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Evaluation of the Root Zone Water Quality Model Using Field-Measured Data from the Missouri MSEA

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ABSTRACT

The USDA-ARS Root Zone Water Quality Model (RZWQM) is a comprehensive computer model developed to simulate water, chemical, and biological processes in the root zone of agricultural management systems. The model is capable of evaluating the effects of various cropping and management practices on surface and ground water quality. In this study, the performance of RZWQM Version 3.2 was evaluated for a claypan soil, particularly surface runoff and chemical loss to surface runoff predictions. The model was calibrated and evaluated using data collected from the Missouri Management Systems Evaluation Area (MSEA) and the Kingdom City runoff plots. Soil water predictions of the model compared well with those measured, particularly at the 15-, 60-, 75-, and 90-cm soil depths. In most cases, corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] yield predictions were within 15 and 20%, respectively, of those measured. Using the macropore option (constant cracking) greatly improved the prediction of chemical losses to seepage. Annual runoff simulated for corn and soybean under conventional and no-till systems was adequately predicted. The model underpredicted large runoff events and overpredicted runoff events that occurred after long dry periods when soil cracking was a dominant factor. The model overpredicted NO_3–N concentrations in runoff but underpredicted concentrations in near-surface soils. Predicted and measured atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide) concentrations in surface runoff compared well, particularly when the computed runoff was close to that measured. In this study, the model was run using the option of constant cracking in the soil. To improve the predictions of agrichemical losses to runoff and seepage, RZWQM should include the capability to predict variable soil cracking based on soil moisture.

The Missouri Management Systems Evaluation Area (MSEA) project and the Kingdom City runoff plots are located within the Central Claypan Soil Major Land Resource Area (MLRA 113), an area of about 4 million ha. Claypan soils have a unique hydrology characterized by the impedance of vertical soil matrix water flow by a restrictive clay layer (Jamison et al., 1968). Runoff from claypan soils is relatively high during the seedbed preparation period, when agrichemicals are often applied (Ghidey and Alberts, 1996). As a result, regions with claypan soils have been identified as potentially vulnerable areas for pesticide and nutrient contamination of surface water. Surface and ground water samples taken from sites across the Corn Belt by the U.S. Geological Survey (USGS) indicated that surface water was more strongly affected by herbicides than ground water was (Thurman et al., 1992; Burkhart and Koplin, 1993). Blanchard et al. (1995) reported similar results from a study on claypan region soils.

The Missouri MSEA project was initiated to develop environmentally sound, economically profitable, and socially acceptable farming systems and technologies (Alberts et al., 1993). Research has been conducted on watershed, field, and plot scales to evaluate the effects of various farming systems on ground and surface water quality. Concentrations of NO_3–N, atrazine, and alachlor in surface runoff from a 73-km^2 watershed and three field-sized watersheds were monitored (Alberts et al., 1995). The effects of farming systems on grain yield, biomass production, crop N uptake, and agrichemical leaching were studied (Hughes et al., 1995). The effect of prevailing and alternative farming systems on ground water contamination was also observed (Blanchard et al., 1995).

One objective of the Missouri MSEA project was to use existing water quality models to make regional assessments of how changes in farming systems and technologies would affect ground and surface water quality. One of the models selected was the Root Zone Water Quality Model (RZWQM Team, 1992). Our objective for this part of the project was to evaluate the performance of RZWQM Version 3.2, particularly surface runoff and chemical loss to surface runoff predictions of the model, using data collected from the Missouri MSEA site. Additional data collected from long-term Kingdom City runoff plots were also used to calibrate and evaluate the surface runoff prediction of the model.

SITE DESCRIPTION

The Missouri MSEA project is located in the Goodwater Creek watershed, a 73-km^2 agricultural area in north-central Missouri. Predominant soils are Aeric Vertic Epiaqualfs, Vertic Albaqualfs, and Vertic Epiaqualfs of the Mexico, Adco, and Leonard series, respectively. The clay content of the argillic horizon is generally greater than 50% and is primarily montmorillonite. Experimental research at the Missouri MSEA site was conducted on three scales: watershed, field, and plot. Goodwater Creek was gauged at three locations, resulting in a nested watershed system with contributing drainage areas of 13, 31, and 73 km^2. Each gauging site was instrumented with a concrete V-notch weir, water stage recorder, and a refrigerated pumping sampler to measure and sample surface runoff. Each large watershed contained a field-size area ranging in area from 20 to 40 ha. Field outlets were also instrumented with weirs and automatic samplers. Each field was instrumented with well nests to assess the impact of different

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Abbreviations: FS1, Farming System 1; FS5, Farming System 5; MLRA, Major Land Resource Area; MSEA, Management Systems Evaluation Area[s]; RZWQM, Root Zone Water Quality Model; UAN, urea–ammonium nitrate.

farming systems on ground water quality. The effect of six farming systems on grain yield, plant N uptake, and agrichemical leaching was also studied on thirty 0.35-ha plots located near one of the fields (Field 1). In this study, data collected from two farming systems and Field 1 were used in the analysis.

Aboveground biomass, crop yield, crop N uptake, and NO_3–N, atrazine, and alachlor concentrations in the soil profile measured in 1992–1994 at the Missouri MSEA plots under Farming System 1 (FS1) and Farming System 5 (FS5) were used in the calibration and evaluation of RZWQM. FS1 was a high-chemical-input, minimum-till corn–soybean rotation with the goals of maximizing grain yield and profit. FS5 was a high-chemical-input, no-till corn–soybean rotation with emphasis on profitability and erosion control. Soil cores were collected from each plot in the spring prior to chemical application and after harvest in the fall. Samples of dry matter and grain were collected at senescence from each plot to determine dry matter and grain production. In some plots, pan lysimeters (230 cm long by 30 cm wide) were installed 90 cm below the surface to monitor chemical leaching out of the root zone.

Data collected from Field 1 of the Missouri MSEA in 1993 were also used to further evaluate the runoff, chemical concentrations in runoff, and chemical concentrations in soil surface layer predictions of RZWQM. Field 1 is a 35-ha area and was farmed using a high agricultural input farming system (FS1) consisting of a corn–soybean rotation. In 1993, Field 1 was planted to corn, and 190 kg ha^{-1} of N (as UAN), 2.24 kg ha^{-1} of atrazine, and 2.8 kg ha^{-1} of alachlor were applied to the soil. The chemicals were broadcast and incorporated using a field cultivator prior to planting. The field was divided into 36 equally spaced cells (80 by 120 m) to measure the spatial and temporal variability of agrichemicals (Ghidey et al., 1994). Soil samples were collected from each cell within the 0- to 5-cm depth prior to fertilizer or herbicide application. Additional samples were collected at 3 d, 1 wk, 2 wk, 4 wk, 8 wk, and 27 wk after chemical application and analyzed for NO_3–N, atrazine, and alachlor concentrations. During each runoff event, water samples were collected from the field outlet and analyzed for NO_3–N, atrazine, and alachlor concentrations.

