGRO simulated water stresses that responded to irrigation amount (Figures 7.20 and 7.21). RZWQM-simulated water stress matched the measured CWSI well, except for the early part of the growing season. CROPGRO simulated greater water stress than CWSI during the early growing season but less water stress in later growing season. Both models failed to simulate water stress for the rain shelter system. CROPGRO did not predict any water stress under all irrigation amounts in both 1985 and 1986, which may be responsible for the lack of response in simulated ET and yields (Figures 7.14 and 7.16). RZWQM

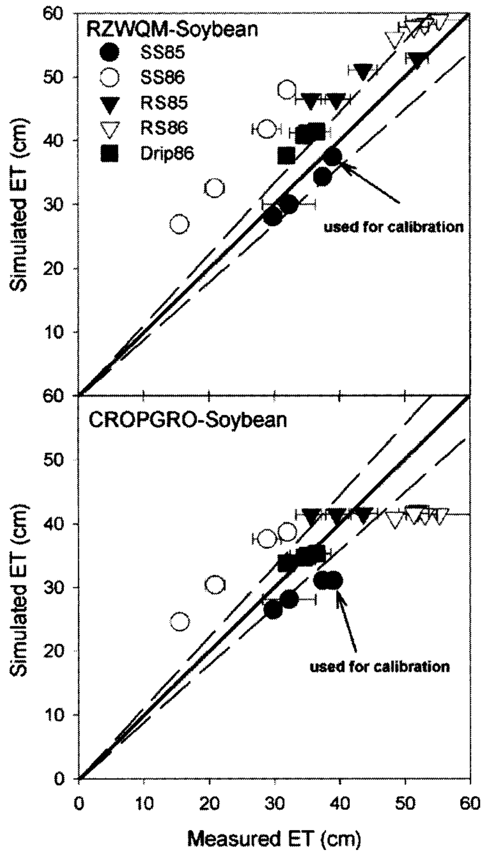

Figure 7.14 Predicted evapotranspiratioin (ET) with RZWQM-soybean and CROPGRO-Soybean (dates). LS: line-source irrigation system; RS: rain shelter irrigation system; and Drip: drip irrigation system. ET was from July 10 to September 9 for 1985 LS; from June 20 to September 10 for 1986 LS; from May 20 to September 16 for 1985 RS; from June 6 to September 12 for 1986 RO; and from June 24 to September 12 for the 1986 Drip.

simulated some water stress later during the growing season but failed to predict water stress for the early growth phase (data not shown). The simulation of stress effects in RZWQM was attributed to its better ET and yield simulations in Figures 7.14 and 7.16.

SUMMARY AND DISCUSSION

An agricultural system model is generally derived from knowledge gained in different disciplines of science and is designed to integrate the interactions among agricultural processes that have been studied individually in different scientific disciplines. Due to limited understanding and diversified theories on these processes, an agricultural system model can be developed quite differently by individual model developers. For the three models tested here, RZWQM was originally developed as a water quality model, and the generic plant growth component was used to predict biomass and yield production and interaction between plants and soils. Predictions of phenology and yield components were not the original goal of the RZWQM. On the other hand, the CERES-Maize and CROPGRO-Soybean models were developed specifically to simulate corn and soybean production, including phenology, biomass, and yield components. The soil water component was simply a medium for the plant to extract water and nutrients.

