Simulating Alternative Dryland Rotational Cropping Systems in the Central Great Plains with RZWQM2

S. A. Saseendran, David C. Nielsen, Liwang Ma,* Laj R. Ahuja, and Merle F. Vigil

ABSTRACT

Long-term crop rotation effects on crop water use and yield have been investigated in the Central Great Plains since the 1990s. System models are needed to synthesize these long-term results for making management decisions and for transferring localized data to other conditions. The objectives of this study were to calibrate a cropping systems model (RZWQM2 with the DSSAT v4.0 crop modules) for dryland wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and proso millet (*Panicum miliaceum* L.) production in the wheat–corn–millet (WCM) rotation from 1995 to 2008, and then to evaluate the model from 1992–2008 for two additional rotations, wheat–fallow (WF) and wheat–corn–fallow (WCF) on a Weld silt loam soil under no-till conditions. Measured biomass and grain yield for the above three rotations were simulated reasonably well with root mean squared errors (RMSEs) ranging between 1147 and 2547 kg ha^{-1} for biomass, and between 280 and 618 kg ha^{-1} for grain yield. Corresponding index of agreement (d) ranged between 0.70 and 0.95 for biomass, and between 0.87 and 0.97 for grain yield. The validated model was further used to evaluate two additional crop rotations: wheat–millet–fallow (WMF) and wheat–corn–millet–fallow (WCMF) (1993–2008) without prior knowledge of the two rotations. We found that the model simulated the mean and range of yield and biomass of the three crops well. These results demonstrated that RZWQM2 can be used to synthesize long-term crop rotation data and to predict crop rotation effects on crop production under the semiarid conditions of eastern Colorado.

TRADITIONAL WINTER WHEAT production in a wheat–fallow rotation with conventional mechanical tillage in the Great Plains faces a number of natural resource conservation and quality issues that can affect the productivity and livelihood of the region's farmers. Because water is generally the most yield-limiting factor in the semiarid climate of the Great Plains, a 14-mo fallow period between crops has traditionally been used to increase stored soil water before planting, thereby increasing the subsequent crop yield (Greb, 1979). Notwithstanding the potential yield-stabilizing merits of fallow, this practice has often been the cause of severe soil erosion and quality degradation in the region (Bowman et al., 1999). The loss of soil quality resulting from conventionally tilled fallow has raised concerns about the long-term sustainability of wheat– fallow.

Sustainable farming systems must make use of diversified crops and rotations to mitigate the negative impacts of the wheat–fallow monoculture in the Great Plains (Anderson et al., 1999; Bowman et al., 1999; Shanahan et al., 1988; Norwood et al., 1990: Dhuyvetter et al., 1996). Long-term experiments that focus on reducing the amount of summer fallow time and reversing the soil degradation using no-till were established in eastern Colorado in 1985 (Peterson and Westfall, 2004). In those experiments, cropping system intensification (reduced fallow frequency) increased annualized grain and residue yields by 75 to 100%, and net return to farmers by 25 to 45%. In addition, soil organic carbon was found to be impacted significantly to a depth of 5 cm with an increase of 35% in the 12 yr of study compared to the WF system (Sherrod et al., 2003). Another cropping system experiment with decreased tillage and various degrees of increased cropping intensity involving a variety of summer crops (such as corn, proso millet, foxtail millet (*Setaria italica* L. Beauv.), sorghum [*Sorghum bicolor* (L.) Moench], field pea (*Pisum sativum* L.), sunflower (*Helianthus annuus* L.), canola (*Brassica napus* L.), triticale (*X Triticosecale rimpaui* Wittm, etc.) was established in 1991 at the Central Great Plains Research Station, USDA-ARS, Akron, CO in the Great Plains of the United States (Anderson et al., 1999).

Many potential alternative crop rotations for the semiarid Great Plains have been investigated since the 1990s with promising results that encourage farmers to adopt environmentally friendly farming practices (Acosta-Martinez et al., 2007; Vigil and Nielsen, 1998; Nielsen et al., 1996). However, uncertainty exists with regard to the specific impacts of these alternative cropping systems on sustainable crop production, natural resource conservation, and long-term soil and water quality issues. Also, in view of the large-scale spatial heterogeneity associated with the landscapes in the semiarid regions, questions arise on the validity of extrapolating the location-specific

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Abbreviations: C, corn; CT, conventional tillage; ET, evapotranspiration; F, fallow; GDD, growing degree days; LAI, leaf area index; M, proso millet; NT, no tillage; PUE, precipitation use efficiency; RMSE, root mean squared error; RZWQM, Root Zone Water Quality Model; W, winter wheat; WCF, wheat–corn–fallow; WCM, wheat–corn–millet; WCMF, wheat–corn–millet–fallow; WF, wheat–fallow; WMF, wheat–millet–fallow; WUE, water use efficiency.