Additional data collected from long-term runoff plots outside the MSEA project were used to calibrate and evaluate the surface runoff component of the model. The runoff plots are located near Kingdom City, Missouri. Forty natural rainfall runoff plots were established in 1941 and have been continuously operated to date. Each plot is 3.2 m wide by 27.4 m long. The soil is Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) on a 3 to 3.5% slope. A study evaluating the effect of seven cropping and management treatments on runoff and soil loss was initiated on these plots in 1982 and continued until 1995. The experimental design for the treatments was a completely randomized block design with four replications. The treatments were continuous cultivated fallow and continuous corn and soybean cropping systems under conventional, chisel, and no-till tillage methods. Surface runoff data obtained from conventionally tilled and no-till continuous corn and continuous soybean plots in 1983, 1985, 1990, and 1993 were used in the calibration and evaluation of the runoff component of the model. Conventional tillage consisted of spring moldboard plowing, primary and secondary disking, planting, and cultivation for weed control. Minor soil disturbance occurred at planting in no-till from a fluted coulter that prepared a narrow seedbed.

Representative soil properties of the Missouri MSEA and the Kingdom City runoff plots are presented in Table 1. A summary of the cropping and management practices used for RZWQM simulations is given in Table 2.

Table 1. Representative soil properties of the Missouri MSEA site (Goodwater Creek watershed) and Kingdom City, MO.

Soil depth	Sand	Clay	Bulk density
cm	%		g mL^{-1}
Missouri MSEA			
0–20	8.0	15.0	1.3
20–27	6.0	16.0	1.3
27–38	11.0	21.0	1.3
38–48	3.0	54.0	1.3
48–58	1.0	54.0	1.4
58–91	1.0	38.0	1.4
91–131	4.0	30.0	1.4
Kingdom City			
0–12	5.3	26.0	1.2
12–24	5.9	24.6	1.4
24–34	3.2	39.8	1.3
34–47	1.3	52.9	1.9
47–70	1.6	39.5	1.4
70–124	1.4	31.7	1.4
124–178	4.6	21.1	1.6

MODEL CALIBRATION

Some of the theoretical parameters in RZWQM cannot be easily measured or determined for complex and variable field conditions. As such, the model was first calibrated against one year of data for these parameters, and the calibrated model was subsequently evaluated against independent data for other years.

The first step in the calibration process was to establish steady-state values for the soil nutrient pools. These pools were slow and fast residue pools; slow, medium, and fast humus pools; and three microbial pools (aerobic heterotrophs, autotrophs, and anaerobic heterotrophs). To determine the nutrient pool values, the model was run for 10 continuous years prior to the calibration year. The final nutrient pool values were used as initial conditions for the single-year calibration and validation simulations. The final nutrient pool values showed considerable variations when the model was run for different crops and management systems. Since the data used for calibration and validation processes were obtained from fields and plots with different cropping and management history, the nutrient pool initialization process was repeated several times to represent each system. Final nutrient pools from 10 years of continuous corn and continuous soybean simulations under FS1 are presented in Table 3.

In the plant growth calibration process, only the site-specific parameters were calibrated. These parameters were: (i) maximum N uptake rate, (ii) proportion of photosynthesis to respire, (iii) amount of biomass needed to obtain leaf area index of 1.0 (CONVLA), (iv) age effect of propagules, and (v) age effect of seeds as a proportion of photosynthesis. The model was very sensitive to CONVLA; most of the adjustment was made for this parameter. The plant growth component of RZWQM was calibrated for corn using 1992 FS1 data and for soybean using 1992 FS5 data.

Our main focus was to evaluate the performance of the model in predicting runoff and chemical concentrations in the runoff. The model used measured soil physical properties, including bulk density, porosity, % sand, % silt, and % clay (Table 1). Measured 0.033 MPa and saturation water content values were also used. In the prediction of runoff, the model was very sensitive to the initial saturated hydraulic conductivity (K_{sat}) value. The model has two options regarding the initial K_{sat} value; it can be either a measured value or an estimate based on the soil bulk density and 0.033 or 0.01 MPa soil water content. Model predictions of runoff were significantly lower when the model-estimated K_{sat} was used. The model was thus calibrated using field runoff data measured from

Table 2. Description of the cropping and management practices at the Missouri MSEA site and Kingdom City, MO, used for RZWQM simulation.

Farming system†	Site	Tillage	Fertilizer	Herbicide
Corn FS1	Missouri MSEA	preplant field cultivator (12–18 cm deep); postharvest field cultivator (20–25 cm deep)	190 kg ha^{-1} urea–NH_4NO_3 (UAN) (broadcast and incorporated)	atrazine 2.24 kg ha^{-1} and alachlor 2.8 kg ha^{-1} (preplant incorporated)
Soybean FS1	Missouri MSEA	preplant field cultivator (12–18 cm deep)	none	alachlor 3.36 kg ha^{-1} (preplant incorporated)
Corn FS5	Missouri MSEA	no-till	118 kg ha^{-1} UAN (preplant broadcast, and incorporated)	same as Corn FS1
Soybean FS5	Missouri MSEA	no-till	none	same as Soybean FS1
CCCN	Kingdom City	moldboard, early April; disking, preplant; cultivation (field cultivator)	160 kg ha^{-1} NO_3–N and 16 kg ha^{-1} NH_4–N (preplant broadcast and incorporated)	none
CCSB	Kingdom City	same as CCCN	13 kg ha^{-1} NO_3–N (preplant broadcast, and incorporated)	none
NTCN	Kingdom City	no-till	same as CCCN	none
NTSB	Kingdom City	no-till	same as CCSB	none

† FS1, Farming System 1 (high chemical input, minimum-tillage corn–soybean rotation); FS5, Farming System 5 (high chemical input, no-till corn–soybean rotation); CCCN, conventionally tilled continuous corn; CCSB, conventionally tilled continuous soybean; NTCN, no-till continuous corn; NTSB, no-till continuous soybean.

1993 conventionally tilled continuous corn plots at Kingdom City, MO. The calibrated K_{sat} values in the soil horizons ranged from 0.38 cm h^{-1} in the top layer to 0.15 cm h^{-1} in the claypan horizon. The model also assumed the presence of surface crust under the conventionally tilled corn and soybean conditions.

The model uses the nonuniform mixing model (Ahuja and Lehman, 1983) to describe the transfer of chemicals to overland flow during rainfall events. It assumes that rainfall extracts chemicals from the soil surface by raindrop impact after the soil surface is saturated. The extraction occurs from depths as great as 2 cm, but the contribution decreases exponentially with depth (degree of mixing = e^{-bz}, where z is the soil depth and b is a parameter that depends upon the soil type, surface roughness, and cover conditions). The model needs to be calibrated for different sites to determine the value of the mixing parameter, b. A value of 3.0 was found to be the best estimate for Field 1.