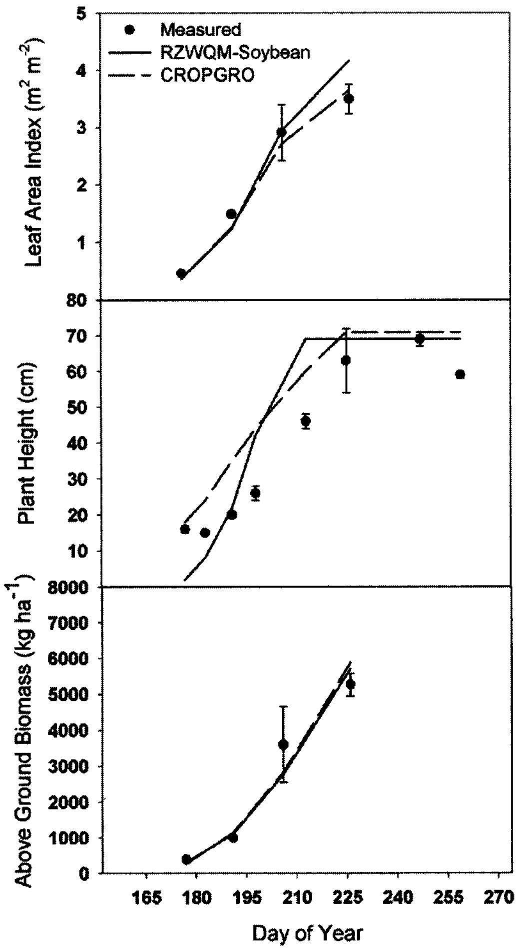

Figure 7.15 Simulated leaf area index (LAI), plant height, and biomass with RZWQM-soybean and CROPGRO for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

The CERES-Maize and CROPGRO-Soybean models were easy to use because of their simple soil water balance components and only a few cultivar-specific plant parameters required calibration (Tables 7.7 and 7.8; also see Ahuja and Ma, 2002). These few soil and plant parameters generally were able to provide good calibration of phenology, biomass, LAI, and yield. In addition, both models included a database with plant parameters categorized by cultivars (Hoogenboom et al. 1994). RZWQM, on the other hand, required more detailed soil hydraulic parameters, which may be obtained from soil texture based default values. In many cases, these default values provided reasonable soil water prediction (Ma et al., 1998; Nielsen et al., 2002). In addition, the detailed approach for soil water movement gave greater flexibility in calibrating soil water contents. Because RZWQM has a generic plant growth component, it did not have a database for each cultivar; rather it provided default plant growth parameters for tested cases in the U.S. Midwest. Therefore, users may have to calibrate additional parameters in the database besides the ones suggested by model developers (Table 7.6).

There was no objective optimization algorithm for calibrating an agricultural system model. Parameters were calibrated more or less by trial and error. CROPGRO and CERES-Maize emphasizes phenology and development, whereas RZWQM concentrates more on crop production. The soil water balance in CROPGRO and CERES-Maize was mainly calibrated through the upper and lower

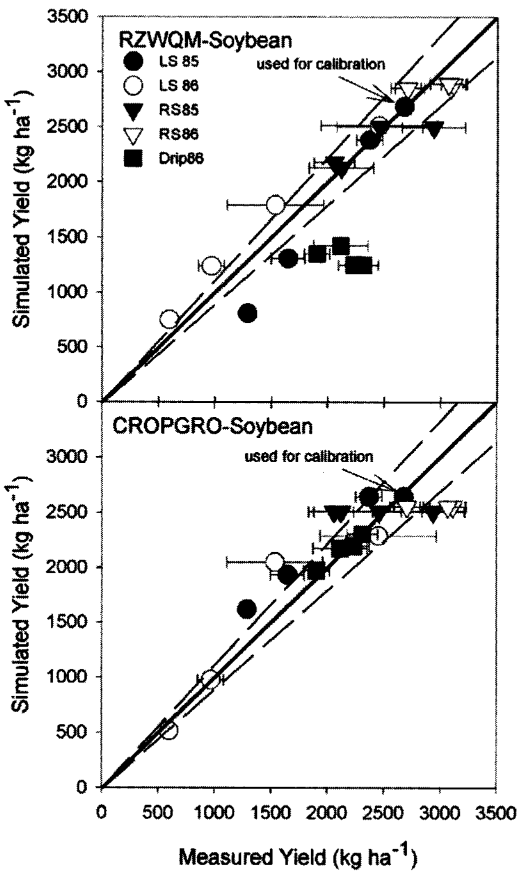

Figure 7.16 Predicted soybean yields with RZWQM-soybean and CROPGRO. LS: line source irrigation system; RS: rain shelter irrigation system; Drip: drip irrigation system.