systems that might replace the traditional WF system and reduce the frequency of fallow (Bowman and Halvorson, 1997; Anderson et al., 1999). In this experiment 20 crop rotations involving combinations of six crops and fallow, and three tillage treatments were established. Four cropping intensities were used as fallow frequency declined (one crop in 2 yr, two crops in 3 yr, three crops in 4 yr, and continuous cropping) as described by Bowman et al. (1999). Plots were 9.1 by 30.5 m with east–west row direction. Every phase of every rotation appeared every year, replicated three times in a randomized complete block design on a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls). Detailed descriptions of cultural practices, plot area, and experimental design were reported by Bowman and Halvorson (1997) and Anderson et al. (1999). For this study, we used data from the WF (1992–2008), WCF (1992–2008), and WCM (1995–2008) rotations to calibrate and evaluate the model. All rotations were managed under NT conditions in which herbicides (primarily glyphosate) were used to control weeds during fallow periods. The data used in the current modeling study comprised eight data sets of 14 to 17 yr each: (i) WF-W (wheat phase in 1992), (ii) WF-F (fallow phase in 1992), (iii) WCF-W (wheat phase in 1992), (iv) WCF-C (corn phase in 1992), (v) WCF-F (fallow phase in 1992), (vi) WCM-W (wheat phase in 1995), (vii) WCM-C (corn phase in 1995), and (viii) WCM-M (millet phase in 1995). Two additional crop rotations (WMF and WCMF) were reserved to compare with "proposed" WMF and WCMF rotations (constructed from the management data of the other rotations, WF, WCF, and WCM) using the calibrated model and were withheld from the model users.

Winter wheat cultivars planted were 'TAM 107' from 1991 to 1995, 'Akron' from 1996 to 2005, and 'Danby' from 2006 to 2008. Corn hybrids 'Pioneer Hybrid 3732' from 1992 to 1997, 'DK493 BT' in 1998 and 1999, 'DKC49–92' in 2000, 'NK4242 BT' from 2001 to 2003, and 'N42B7' from 2004 to 2008 were used. Relative maturity of hybrids was 101 d from 1992 to 1997 and 99 d for subsequent years. Proso millet cultivars planted were 'Sunup' from 1995 to 2000, and from 2002 to 2005, and 'Huntsman' in 2001 and from 2006 to 2008.

Fertilizer N was applied to achieve projected yields of 2688 kg ha^{-1} for winter wheat, 4100 kg ha^{-1} for corn, and 2000 kg ha^{-1} for proso millet. Actual fertilizer applied for different crops in different crop sequences over different rotation phases and seasons ranged between 12 and 67 kg N ha^{-1} for winter wheat, 34 and 95 kg N ha^{-1} for corn, and 0 and 84 kg N ha^{-1} for millet. All crops were grown under rainfed conditions. Wheat planting occurred between 18 and 26 September, corn planting occurred between 29 April and 18 May, and proso millet planting occurred between 6 and 25 June in individual crop seasons. Average seeding densities were 70 kg ha^{-1} for wheat, 16,000 seeds ha^{-1} for corn, and 15 kg ha^{-1} for proso millet.

Soil water measurements were made with a neutron probe (Model 503, Hydroprobe, CPN International, Martinez, CA) at two locations near the center of each plot at depths of 45, 75, 105, 135, and 165 cm. Time-domain reflectometry (Trase System I, Soil Moisture Equipment Corp., Santa Barbara, CA) was used to measure soil water in the 0- to 30-cm depth. Measured soil water from the surface to 180 cm depth was used for calculating crop evapotranspiration (ET) employing the water balance method, assuming deep percolation and runoff losses in the experimental plots were negligible. Daily precipitation recorded in the plot area, and maximum and minimum air temperature, solar radiation, wind speed, and relative humidity recorded by an automated weather station approximately 350 m from the plot area provided input for model simulations.

Leaf area index (LAI) and biomass measurements were made periodically throughout the growing season. The LAI was estimated using a plant canopy analyzer (LAI-2000, LI-COR, Lincoln, NE) with the 270° view restrictor to mask the operator (i.e., 270° open, 90° masked). Two sets of one measurement above and four measurements below canopy were taken on a diagonal transect between crop rows in the center of the plot. Dry matter sample size was 2 m of a single row. Samples were oven-dried at 60°C until weight remained constant.

Model Inputs

The RZWQM2 model requires detailed data for crop management, soil, and weather. Crop management data needed are planting date and depth, row spacing, and plant population. Also, amount, dates, and methods of fertilizer applications, are required. These data were collected for the current experiment. In addition, the model also requires initial inputs of dry and wet soil albedo (shortwave reflectivity), crop canopy albedo, and crop residue albedo for potential ET computations. Based on Ahuja et al. (2000) these parameters were assumed to be 0.25, 0.20, 0.35, and 0.30, respectively for all three crops. Soil physical and hydraulic properties for silt loam soil as available in the RZWQM2 model database (Ahuja et al., 2000) were used for simulations. The weather variables required by RZWQM2 are daily solar radiation, maximum and minimum air temperatures, wind speed, relative humidity, and precipitation. We assumed the daily precipitation events to be storms of 120 min duration to create the break point precipitation records required by RZWQM2.