Hua (1995) studied the role of variable soil cracking on agrichemical transport at the Missouri MSEA site using RZWQM. Macroporosity information data were used in constant crack model simulation, including total macroporosity, average radius of cylindrical pores, width and length of rectangular cracks in lower horizons, and fraction of dead end pores measured or estimated in his study.

Calibration Results and Discussion

Calibration results obtained using 1992 corn FS1 of the plots are shown in Table 4. Estimated aboveground biomass, grain yield, and N uptake by plants were within 10% of the measured values. Chemical concentrations in the soil profile from these plots were measured prior to planting and after harvest. The difference between measured and simulated NO_3–N in the profile before planting was less than 5%. However, the predicted NO_3–N at the end of the growing season was less than one-half of the measured value, probably because humus pool sizes were not adequately estimated. No atrazine and alachlor residues were detected in the soil samples taken before planting. Prior to planting, atrazine and alachlor were incorporated into the soil at 2.24 and 2.8 kg ha^{-1}, respectively. Predicted atrazine and alachlor amounts after harvest compared well with those measured.

Calibration results for 1992 soybean under FS5 are shown in Table 4. The model underestimated grain yield by 13%. Aboveground biomass and N uptake by plants were not measured. Nitrate N and atrazine were not applied to the soybean plots. Alachlor at the rate of 2.8 kg ha^{-1} was incorporated 2 d before planting. Chemical concentrations in the soil profile were well estimated. The difference between predicted and

Table 3. Final nutrient pools (per gram of soil) from 10-year continuous corn and continuous soybean RZWQM simulations under FS1.†

Soil depth	CR-1‡	CR-2	OM-1	OM-2	OM-3	HET1†	AUTO	HET2	NO_3–N	NH_4–N
cm	g C g^{-1}					no. g^{-1}			g N g^{-1}	
					Corn					
0–20	201	0.3	86	221	14 609	596 624	22 049	32 513	4.5	0.015
20–27	86	4.5	66	318	8 492	138 804	5 742	4 543	4.0	0.000
27–38	78	3.4	63	295	9 358	111 705	4 231	2 638	4.0	0.000
38–48	79	2.9	61	338	7 470	83 254	3 032	6 878	3.1	0.000
48–58	152	1.6	22	244	3 439	42 315	395	4 043	2.0	0.000
58–91	60	0.4	15	142	1 585	10 648	106	1 004	1.5	0.000
91–131	1	0.0	24	151	1 581	3 480	105	370	1.5	0.000
					Soybean					
0–20	306	208.0	77	279	14 527	1 164 009	29 817	42 837	4.0	0.025
20–27	239	6.6	74	352	8 424	232 366	6 463	6 088	4.0	0.003
27–38	197	10.3	70	317	9 321	173 208	4 534	3 384	4.2	0.003
38–48	183	6.5	69	391	7 425	109 302	2 573	9 806	3.0	0.001
48–58	193	7.6	30	263	3 428	49 660	360	4 824	2.7	0.000
58–91	60	4.1	17	146	1 582	12 674	105	907	2.0	0.000
91–131	1	0.1	24	153	1 579	3 211	97	189	1.5	0.000

† FS1, Farming System 1 (high chemical input, minimum-tillage corn–soybean rotation).

‡ CR-1, CR-2, OM-1, OM-2, and OM-3 indicate slow residue pool, fast residue pool, fast soil humus pool, medium soil humus pool, and slow soil humus pool, respectively.

§ HET1, AUTO, and HET2 indicate aerobic heterotroph, autotrophs, and anaerobic heterotroph populations, respectively.

Table 4. Comparison of measured with RZWQM-predicted values after calibration using 1992 minimum-tillage (FS1) corn and 1992 no-till (FS5) soybean.

Parameter	FS1 corn			FS5 soybean		
	Measured	Predicted	% Difference	Measured	Predicted	% Difference
Aboveground biomass, kg ha^{-1}	14 533	13 088	−9.9	NA†	7 618	—
Grain yield, kg ha^{-1}	7 219	7 645	5.9	1969	1 713	−13.0
N uptake by plants, kg ha^{-1}	153	152	<1.0	NA	155	—
$\mathrm{NO_3}$–N in soil profile before planting, kg ha^{-1}	46.7	44.8	−4.1	51.9	51.2	−1.4
$\mathrm{NO_3}$–N in soil profile after harvest, kg ha^{-1}	20.3	45.5	124.3	24.6	24.3	<1.0
Atrazine in soil profile before planting, g ha^{-1}	0.0	0.0	0.0	27.9	29.4	5.3
Atrazine in soil profile after harvest, g ha^{-1}	51.8	45.5	−12.2	12.5	8.3	−33.9
Alachlor in soil profile before planting, g ha^{-1}	0.0	0.0	0.0	8.1	7.9	−2.3
Alachlor in soil profile after harvest, g ha^{-1}	8.2	8.1	−1.2	5.2	13.9	169.4

† NA, not available.

measured $\mathrm{NO_3}$–N prior to planting and after harvest was less than 2.0%. Predicted atrazine and alachlor amounts before planting were within 5% of those measured. After harvest, measured and predicted herbicide residues remaining in the soil were very small.

Runoff prediction of the model was calibrated using 1993 conventionally tilled continuous corn runoff data from the runoff plots at Kingdom City, MO. Model simulation was performed from 1 April until 1 November (i.e., from the period of primary tillage until after harvest). The difference between the measured and predicted runoff in 1993 was less than 5% for both conventional and no-till corn. Although the cumulative runoff prediction of the model was quite accurate, there was variability between predicted and measured runoff for individual events. Generally, the model overpredicted for small runoff events that occurred after a long dry period and underpredicted for large runoff events.

MODEL EVALUATION

Precipitation Characteristics

Cumulative annual precipitation in 1992, 1993, and 1994 from the Missouri MSEA site was 723, 1265, and 840 mm, respectively. The 53-year mean annual precipitation measured near the MSEA site at Centralia, MO, was 900 mm. Total precipitation during the 1992, 1993, and 1994 growing seasons was 295, 789, and 255 mm, respectively, which was below the long-term average in 1992 and 1994 and above the long-term average in 1993. Mean monthly minimum and maximum temperatures in 1992, 1993, and 1994 at the Missouri MSEA site are given in Table 5.

Table 5. Mean monthly minimum and maximum air temperature for three study years at the Missouri MSEA site.