drained limits, whereas RZWQM had a series of soil hydraulic properties that may be calibrated (Ahuja and Ma, 2002). In addition, because RZWQM has its strength in soil and water simulation, users have to be aware of the soil nitrate and chemicals in percolation and runoff waters. For the same data sets, different users may calibrate the models differently. For example, in this chapter, we used the upper and lower drained limits from Ritchie et al. (1999) for CERES and CROPGRO and interpreted as 33 kPa and 1500 kPa soil water content values to be used in RZWQM. Default 33 kPa and 1500 kPa soil water content values in RZWQM based on soil texture class would be used and interpreted as upper and lower drained limits to be applied in CERES-Maize and CROPGRO as done by Nielsen et al. (2002). Many other ways (or even better ways) can be used to calibrate the data sets. As shown in Figure 7.19, given a fixed set of soil hydraulic properties, RZWQM provided overall better soil water content prediction than CERES-Maize and CROPGRO-Soybean.

All the models could be calibrated satisfactorily, but applications depended on year and irrigation methods. For corn yield, RZWQM provided more accurate simulations and responded better to irrigation than CERES-Maize (Figure 7.8). For corn LAI, CERES-Maize predicted better than RZWQM (Figure 7.9). For corn biomass, RZWQM predictions were better in 1984 but worse in 1985 than those of CERES-Maize (Figure 7.10). Although both RZWQM and CROPGRO simulated ET equally well, RZWQM-simulated ET responded better to irrigation than CROPGRO-Soybean (Figure 7.14). For soybean yield, RZWQM provided the worst yield prediction, whereas CROPGRO provided the best yield prediction for the drip irrigation study in 1986 (Figure 7.16); however, for the rain shelter irrigation study, RZWQM predicted yield better than CROPGRO (Figure 7.16), although

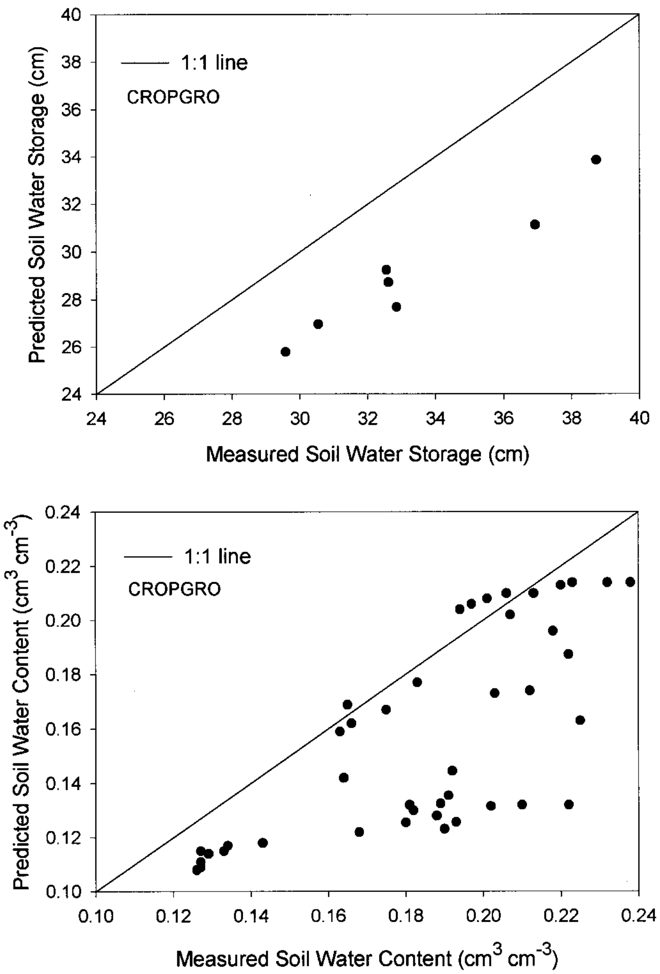

Figure 7.17 Predicted soil water storage and soil water contents with CROPGRO for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

overall RMSE was larger for RZWQM than for CROPGRO. Therefore, the benefits of developing complex and crop specific growth models, such as CROPGRO-Soybean and CERES-Maize, were minimized if other components of the agricultural systems, such as water, ET, and nutrient, were not comparable. There is a need to improve these components in CROPGRO and CERES.