Precipitation recorded during the experimental period (1992–2008) exhibited high inter-annual variability in amount and seasonal distribution (Table 1). From 1992 to 2008, annual precipitation ranged from 241 mm (2002) to 524 mm (1995). From March to June (roughly the spring growth period for winter wheat) precipitation ranged from 57 mm (1998) to 350 mm (1995). From May to September (roughly the corn growth period) precipitation varied between 143 mm (1994) and 418 mm (1996). From June to August (roughly the proso millet growth period) precipitation varied between 106 mm (1994) and 275 mm (1999).

Model Calibration

In this study, simulation of wheat, corn, and proso millet was conducted using the CSM-CERES model in RZWQM2. Initial parameters were obtained from Saseendran et al. (2005a) for wheat and corn and from Saseendran et al. (2009) for proso millet. The most commonly accepted method for calibrating cultivar parameters of the CSM-DSSAT crop models in RZWQM2 is a step-by-step procedure following the systematic procedure recommended by Boote (1999) by calibrating soil moisture first, followed by plant growth (phenology, biomass, and yield in that order). The detailed model calibration procedure can be found in Saseendran et al. (2005a, 2009).

Table 3. Cultivar parameters (genetic coefficients) for corn hybrids† and winter wheat cultivars‡ developed for simulations using the CERES-maize and CERES-wheat modules in RZWQM2.

Parameters	Definitions	Corn		Wheat
		Values used by Sassendran et al. (2008)	Current calibrated values	Current calibrated values
P1	Thermal time from seedling emergence to the end of Juvenile phase during which the plants are not responsive to changes in photoperiod (degree days) (corn)	290	300	–
P1V	Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 d of vernalization is sufficient for all cultivars (wheat).	–	–	55
P1D	Relative amount that development is slowed when plants are grown in a photoperiod 1 h shorter than the optimum (which is considered to be 20 h) (wheat).	–	–	90
P2	Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development is at maximum rate, which is considered to be 12.5 h (corn).	0.8	0.8	–
P5	Thermal time from silking (or begin grain filling) to physiological maturity (corn, wheat).	615	600	350
G1	Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (no. g^{-1}) (wheat).	–	–	35
G2	Maximum possible number of kernels per plant (corn) or Kernel filling rate under optimum conditions (mg d^{-1}) (wheat).	690	600	11
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg d^{-1}) (corn) or Nonstressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases (g) (wheat).	9.6	9.6§	1.8
PHINT	Phyllochron interval (degree days) (corn, wheat).	38.9	43.9	60.0

† Pioneer 3732, Dekalb 493 BT, DKC-49–92, N4242BT, and N42B7.

‡ TAM 107, Akron, and Danby

§ G3 = 9.6 for Pioneer 3732 and Dekalb 493 BT; G3 = 7.0 for DKC-49–92, N4242BT, and N42B7.

on 31 Dec. 2008. Over the 14 yr there were 13 biomass (at harvest), 13 grain yield (at harvest), 14 ET (crop period), 43 LAI, and 28 d of soil water content measurements available for model calibration.

Simulation RMSEs over the entire cropping system sequence (WCM-M) for soil water storage (180 cm profile), ET, LAI, biomass, and grain yield were 7.5 cm, 4.2 cm, 0.26 m^2 m^{-2}, 1518 kg ha^{-1}, and 485 kg ha^{-1}, respectively (Table 5). Corresponding index of agreement (d) values were 0.69, 0.85, 0.96, 0.82, and 0.93 (Table 5). Total profile soil water was not so well simulated (d = 0.69), with overestimations at soil depths <30 cm. However, inspection of the data comparisons presented in Fig. 1 indicates that the model was adequately calibrated for biomass and yield of wheat, corn, and millet in a WCM rotational sequence.

Model Validation

Simulations of the WCM-W and WCM-C Phases

The calibrated model was then evaluated on the remaining two phases of the WCM (WCM-W and WCM-C). The RMSEs of simulated grain yield were 561 and 520 kg ha^{-1}, and that of simulated biomass were 1215 and 891 kg ha^{-1} for the WCM-W and WCM-C phases, respectively (Table 6). Corresponding d values were 0.90 and 0.93 for grain yield, and 0.87 and 0.97 for biomass (Fig. 2 and 3, Table 6). These results are comparable with that for the WCM-M phase in calibration. The RMSEs of soil water, ET, and LAI simulations were between 0.056 and 0.04 m^3 m^{-3}, 4.6 to 7.6 cm and 0.58 to 0.64, respectively for the two phases.

Table 4. Cultivar parameters (genetic coefficients) calibrated for simulation of proso millet (cultivar 'Sunup' and 'Huntsman') using the CERES-proso millet module in RZWQM2.