Month	Temperature					
	1992		1993		1994	
	Min	Max	Min	Max	Min	Max
	°C					
Jan.	−3.1	5.6	−5.5	2.4	−8.6	−0.7
Feb.	−1.3	7.6	−6.6	3.1	−6.1	3.5
Mar.	1.6	13.3	−0.7	8.1	0.9	12.8
Apr.	5.5	17.2	5.4	15.2	7.2	18.4
May	10.7	22.7	12.4	22.7	11.2	22.9
June	14.3	27.5	17.4	28.0	18.8	29.1
July	17.6	28.6	21.0	29.8	18.1	29.4
Aug.	14.8	27.1	19.5	30.6	16.9	30.3
Sept.	12.8	25.9	13.0	23.1	13.6	24.8
Oct.	6.5	21.5	7.3	19.6	9.6	21.0
Nov.	3.4	9.9	0.8	9.4	5.2	14.3
Dec.	−2.9	4.7	−1.7	6.4	−0.8	7.5

Annual precipitation at the Kingdom City runoff plots in 1983, 1985, 1990, and 1993 was 1067, 1145, 1295, and 1351 mm, respectively, which was 15, 23, 39, and 45% higher than the long-term (53-year) mean annual precipitation of 930 mm measured at the site. Above-average-precipitation years were used in the analyses because these were generally high-runoff years. Precipitation during the simulation period (1 Apr.–1 Nov.) was 751, 584, 714, and 966 mm in the same four years.

Soil Water Content

Soil water content prediction of the model was compared with measured data from soybean plots under FS1 in 1992 (Fig. 1) and corn plots under FS1 in 1993 (Fig. 2). Volumetric water content from the plots was measured at the 15-, 30-, 45-, 60-, 75-, and 90-cm depths using neutron probes. 1992 was a relatively dry year, with annual precipitation 20% less than the long-term mean annual precipitation measured at the site, whereas 1993 was a wet year, with annual precipitation 40% higher than the long-term mean. Model prediction compared well with measured values at the 15-, 60-, 75-, and 90-cm depths. The model generally underpredicted volumetric water content at all depths below 15 cm, and greatly underpredicted water content at the 30- and 45-cm depths (where clay content was >50%).

Plant Growth

Data collected in 1993–1994 from the Missouri MSEA corn and soybean plots under FS1 and FS5 were used to evaluate the calibrated plant growth component of RZWQM. For both corn and soybean, the model predicted that more than 90% of the planted seeds would produce harvestable plants, which is slightly higher than was measured. The average measured seed-to-plant survival rates were 75 and 85% for corn and soybean, respectively.

Although total rainfall during the 1992 and 1994 growing seasons was similar (295 mm in 1992 and 255 in 1994), in 1992 two-thirds of the total precipitation occurred within 100 d after planting, and the rainfall events were fairly evenly distributed throughout this period, whereas in 1994 about 40% of the total rain fell within a 2-wk period before harvest. Because of this, predicted and measured grain yields for both corn and soybean under FS1 and FS5 were lower in 1994 than the mea-

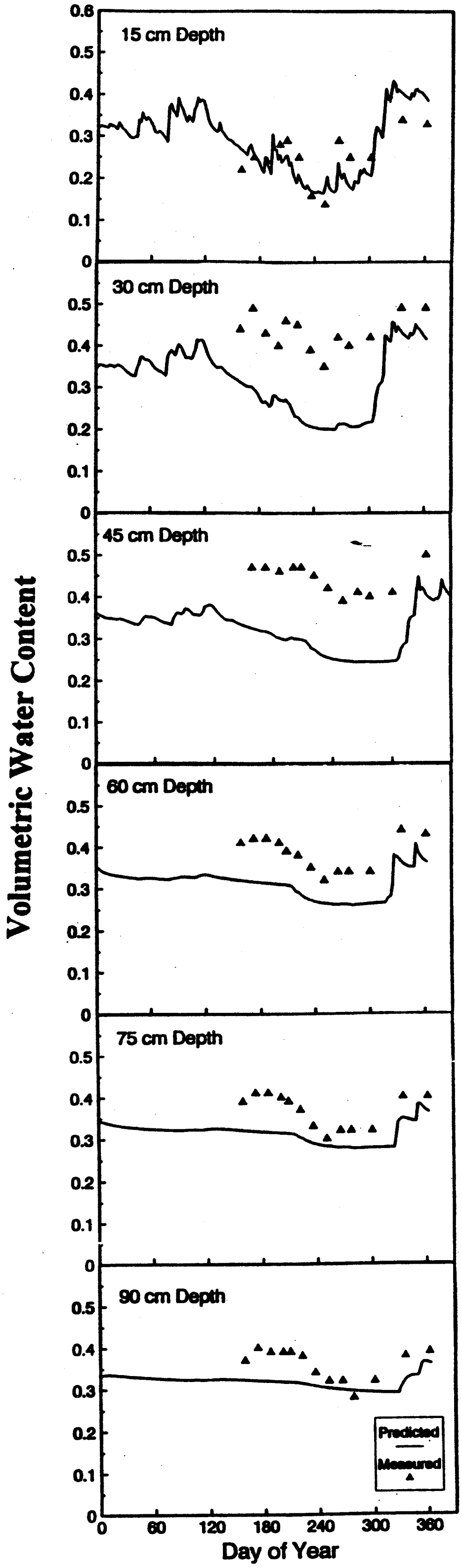

Fig. 1. Predicted and measured volumetric water content in 1992 from soybean plots under FS1.

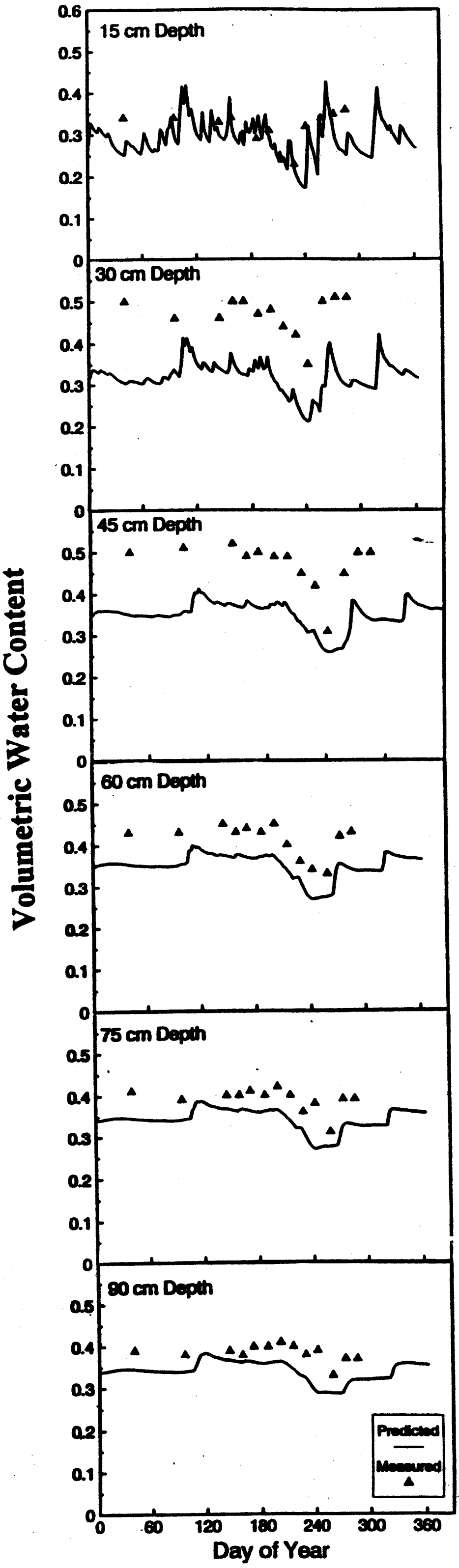

Fig. 2. Predicted and measured volumetric water content in 1993 from corn plots under FS1.