All the models served the purposes for which they were designed. The crop growth component in RZWQM was designed to provide biomass and yield prediction for an agricultural water quality model. As shown in this chapter, its simulations of corn and soybean yields were adequate, once it was calibrated (Figures 7.8 and 7.16). Simulations of biomass were also reasonable (Figures 7.10 and 7.15). CERES-Maize and CROPGRO-Soybean were designed to simulate many agronomic attributes, such as phenology, leaf number, and yield components. As shown in Figures 7.5 and 7.18, both models were able to simulate the various growth and developmental stages fairly well. CROPGRO also simulated the number of leaves correctly, although CERES-Maize overestimated leaf number. CROPGRO also predicted soybean yields adequately except for the rain shelter experiments (Figure 7.16). Unfortunately, there was no experimental data to validate kernel number, kernel weight, pod number, pod weight, seed number, and seed weight as simulated by both CERES-Maize and CROPGRO-Soybean.

Table 7.8 Cultivar-Specific Parameters Used in CROPGRO-Soybean Model and Their Calibrated and Default Values for Maturity Group 2

Parameter Name	Calibrated Value	Default Value
CSDL: Critical day length for crop development (hr)	13.59	13.59
PPSEN: Sensitivity to photoperiod (1/hr)	0.249	0.249
EM-FL: Time from end of juvenile phase to first flower in photothermal days	20	17.4
FL-SH: Time from first flower to first pod greater than 0.5 cm (photothermal days)	6	6
FL-SD: Time from first flower to first seed (photothermal days)	13.5	13.5
SD-PM: Time from first seed to physiological maturity (photothermal days)	20	33
FL-LF: Time from first flower to end of leaf growth (photothermal days)	26	26
LFMAX: Maximum leaf photosynthesis rate ($CO_2/m^2/s$)	0.92	1.03
SLAVAR: Specific leaf area (SLA) (cm^2/g)	250	375
SIZLF: Maximum size of fully expanded leaf (cm^2)	180	180
XFRUIT: Maximum fraction of daily available photosynthate to seeds plus shells (dimensionless)	1.0	1.0
WTPSD: Maximum weight per seed (g)	0.19	0.19
SFDUR: Seed filling duration for a cohort of seed (photothermal days)	20	23
SDPDV: Average seed per pod	2.2	2.2
PODUR: Time for cultivar to add full pod load under optimal conditions (photothermal days)	8.0	10.0