Parameter	Definition	Values used by Saseendran et al. (2009) for 'Sunrise'	Current 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, GDD†.	40.0	40.0
P20	Critical photoperiod or the longest day length at which development occurs at a maximum rate. At values higher than P20, the rate of development is reduced.	16.5	16.5
P2R	Extent to which phasic development leading to panicle initiation is delayed for each hour increase in photoperiod above P20, GDD†.	20.0	30.0
P5	Thermal time from beginning of grain filling (3–4 d after flowering) to physiological maturity, GDD†.	55.0	155.0
G1	Scaler for relative leaf size.	12.5	1.5
G2	Scaler for partitioning of assimilates to the panicle (head).	7.5	11.5
PHINT	Phyllochron interval; the interval between successive leaf tip appearances, GDD†.	35.0	35.0

† Growing degree days above a base temperature of 10°C.

Table 6. Mean or maximum measured values, and root mean squared error (RMSE) and d values in simulations of evapotranspiration (ET), leaf area index (LAI), grain yield, biomass, and soil water in the wheat–fallow (WF), wheat–corn–fallow (WCF), and wheat–corn–millet (WCM).

Cropping system	ET			LAI			Grain yield			Biomass			Total profile, 180 cm soil water		
	Mean	RMSE	d	Max.	RMSE	d	Mean	RMSE	d	Mean	RMSE	d	Mean	RMSE	d
	—— cm ——			— m^2 m^{-2} —			— kg ha^{-1} —			— kg ha^{-1} —			——— cm ———		
WF-W†	38	9.0	0.87	3.1	0.98	0.33	2046	363	0.80	6783	1803	0.44	32	7.1	0.83
WF-F	46	8.4	0.74	3.0	0.72	0.59	3110	409	0.77	8745	2483	0.88	34	6.6	0.43
WCF-W	42	5.9	0.89	2.7	0.60	0.79	2846	509	0.92	6646	960	0.96	31	6.3	0.65
WCF-C	38	7.3	0.78	3.4	0.96	0.62	2708	470	0.93	6603	1435	0.88	31	6.7	0.57
WCF-F	36	6.9	0.73	3.2	0.76	0.63	2017	587	0.91	5693	1909	0.85	30	6.5	0.50
WCM-W	27	7.4	0.93	2.7	0.64	0.90	1157	561	0.90	3288	1215	0.87	26	7.9	0.65
WCM-C	29	7.6	0.89	2.8	0.86	0.85	2014	520	0.93	4425	891	0.97	32	7.4	0.63
WCM-M	26	4.2	0.85	2.9	0.26	0.96	1389	485	0.93	3747	1518	0.82	29	7.5	0.69

† WF–W (beginning with the wheat phase in 1992), WF–F (beginning with the fallow phase in 1992), WCF–W (beginning with the wheat phase in 1992), WCF–C (beginning with the corn phase in 1992), WCF–F (beginning with the fallow phase in 1992), WCM–W (beginning with the wheat phase in 1995), WCM–C (beginning with the corn phase in 1995), and WCM–M (beginning with the millet phase in 1995).