sured yields in 1992 (Fig. 3). The above-average rainfall in 1993 resulted in higher measured and predicted soybean yields for both FS1 and FS5 than in 1992 and 1994. In contrast to soybean, measured and predicted corn yields were higher in 1992 than in 1993, except for 1992 corn FS5, where measured yield was extremely low. Low yield for 1992 corn FS5 could be due to factors

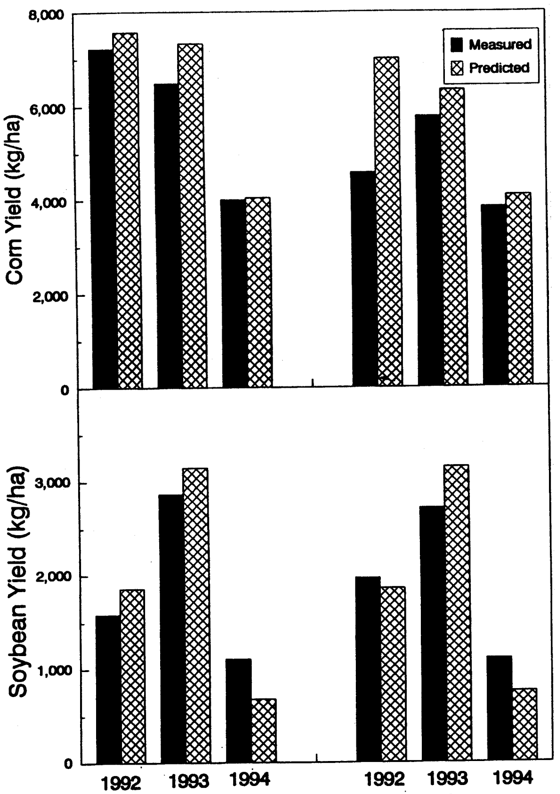

Fig. 3. Measured and predicted corn and soybean yields from FS1 and FS5 of the Missouri MSEA. Measured yields in 1992 for corn under FS1 and soybean under FS5 were used in the calibration of the plant growth component of RZWQM.

not considered by the model, such as disease, insect damage, or weed competition.

Generally, RZWQM predictions of grain yield were within 15% of the measured values, except for the 1992 corn FS5 and 1994 soybean FS1 and FS5. In 1992, predicted yield seemed to be reasonable; however, since the measured yield from corn FS5 was extremely low, the model overpredicted by almost 50%. In 1994, measured soybean yields from FS1 and FS5 were very low, and under the 1994 dry condition the model underestimated by more than 30%.

Chemical Concentrations in the Soil Profile

Not enough data are currently available from the Missouri MSEA plots to test how well the model estimates chemical concentrations in the soil profile, particularly during the growing season. To date, chemical concentrations in the soil have been measured only in the spring prior to chemical application and in the fall after harvest. Table 6 presents total measured and predicted NO_3–N, atrazine, and alachlor concentrations in the soil profile (0–120 cm) before planting and after harvest from FS1 and FS5 corn and soybean plots in 1992.

On Day 1 of simulation, NO_3–N, atrazine, and alachlor concentrations were initialized based on the measured chemical residues remaining from the previous year. Except for soybean FS1, where observed NO_3–N, atrazine, and alachlor were much higher than predicted, the model-estimated values prior to planting were close to those measured. After harvest, the difference between estimated and measured values ranged from less than 1.0% to more than 999%. Because the values measured were relatively small (particularly when compared with to the amount of NO_3–N, atrazine, and alachlor that could be measured during the first few weeks of chemical application), these data cannot test the performance of the model regarding chemical estimation in the soil profile. In future evaluations, several measurements during the growing season will be needed.

Model predictions of NO_3–N, atrazine, and alachlor concentrations in the top of the soil profile were evaluated using data from Field 1 of the Missouri MSEA measured in 1993. Figure 4 presents measured and predicted NO_3–N, atrazine, and alachlor concentrations in the 0- to 5-cm soil depth. For all sampling periods, the model underpredicted NO_3–N concentrations; however, predicted values were within the range of ±1 SD of the measured values. The model underpredicted atrazine concentrations for the samples taken 3 d, 1 wk and 2 wk and overpredicted for the samples collected 4, 8, and 27 wk following application. Predicted atrazine concentrations were also within the range of ±1 SD of the measured values. The model significantly overpredicted alachlor concentrations for all sampling periods except 3 d and 27 wk after application. In most cases, the predicted values were outside the range of the measured ±1 SD.

Chemical Losses to Seepage

Kitchen et al. (1998) measured NO_3–N and atrazine losses to seepage from three farming systems. They

Table 6. Measured and RZWQM-predicted NO_3–N, atrazine, and alachlor in the soil profile (0–120 cm) before planting (PP) and after harvest (PH) in 1992 from the Missouri MSEA site.

Farming system†	Sampling time	NO_3–N		Atrazine		Alachlor	
		Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
		kg ha^{-1}		g ha^{-1}			
Corn FS1	PP	46.7	44.8	0.0	0.0	0.0	7.0
	PH	20.3	45.5	52.0	46.0	8.0	9.0
Corn FS5	PP	64.2	46.8	0.0	0.0	4.0	9.0
	PH	4.5	50.5	15.0	14.0	0.0	8.0
Soybean FS1	PP	164.1	51.2	199.0	30.0	20.0	8.0
	PH	42.7	19.4	29.0	8.0	11.0	15.0
Soybean FS5	PP	51.9	51.1	28.0	29.0	8.0	8.0
	PH	24.6	24.3	13.0	8.0	5.0	15.0

† FS1, Farming System 1 (high chemical input, minimum-tillage corn–soybean rotation); FS5, Farming System 5 (high chemical input, no-till corn–soybean rotation).

monitored chemical leaching out of the root zone on two replicated plots designated as Plot A and Plot B. Lysimeters were sampled within 24 h of every rainfall event for the first 45 d after chemical application. Data obtained from one farming system (corn–soybean rotation under FS1) will be discussed. In 1992, the plots were cropped to soybean where neither NO_3–N nor atrazine were applied. As a result, measured and predicted NO_3–N and atrazine concentrations were below the maximum contamination level (10 Mg L^{-1} for NO_3–N and 3 g L^{-1} for atrazine). Alachlor at the rate of 2.8 kg ha^{-1} was applied to these plots in 1992 prior to planting; however, because of the dry season, no alachlor was measured or predicted in seepage water.