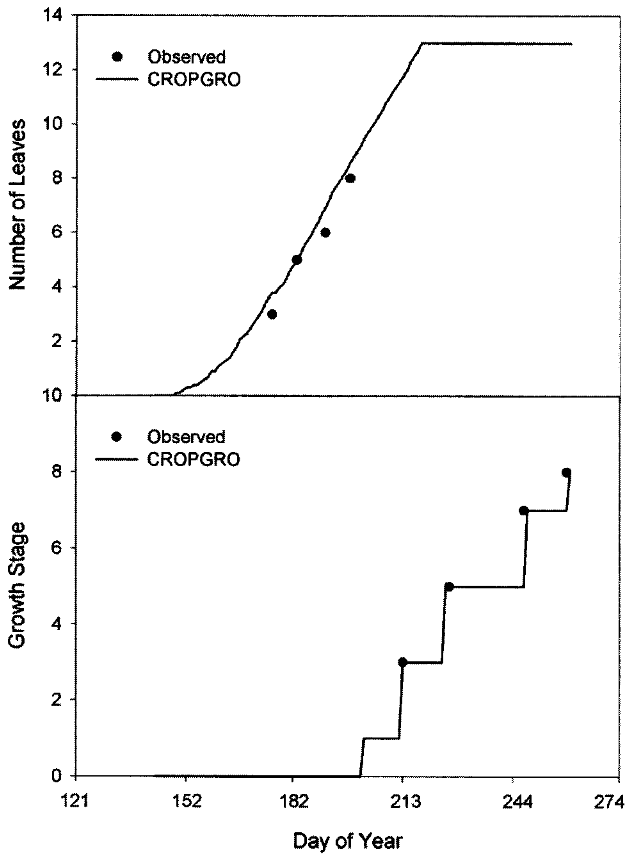

Figure 7.18 Simulated leaf number and growth stage with CROPGRO for the wettest irrigation level (level 4) in the 1985 growing season under the gradient line-source irrigation system.

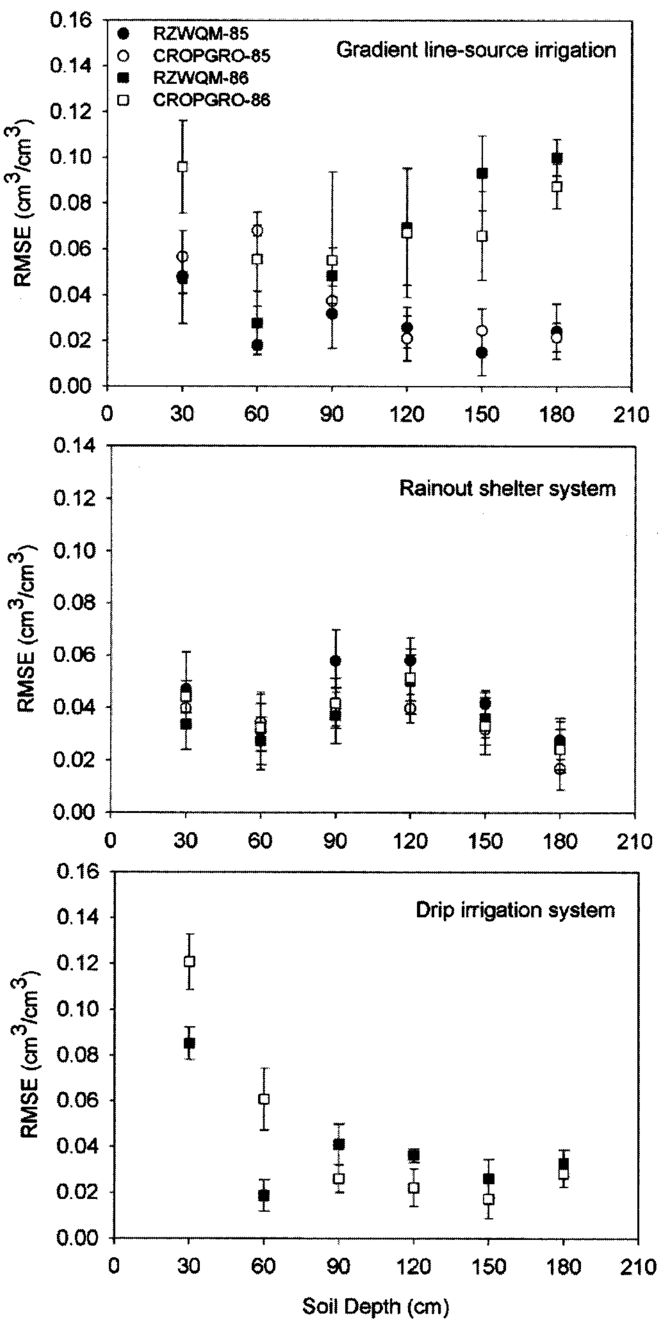

Figure 7.19 Root mean square errors (RMSE) of predicted soil water contents in various layers of the soil profile for different irrigation systems of soybean production. RMSE was averaged across treatments for each year and each irrigation system. The bars are one standard errors around the means. RMSE of each soil layer is plotted at the lower soil boundary of the soil layer.