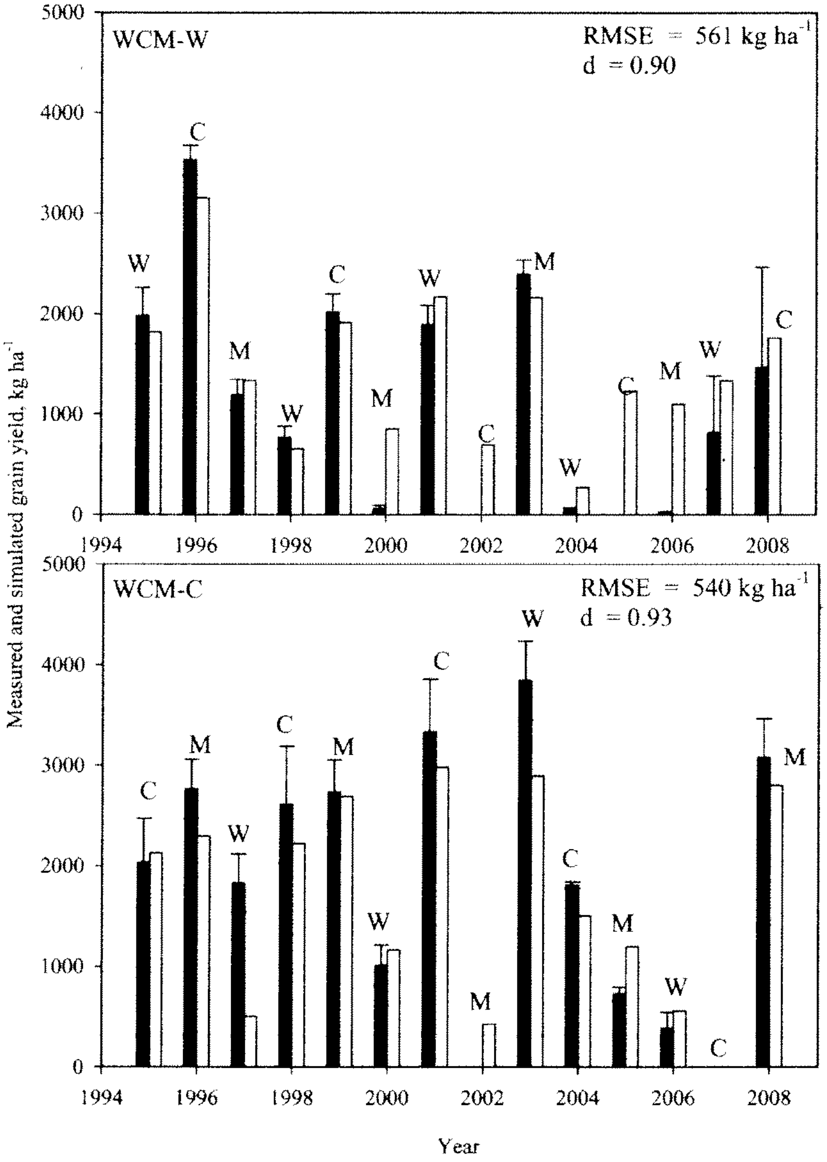

Fig. 2. Comparison of measured (solid bars with error bars) and simulated (open bars without error bars) grain yield for wheat, corn and millet grown in the wheat–corn–millet rotation beginning with the wheat phase in 1995 (WCM-W) and beginning with the corn phase in 1995 (WCM-C). The error bars indicate one standard deviation of measured means. RMSE = root mean squared error and d = index of agreement.

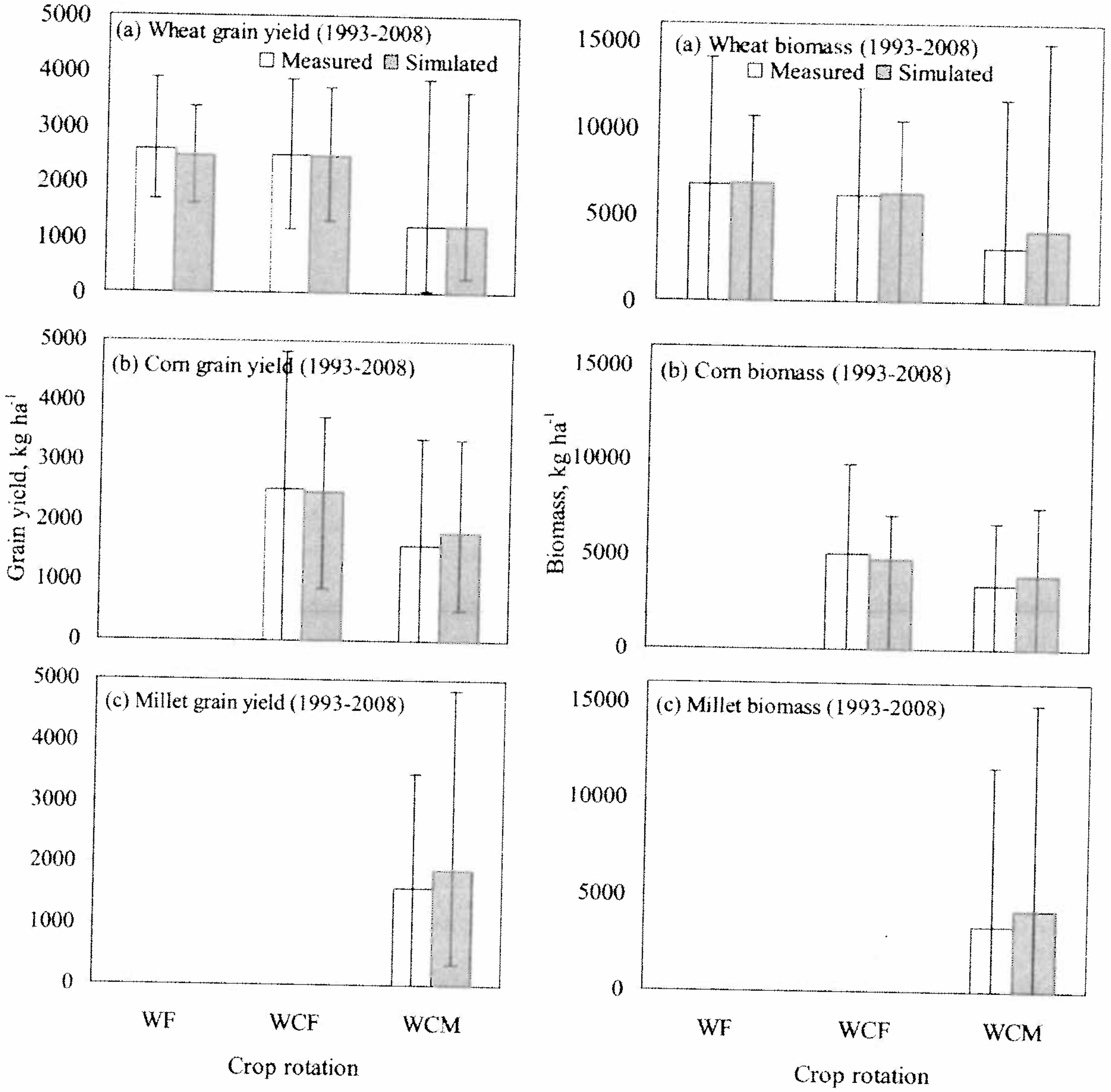

Fig. 4. Average (1993–2008) wheat, corn, and proso millet grain yields as observed at Akron, CO and simulated by RZWQM2 in wheat–fallow (WF), wheat–corn–fallow (WCF), and wheat–corn–millet (WCM) crop rotations. Ends of the bars indicate maximum and minimum observed and simulated yield and biomass.