In 1993, the plots were cropped to corn. Prior to planting, NO_3–N, NH_4–N, Urea-N, and atrazine were applied at 45, 45, 90, and 2.24 kg ha^{-1}, respectively. Although Plots A and B were under the same farming system (FS1), NO_3–N and atrazine concentrations measured from these plots varied greatly. For instance, for the rainfall event that occurred 10 d after chemical application, NO_3–N and atrazine concentrations in seepage from Plot A reached 40 Mg L^{-1} and 100 g L^{-1}, respectively, whereas NO_3–N and atrazine concentrations from Plot B were <7 Mg L^{-1} and <2 g L^{-1}, respectively. For this event, the predicted NO_3–N and atrazine concentrations were 12 Mg L^{-1} and 23 g L^{-1}, respectively. Samples were also taken 20, 33, 40, and 71 d after chemical application. Nonetheless, the measured NO_3–N and atrazine concentrations from Plots A and B varied greatly. For these periods, measured concentrations from Plot A ranged from 26 to 12 Mg L^{-1} for NO_3–N, and 41 to 17 g L^{-1} for atrazine, whereas concentrations from Plot B ranged from 4.7 to 0.16 Mg L^{-1} for NO_3–N and 0.9 to 0.12 g L^{-1} for atrazine. For the three events that occurred at 20, 33, and 40 d after chemical application, the model predicted 13, 27, and 13 Mg L^{-1} for NO_3–N, and 2, 7, and 5 g L^{-1} for atrazine, respectively. Concentrations predicted 71 d after application were <10 Mg L^{-1} for NO_3–N and <3 g L^{-1} for atrazine.

Although the predicted values are within the range of the measured values, because of the variability in the measured values, it is difficult to make a definite conclusion on the overall model prediction. The significantly higher chemical concentrations measured in the root-zone water from Plot A are believed to be due to rapid water and chemical movement through preferential flow paths (e.g., soil cracks) during and immediately after surface runoff events. The model did not predict nitrate or herbicide leaching when run using the option of no cracking present in the soil. Including the macropore option (constant cracking) of the model improved the prediction of nitrate and herbicide leaching. However, the model needs to be modified to predict variable cracking based on soil moisture, rather than assuming constant cracking.

Surface Runoff

Runoff data obtained in 1983, 1985, 1990, and 1993 from the conventionally tilled and no-till continuous corn and continuous soybean runoff plots at Kingdom City were compared with predicted values (Fig. 5a and 5b). Model simulation was performed from 1 April until 1 November. The model overestimated runoff in all cases except 1990 no-till and conventional corn, 1990 no-till soybean, and 1993 no-till corn. In 1990, two large rainfall events produced runoff ranging from 100 to 160 mm. The model greatly underpredicted these events, particularly for the no-till systems. As a result of these two events, model-predicted total runoff was lower than measured.

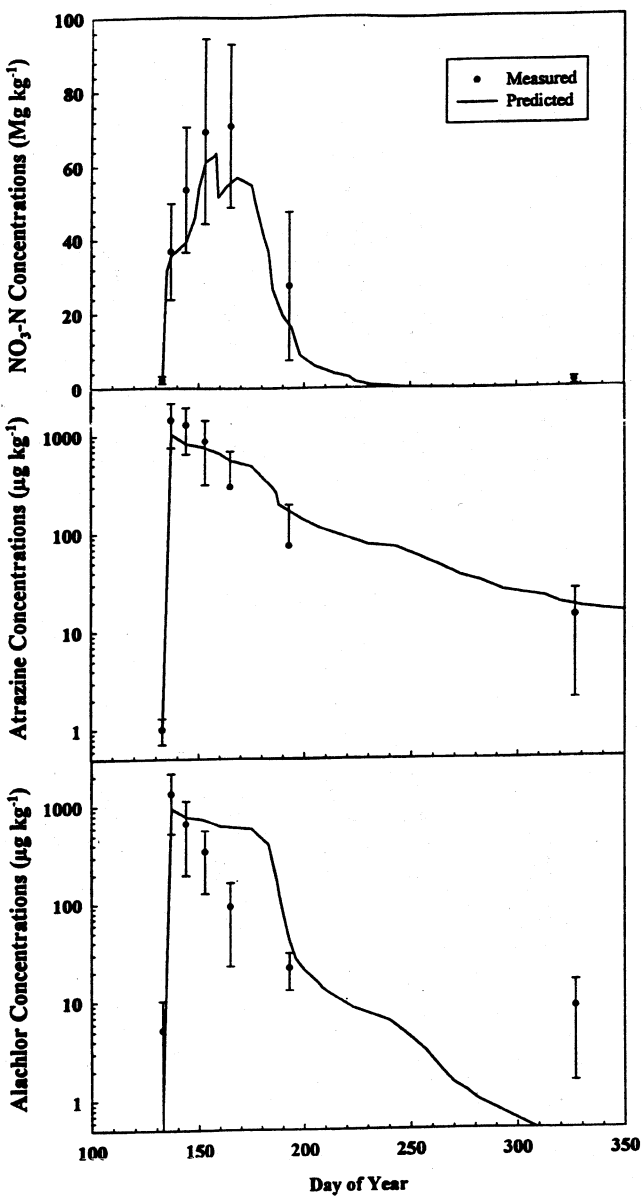

Fig. 4. Measured and predicted NO_3–N, atrazine, and alachlor concentrations in the 0- to 5-cm soil depth from Field 1 under FS1 of the Missouri MSEA in 1993. Vertical bars represent ±1 SD.

As shown in Figures 6a and 6b, the model predicted several runoff events for rainfall events, but no runoff was measured in the plots. Most of these rainfall events occurred after a long dry period during which soil cracking occurred in the plots. The rapid movement of water through soil cracks is the obvious reason for the measured runoff to be significantly less than that predicted. Baer et al. (1995) studied surface and profile soil cracking at the Missouri MSEA site and found that, during