All the models were run without nitrogen stress, which may not be true in the case of corn. The models could have responded differently if nitrogen stress had been simulated in addition to water stress (Ma et al., 2002). RZWQM included very detailed soil carbon–nitrogen components and suggested methods of initializing the soil organic carbon pools (Ahuja and Ma, 2002). RZWQM

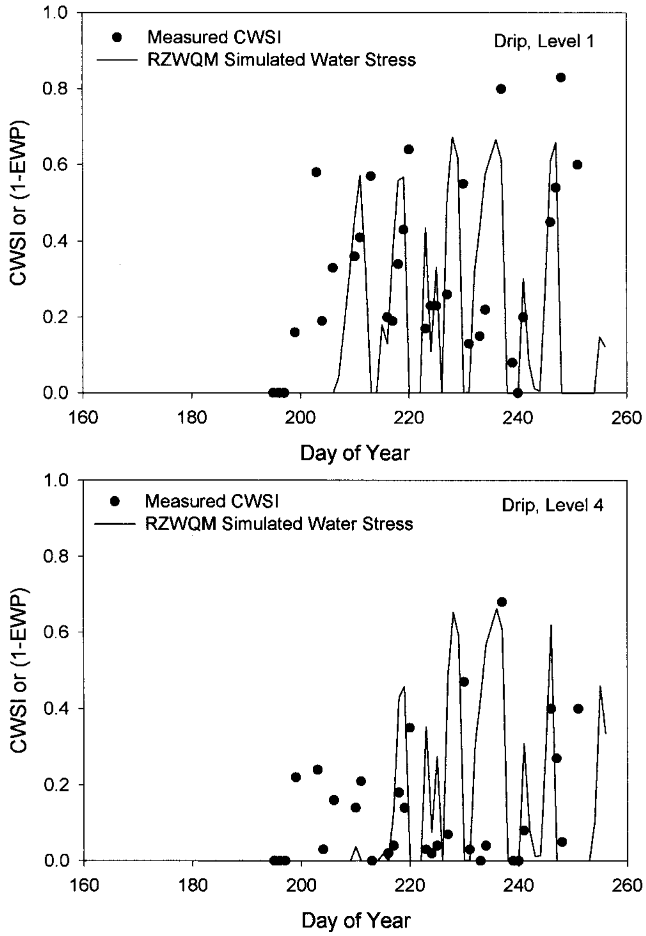

Figure 7.20 Measured crop water stress index (CWSI) and simulated water stress in RZWQM (1-EWP) for soybean under the drip irrigation system in 1986. EWP is the actual transpiration to potential transpiration.

can also be run for multiple years to initialize the pools. CERES-Maize and CROPGRO-Soybean can only run on a yearly basis, although with the DSSAT framework, the models can simulate crop sequences and rotations (Thornton et al. 1995). RZWQM also emphasizes management practices, such as tillage, crop residue management, tile drainage, manure application, and crop rotation. Thus, RZWQM has the advantage of simulating environmental impacts of agricultural systems in addition to crop production, in terms of nitrate and pesticide.

In conclusion, with simple parameterization of the models, this study compared three models for their predictions of corn and soybean production, with the same data sets, using similar initial conditions. It was also a unique study because the models were calibrated for one irrigation level in 1985 and evaluated for other irrigation levels in the same year, so that the responses of models to water stresses could be fully tested. Also, model calibration was kept to a minimum and default values were used to avoid biasing the results toward any one model. Simulation results showed that each model can be calibrated to a certain level of satisfaction, but applications of the models to other conditions, such as water amount, irrigation methods, and weather, depend on the model. Overall, RZWQM provided satisfactory yield predictions for both corn and soybean. RZWQM was better at simulating soil water contents than CROPGRO-Soybean and CERES-Maize. CERES-