With the exception of the wheat grain yield in 1997, all the biomass and grain yields in the WCM-C were simulated well with an RMSE of 540 kg ha^{-1} and d value of 0.93 for grain yield, and an RMSE of 891 kg ha^{-1}, and d value of 0.97 for biomass (Fig. 2 and 3). In 1997, the water stress (average 0.5) simulated during the early vegetative stage of wheat slowed LAI development drastically, resulting in low LAI and poor grain yield at harvest, but there were no LAI and biomass measurements this year to compare with. Probably the model overestimated the stress effects on LAI that year resulting in the large errors in grain yield simulated. In the severe drought year of 2002, no harvestable millet grain yield was reported (0 kg ha^{-1}), and the model simulated a grain yield of 529 kg ha^{-1} which did reflect a sharp decline in yield compared with the millet yields in the preceding and succeeding years (e.g., measured millet yield in 1999 was 2735 kg ha^{-1} that was predicted well).

Overall the simulated means and ranges of grain yields for all three crops in all three phases of WCM corresponded closely to observed means and ranges (Fig. 4). Simulated mean wheat yield and biomass were 101 and 125% of their observed means, respectively. The model correctly simulated the decreased mean wheat yield observed for wheat grown after millet without a fallow period (WCM) compared with wheat after fallow (the two other systems) (Fig. 4). Simulated mean corn yield was 113% of the observed mean. The model also correctly simulated the decreased mean corn yield observed in the more intensively cropped WCM system. Simulated mean millet yield and biomass were within 125% of the observed mean. The simulated yield and biomass ranges for all three crops were generally less than the observed ranges (85% averaged over all crops and systems).

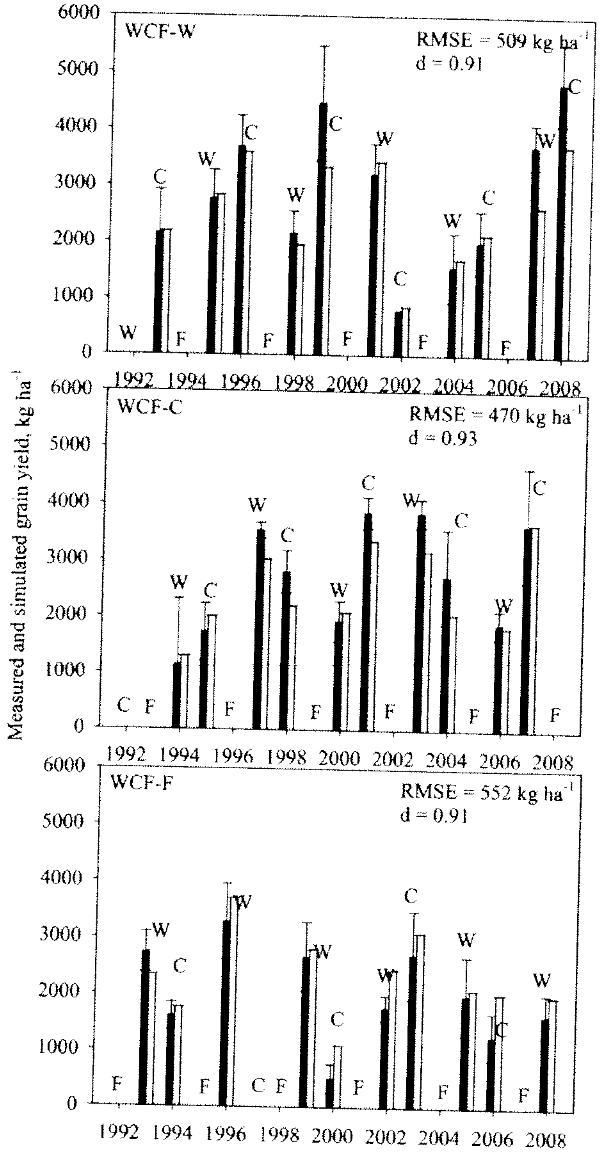

Fig. 7. Measured (solid bars with error bars) and simulated (open bars without error bars) winter wheat, corn, and proso millet grain yields in the wheat–corn–fallow with wheat phase in 1992 (WCF-W), wheat–corn–fallow with corn phase in 1992 (WCF-C), and wheat–corn–fallow with fallow phase in 1992 (WCF-F). The error bars indicate one SD of measured means. RMSE = root mean squared error, SD = standard deviation, and d = index of agreement.