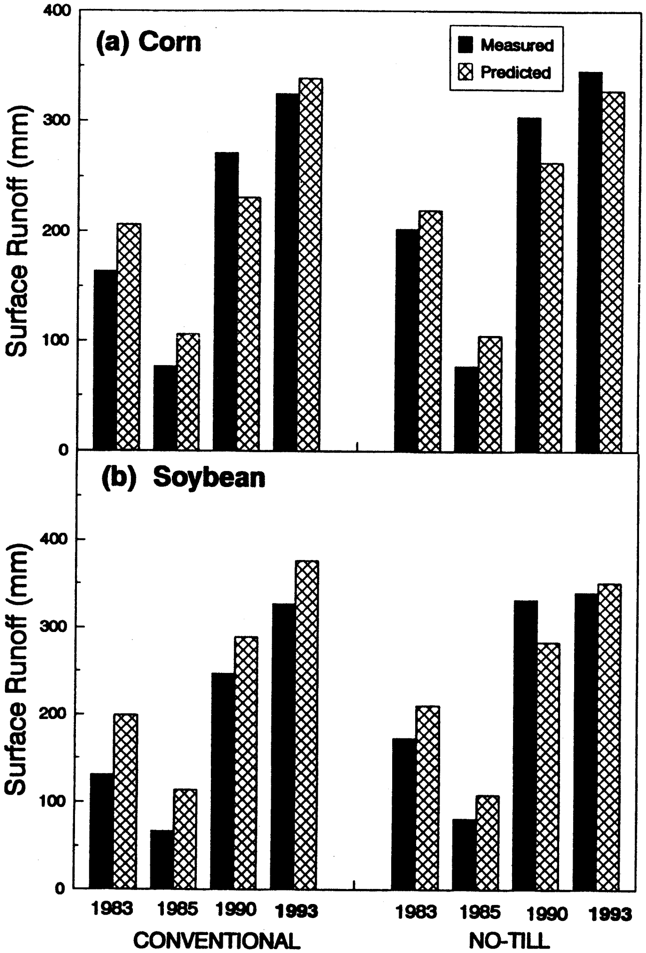

Fig. 5. Measured and predicted surface runoff from conventionally tilled and no-till runoff plots for (a) continuous corn and (b) continuous soybean at Kingdom City, MO, in 1983, 1985, 1990, and 1993. Runoff data measured from 1993 conventionally tilled continuous corn were used to calibrate RZWQM.

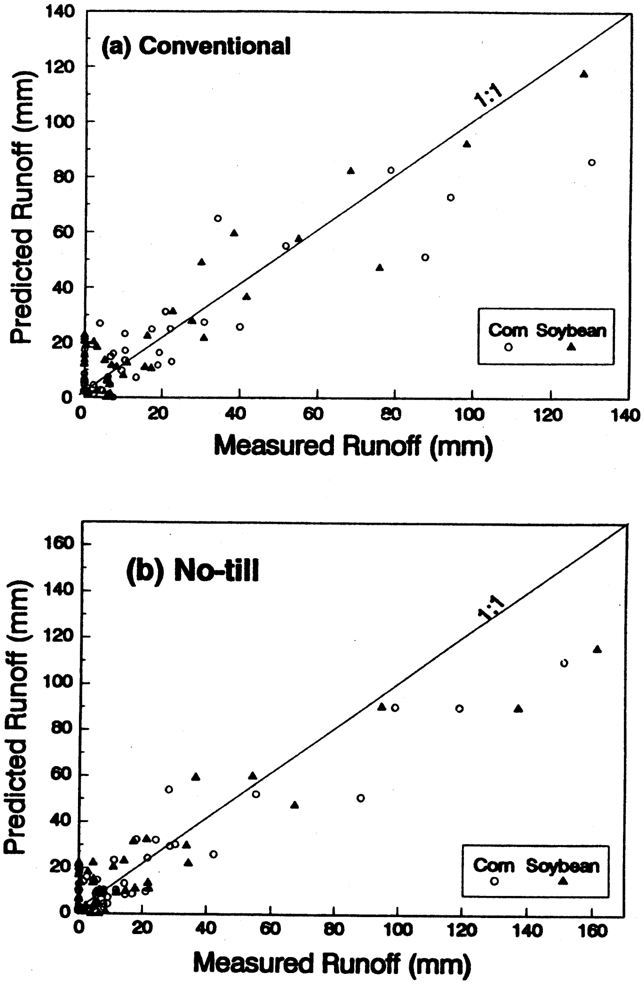

Fig. 6. Predicted and measured runoff events from (a) conventionally tilled and (b) no-till corn and soybean plots in 1983, 1985, 1990, and 1993.

a typical season, the soil profile was occupied by 6% crack volume and the soil surface by 15% crack area, with dry soils extensively cracked and wet soils not cracked at all. Thus, soil cracking is an important phenomenon in the Missouri soils and needs to be correctly predicted by the model. In this analysis, due to limitations of the model, we were forced to assume constant cracking present in the soil.

For both corn and soybean, measured runoff was slightly higher from the no-till system than from the conventional system (Fig. 5). The average annual runoff from no-till corn was 12% higher and soybean was 20% higher than from the conventional corn and soybean systems. The predicted average annual runoff from no-till corn was also 5% higher than from conventional corn; however, the predicted average annual runoff from no-till soybean was slightly lower (<3%) than from conventional soybean.

Chemical Transfer to Surface Runoff

Chemical concentrations in surface runoff measured from Field 1 of the Missouri MSEA in 1993 were used in the analysis. Runoff events were measured 3, 23, 41, 45, 54, and 60 d after chemical application. The predicted and measured NO_3–N, atrazine, and alachlor concentrations in surface runoff are presented in Table 7. Chemical concentrations were very low in the runoff events that occurred 60 d after application. The NO_3–N concentrations in surface runoff were greatly overpredicted for all events. Predicted atrazine and alachlor concentrations in runoff compared well with those measured, except for the event (33 mm of rainfall) that occurred 3 d after chemical application, when 1.8 mm of runoff was measured from the area but the model predicted 5.3 mm of runoff. For this event, the model underpredicted atrazine and alachlor concentrations by more than 50%. In contrast, the model overpredicted NO_3–N concentration by more than 80%. The lower chemical concentration is the result of high runoff prediction. The difference between the predicted and measured atrazine and alachlor mass losses to runoff for this event was less than the difference in concentrations. The predicted atrazine and alachlor mass losses to runoff were 6.14 and 6.8 g ha^{-1}, compared with the measured 5.4 and 4.2 g ha^{-1}, respectively. In the following events, the predicted atrazine and alachlor concentrations and amounts compared well with those measured.

Table 7. Measured and RZWQM-predicted surface runoff and NO_3–N, atrazine, and alachlor concentrations in surface runoff from Field 1 under FS1 at the Missouri MSEA site.†

				Concentrations in surface runoff					
		Runoff		NO_3–N		Atrazine		Alachlor	
Days after application	Rainfall	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
	mm			mg L^{-1}		μg L^{-1}			
3	32.3	1.8	5.3	36.9	66.9	300.9	114.8	235.5	127.3
23	38.4	13.6	12.4	27.1	58.9	81.6	43.4	21.8	18.6
41	29.2	3.4	7.4	8.3	115.3	16.6	16.4	3.7	4.0
45	25.9	13.6	11.4	4.2	32.7	13.9	11.0	2.7	2.6
54	38.4	18.0	18.5	1.7	2.5	2.9	1.0	1.0	1.0
60	28.5	6.7	10.0	1.0	5.2	1.3	4.2	1.0	1.0

† FS1, Farming System 1 (high chemical input, minimum-tillage corn–soybean rotation).