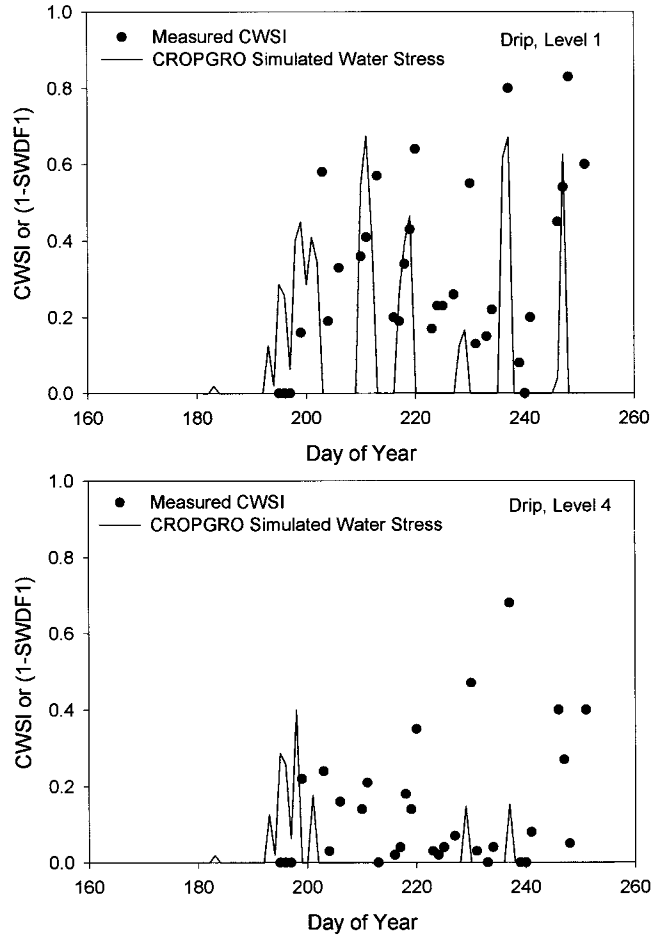

Figure 7.21 Measured crop water stress index (CWSI) and simulated water stress in CROPGRO (1-SWDF1) for soybean under the drip irrigation system in 1986. SWDF1 is the ratio of potential uptake to potential transpiration.

Maize-simulated corn yields did not respond to irrigation adequately. CROPGRO predicted soybean yields better in terms of RMSEs, but it did not respond to irrigation under the rain shelter irrigation system. RZWQM predicted water stresses better than CROPGRO-Soybean and CERES-Maize, based on CWSI.

So far, CERES-Maize and CROPGRO-Soybean have been used worldwide by international agencies and organizations. Through efforts of the IBSNAT project, the two models were adapted by and subsequently released as part of the DSSAT product. Although the IBSNAT project ended in 1993, the international collaboration has continued through the International Consortium for Agricultural Systems Applications (ICASA; www.ICASAnet.org). Through this international effort the visibility and utility of the models were considerably improved, with the distribution of DSSAT in more than 90 countries worldwide. Within the DSSAT package (a DOS-based user interface), the two models represent the grain legumes and grain cereals as part of a suite of models for more than 17 different crops. They are very easy to calibrate for crop production and generally give model users satisfaction. At present, model users are satisfied if they can only calibrate their data adequately with a few steps. Use of the models for technology transfer has limited success so far.

On the other hand, RZWQM was developed and tested mainly in collaboration with the Management Systems Evaluation Areas (MSEA) project. It has been used in only a few countries (Ma et al., 2000).

Also, its application was mainly on soil water quality. This chapter is the first study to systematically evaluate the generic crop growth components in RZWQM against the more widely used crop growth models. The development of a Windows-based user interface has promoted the use of RZWQM, and it can be downloaded free from http://arsagsoftware.ars.usda.gov. Although conclusions were drawn only from this particular study in the Central Great Plains of the U.S., more comparison studies will be needed for other experimental conditions. This study clearly showed the weaknesses and strengths of each model, and should help and encourage field scientists to use models as a tool with the analysis of their experimental results and promote technology transfer via system models.

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