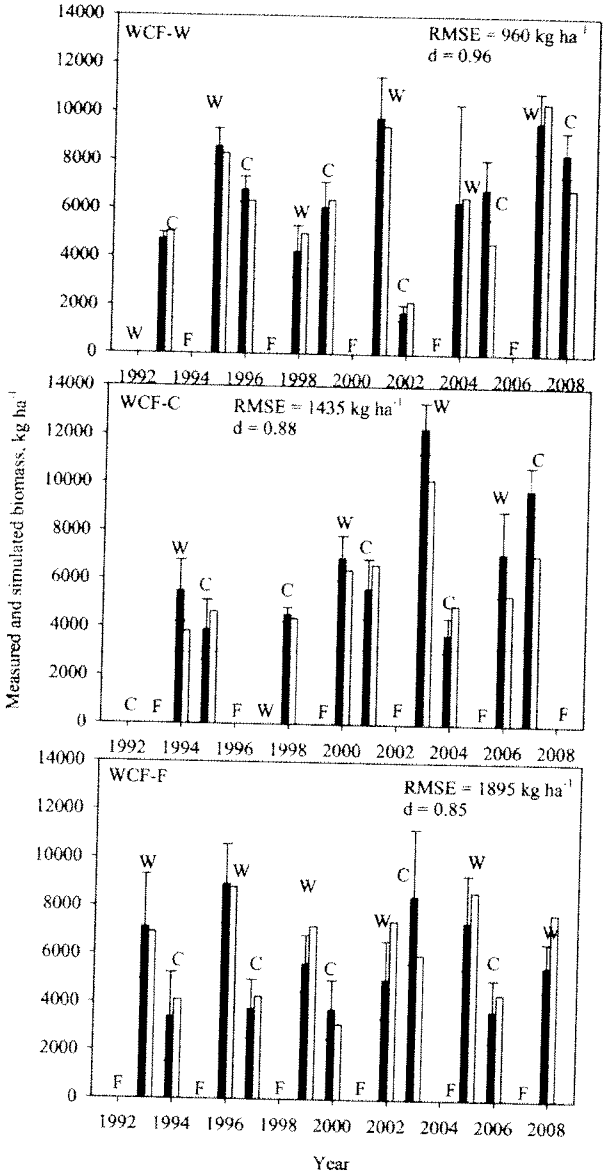

Fig. 8. Measured (solid bars with error bars) and simulated (open bars without error bars) winter wheat, corn, and proso millet biomass in the wheat–corn–fallow with wheat phase in 1992 (WCF-W), wheat–corn–fallow with corn phase in 1992 (WCF-C), and wheat–corn–fallow with fallow phase in 1992 (WCF-F). The error bars indicate one SD of measured means. RMSE = root mean squared error, SD = standard deviation, and d = index of agreement.

(wheat and corn together) simulations in the WCF–W were reasonably accurate with RMSE of 960 kg ha^{-1} and d value of 0.96 (Fig. 8). The RMSEs of simulations of ET, LAI, and soil water at various depths were 5.9 cm, 0.60, and 0.061 m^3 m^{-3}.

Wheat and corn grain yields in the WCF–C were also simulated with reasonable degree of accuracy, with RMSE of 470 kg ha^{-1} and d value 0.93 (Fig. 7). With the exception of the wheat crop in 1997 and corn in 2001 (both were undersimulated), all measured crop yields were predicted within two SDs of the measured means, with six of the simulations within one SD. Deviation of simulations from the measured was −15% in 1997 and −13% in 2001. The measured wheat yield in 1997 was 3535 kg ha^{-1} with a SD of only 139 kg ha^{-1} of the measured mean. In the case of corn in 2001, the model simulated on average water stress of 0.41 during the grain filling period causing the yield reduction that was not observed in the field. However, the simulated yield in general was well correlated with the measurements and yearly variability with high prediction accuracy (d). Combined wheat and corn biomass in the WCF–C were simulated well, with RMSE of 1435 kg ha^{-1} and d value of 0.88 (data not shown). Out of the nine biomass measurements available for comparison, five of the simulations were within one SD and the remaining four simulations were within two SDs of the measured means. The RMSEs of simulations of ET, LAI, and soil water at various depths were 7.3 cm, 0.96, and 0.064 m^3 m^{-3} (data not shown).