For both atrazine and alachlor, predicted and measured total losses to runoff were less than 1% of the amounts applied to the soil. The total predicted losses were 0.64% for atrazine and 0.92% for alachlor, compared with measured losses of 0.43 and 0.33%. The total predicted NO_3–N loss to runoff was 12.7% of that applied, compared with the 2.6% loss measured. As previously mentioned, the model underpredicted NO_3–N concentrations in the near soil surface throughout the sampling periods; this could be attributed to NO_3–N overprediction in surface runoff.

SUMMARY AND CONCLUSIONS

Data from the Missouri MSEA site and from the Kingdom City runoff plots were used to test the performance of RZWQM Version 3.2 for claypan soils. Soil water content predictions of the model compared well with those measured at the 15-, 60-, 75-, and 90-cm depths; however, the model underpredicted at the 30- and 45-cm depths.

For corn under FS1 and FS5, predicted yields were within 15% of those measured, except for 1992 corn FS5, where the model overestimated by 50%. The low yield in this year could be due to factors (such as weeds, insect damage, or disease) that the model does not take into account. Estimated soybean yields were also within 20% of those measured, except for 1994 soybean under both FS1 and FS5, where the model underestimated by almost 35%. Both measured and predicted soybean yields were very low in 1994 (a relatively dry year).

Insufficient data were available to evaluate the performance of the model to predict chemical concentrations in the soil profile. Samples for chemical concentrations in the soil profile analysis from the MSEA plots were collected before planting and after harvest only. In the future, for further evaluation of the model, samples should be taken at several periods during the growing season. For the limited data available, the predicted NO_3–N, atrazine, and alachlor concentrations were within the ranges of the measured values.

Throughout the growing season, NO_3–N and atrazine concentrations were detected in the seepage water from the MSEA plots. However, the measured nitrate and herbicide losses varied greatly within plots under the same farming system. Because of this, it was difficult to evaluate the performance of the model regarding the prediction of agrichemical movement below the root zone. The model did not predict any chemical losses to seepage when it was run with the assumption that no macropores exist in the soil. Model prediction improved when the macropore option was included.

For both corn and soybean under conventional and no-till systems, the total runoff prediction during the simulation period compared well with that measured. However, there was great variability when some individual events were compared. Generally, the model underestimated runoff for large events (>100 mm) and overestimated runoff for events that occurred after a long dry period when soil cracking was a dominant factor. Measured and predicted runoff was higher from no-till corn and soybean systems than from conventional tillage corn and soybean systems.

The model overpredicted NO_3–N concentration and mass in surface runoff throughout the growing season. Predicted atrazine and alachlor concentrations in runoff compared well, except for the runoff event that occurred immediately (3 d) after application. For this event, the model overpredicted runoff, which resulted in lower herbicide concentrations in runoff. For both atrazine and alachlor, predicted and measured total mass losses were less than 1% of the amounts applied to the soil.

Generally, the model performed reasonably well in predicting soil water content, grain yield, runoff, chemical concentrations in runoff and seepage, and chemical concentrations in the soil profile. However, one major limitation of RZWQM is that the cracks specified in the model cannot be changed during the simulation period. In a claypan soil, cracking is an important phenomenon, particularly during a dry period. Although applying the constant cracking assumption improved model predictions, the model underestimated runoff and chemical concentrations in runoff for wet periods, where cracking does not exist. To improve the predictions of runoff, seepage, and chemical concentrations in runoff and seepage (particularly in areas where soil cracking is a dominant factor), the model needs to include a routine that estimates soil cracking based on soil moisture content.

REFERENCES

Ahuja, L.R., and O.R. Lehman. 1983. The extent and nature of rainfall–soil interaction in the release of soluble chemicals to runoff. J. Environ. Qual. 12:34–40.

Alberts, E.E., T. Prato, N.R. Kitchen, and D.W. Blevins. 1993. Research and education to improve surface and ground water quality of a claypan soil. p. 21–38. Proc. Agric. Res. to Protect Water Quality Conf., Minneapolis, MN. 21–24 Feb. Soil Water Conserv. Soc., Ankeny, IA.

Alberts, E.E., A.T. Hjelmfelt, Jr., W.W. Donald, and N.R. Kitchen. 1995. Herbicide transport in surface runoff from three field-sized watersheds in Missouri. p. 5–8. *In* Clean water–clean environment–21st century. ASAE Conf. Proc., Kansas City, MO. Vol. 1. ASAE, St. Joseph, MI.

Baer, J.U., H.V. Kazemi, D.F. Hughes, and S.H. Anderson. 1995. Shrinkage cracks and chemical leaching in a Missouri claypan soil. p. 9–12. *In* Clean water–clean environment–21st century. ASAE Conf. Proc., Kansas City, MO. Vol. 1. ASAE, St. Joseph, MI.

Blanchard, P.E., W.W. Donald, and E.E. Alberts. 1995. Herbicide concentrations in ground water in a claypan soil watershed. p. 21–24. *In* Clean water–clean environment–21st century. ASAE Conf. Proc., Kansas City, MO. Vol. 1. ASAE, St. Joseph, MI.

Burkhart, M.R., and D.W. Koplin. 1993. Hydrologic and land-use factors associated with herbicides and nitrate in near surface aquifers. J. Environ. Qual. 22:646–656.

Ghidey, F., and E.E. Alberts. 1996. Comparison of measured and WEPP predicted runoff and soil loss from Midwest claypan soil. Trans. ASAE 39(4):1395–1402.

Ghidey, F., E.E. Alberts, and S.J. Birrell. 1994. Spatial and temporal variability in agrichemicals from a claypan soil. ASAE Pap. 94-2556.

Hua, Y.-X. 1995. The role of variable cracking on agrichemical transport at the Missouri MSEA site using RZWQM model. M.S. thesis. Univ. of Missouri–Columbia.

Hughes, D.F., N.R. Kitchen, W.W. Donald, and E.E. Alberts. 1995. Root-zone water quality and grain production at the Missouri MSEA. p. 137–120. *In* Clean water–clean environment–21st century. ASAE Conf. Proc., Kansas City, MO. Vol. 3. ASAE, St. Joseph, MI.

Jamison, V.C., D.D. Smith, and J.F. Thornton. 1968. Soil and water research on a claypan soil. USDA-ARS Tech. Bull. 1379. U.S. Gov. Print. Office, Washington, DC.

Kitchen, N.R., D.F. Hughes, W.W. Donald, and E.E. Alberts. 1998. Agrichemical movement in the root-zone of claypan soils: Ridge- and mulch-tillage farming systems compared. J. Soil Till. Res. 48: 179–193.

RZWQM Development Team. 1992. Root Zone Water Quality Model. Version 1.0. Technical documentation. GPSR Tech. Rep. 2. USDA-ARS, Fort Collins, CO.

Thurman, E.M., D.A. Goolsby, M.T. Meyer, M.S. Mills, M.L. Pomes, and D.A. Koplin. 1992. A reconnaissance study of herbicides and their metabolites in surface water of the Midwestern United States using immunoassay and gas chromatography/mass spectrometry. Environ. Sci. Technol. 26:2440–2447.