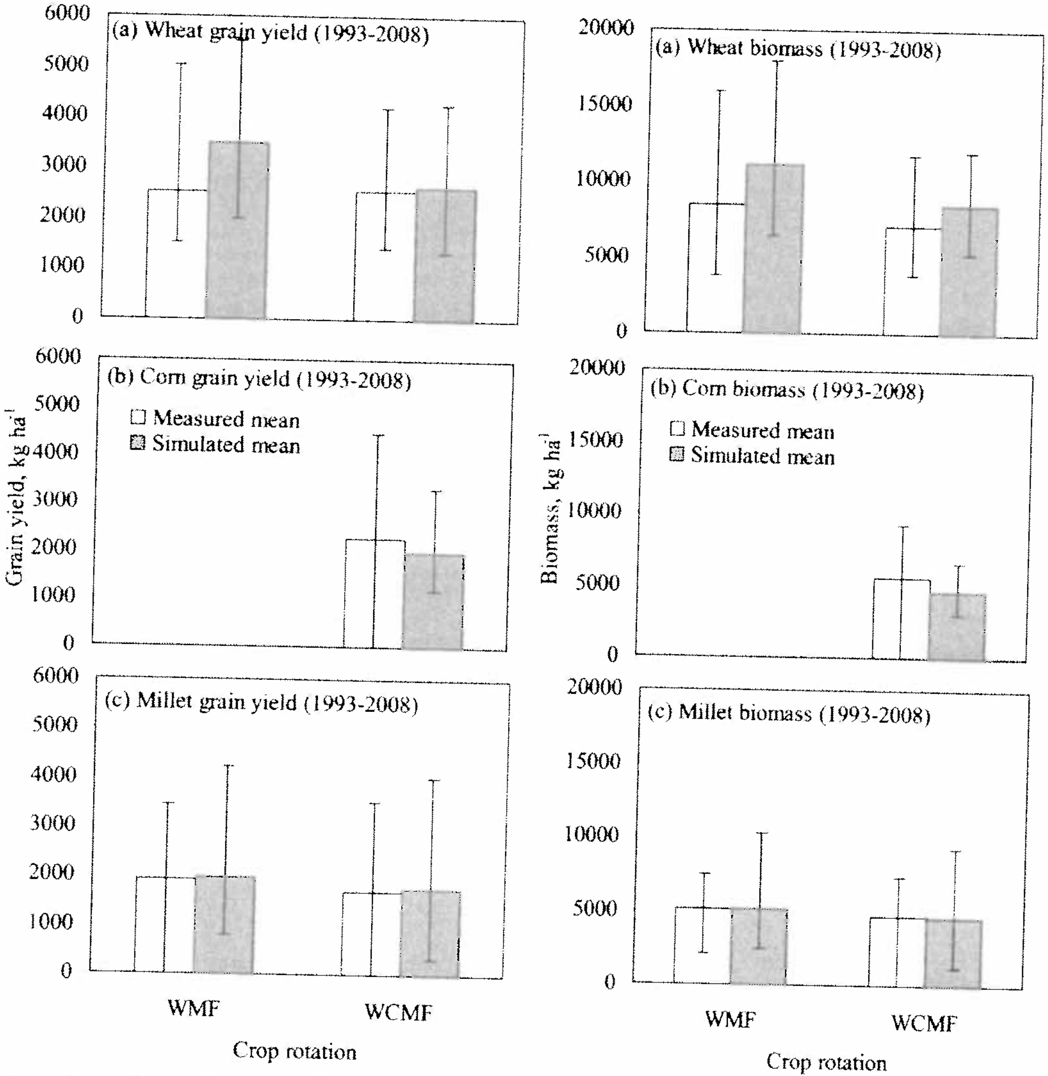

Fig. 10. Average (1993–2008) wheat, corn, and proso millet grain yields and biomass as observed at Akron, CO and simulated by RZWQM2 in wheat–millet–fallow (WMF) and wheat–corn–millet–fallow (WCMF) crop rotations. Ends of the bars indicate maximum and minimum observed and simulated yield and biomass.

model did not correctly simulate the zero yield obtained during the severe drought year of 2002.

Precipitation Use Efficiency and Water Use Efficiency of All Crop Rotations

Precipitation use efficiency (PUE) and water use efficiency (WUE) were defined as total yield of all crops divided by total precipitation or total water use for a certain period of time. For estimation and comparison of PUE and WUE of the WF, WCF, WMF, WCM, and WCMF rotations, precipitation, crop ET, and crop yield data from 1996 to 2008 were used when all rotations had completed their respective cycles. In general, the simulated WUEs and PUEs corresponded well with the measured values (Table 7). Simulated PUE ranged from 3.68 kg ha^{-1} mm^{-1} for WF to 4.76 kg ha^{-1} mm^{-1} for WCF, and corresponded well with measured values of 3.79 kg ha^{-1} mm^{-1} for WF and 4.90 kg ha^{-1} mm^{-1} for WCF (Table 7). Highest measured and simulated WUEs were obtained for the WCM (6.34 and 5.85 kg ha^{-1} mm^{-1}) but the highest PUE was for the WCF in both simulated and measured results. However, in both measurements and simulations, the rotation with the lowest values for both WUE and PUE was WF.

CONCLUSIONS

In this study, we tested a cropping systems model, RZWQM2, for its ability to effectively simulate sequential yield and biomass production, and WUE and PUE in

Table 7. Precipitation use efficiency (PUE) and water use efficiency (WUE) of wheat–fallow (WF), wheat–corn–fallow (WCF), wheat–corn–millet (WCM) and wheat–corn–millet–fallow (WCMF) rotations for the period 1996 to 2008.

Crop rotation	PUE		WUE	
	Measured	Simulated	Measured	Simulated
	kg ha^{-1} mm^{-1}			
WF	3.79	3.68	3.23	3.13
WCF	4.90	4.76	4.64	4.51
WCM	3.99	4.28	5.85	6.34
WMF	4.18	4.05	4.01	3.89
WCMF	4.49	4.24	4.27	4.03