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Abstract

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Calibration and Evaluation of Subsurface Drainage Component of RZWQM V.2.5

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ABSTRACT

This study was designed to calibrate and evaluate the subsurface drain flow component of the Root Zone Water Quality Model (RZWQM; Version 2.5) for four tillage-systems: chisel plow (CP), moldboard plow (MB), no-tillage (NT), and ridge-tillage (RT). Measured subsurface drain flow data for 1990 was used for model calibration. Main parameters calibrated were lateral saturated hydraulic conductivity, and effective porosity. Subsurface drain flow predictions were made using calibrated parameters and compared with measured subsurface drain flows for 1991 and 1992. Measured subsurface drain flow data for all 3 yrs was obtained from the Nashua Water Quality Site in Iowa. The model, in general, showed a good agreement between measured and predicted subsurface drain flow values, although discrepancies existed for several days of a given year. Coefficients of determination calculated for predicted vs. measured daily subsurface drain flows ranged from 0.51 to 0.68 for 1990, 0.70 to 0.78 for 1991, and 0.54 to 0.69 for 1992. Simulated tillage effect on subsurface drain flows for 1991 and 1992 were consistent with those for calibrated year 1990 (maximum subsurface drain flow was observed under NT and minimum under MB). However, observed tillage effects varied from year to year, indicating a change in soil hydraulic properties, e.g., macroporosity. Other factors that could have caused the discrepancies between measured and simulated subsurface drain flows were: groundwater flux due to natural gradient, deep seepage, inaccuracies involved in the estimation of breakpoint rainfall data, and spatial variability in soil properties.

SUBSURFACE DRAINAGE has made agricultural development possible on much of the most productive land in the midwestern USA by supplementing natural drainage and enhancing crop growth conditions. Subsurface drainage of wet areas alters the time and route by which excess precipitation reaches surface waters. Decreases in the amount of overland flow, increases in percolation, lowering of the water table, and alteration in the flow path of some of the infiltrated water result from subsurface drainage (Baker and Johnson, 1976).

The subsurface drainage response of a given soil system can be influenced by soil type, agricultural management practices, rainfall pattern, and topography, as well as by subsurface conditions. Tillage practices directly affect the soil water properties of surface soil and therefore the leaching characteristics (Kanwar et al., 1988). Tillage practices can also influence the distribution and continuity of soil macropores that can act as preferential pathways for rapid movement of water and chemicals to the groundwater (Singh et al., 1991; Logsdon et al., 1990). Because of concerns about nonpoint source pollution, the fate of agricultural chemicals under different tillage systems is of considerable interest and importance. Therefore it is necessary to understand all the factors that affect chemical transport and fate. Investigating the quantity and quality of subsurface drainage water under different tillage systems can be helpful in understanding the leaching characteristics of soil under different tillage systems and in determining the suitable tillage practices for water quality protection. For example, Kanwar and Baker (1991) studied the effects of four tillage systems: CP, MB, NT, and RT, on the quantity and quality of subsurface drain flows. They reported that greater drain flows from no-tillage plots under continuous corn (*Zea mays* L.) resulted in larger NO_3-N losses in comparison with NO_3-N losses from other tillage systems. Several other studies have been conducted to measure the loss of NO_3-N through subsurface drainage (Burwell et al., 1976; Taylor and Thomas, 1977; Gast et al., 1978; Baker and Johnson, 1981; Gold and Loudon, 1982; Kanwar et al., 1985, 1988, 1993a,b).

Several modeling studies have also been conducted involving the development and utilization of mathematical models to simulate subsurface drainage. Kirkham (1958) developed an analytical solution for steady-state flow to parallel tile drains in a homogenous soil underlain by impermeable layers. Dutt et al. (1972) and Duffy et al. (1975) developed mathematical models of biophysiochemical processes that could be applied to a tile-drained agricultural area. Skaggs (1978) developed a computer simulation model DRAINMOD that simulates the movement of soil water as affected by various subsurface water-management systems. DRAINMOD has been extended further as DRAINMOD-N for predicting N transport, uptake, and transformation in artificially drained soils. Kanwar et al. (1983) developed a computer simulation model to simulate N losses with tile drainage water. Scotter et al. (1990) developed a simple numerical solution for transient soil water flow to a mole drain for assumed or measured values for rainfall, evaporation, deep percolation, drain spacing, and depth. Workman and Skaggs (1990) developed a water-management model capable of simulating preferential flow. The recent addition of a subsurface drainage component in the RZWQM (Johnsen et al., 1995) provides the option of simulating subsurface drain flows and evaluate the effects of different tillage practices on subsurface drain flows.

The main purpose of this research was to calibrate and evaluate the subsurface drainage component of the RZWQM (USDA-ARS, 1992a,b) by using subsurface drain flow data from the Nashua Water Quality Research

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Abbreviations: RZWQM, root zone water quality model; CP, chisel plow; MB, moldboard plow; NT, no-tillage; RT, ridge-tillage; BD, bulk density; WEPP, Water Erosion Prediction Project; DOY, day of year; CD, coefficient of determination.

Site located at the Northeast Research Center near Nashua, IA. The specific objectives of this research were:

1. Calibrate the subsurface drain flow component of RZWQM by using measured subsurface drain flow data for four different tillage systems: CP, MB, NT, and RT under continuous corn production for 1990.
2. Evaluate the performance of the RZWQM model by predicting subsurface drain flows for different tillage systems for 1991 and 1992 and comparing those with field-measured subsurface drain flow values.

SUBSURFACE DRAINAGE COMPONENT OF THE RZWQM (V.2.5)

This section describes RZWQM components dealing with water movement through soil profile. The water flow process in RZWQM is divided into two phases: (i) infiltration into soil matrix and macropores and macropore-matrix interaction during a rainfall or irrigation, modeled by using the Green-Ampt approach (Green and Ampt, 1911; Ahuja, 1983); and (ii) redistribution of water in the soil matrix following infiltration, modeled by a mass conservative numerical solution of the Richard's equation (Celia et al., 1990). The two domains of flow, soil matrix and macropore channels, interact through walls of macropore channels.

Potential evapotranspiration calculations are based on a closed form solution of Penman Montieth equation (Shuttleworth and Wallace, 1985) which provides both canopy transpiration and substrate evaporation. Actual evapotranspiration calculations incorporate stomatal resistance and soil resistance as a function of soil water conditions. Input parameters are corrected to reflect a substrate that is made up of both residue and bare soil. A detailed account of water management processes is given in the technical documentation of RZWQM (USDA-ARS, 1992a).

Subsurface drainage is also included in the RZWQM Version 2.5 (Johnsen et. al., 1995). The subsurface drainage rate is calculated from Hooghoudt's steady-state equation (Bouwer and van Schilfgaarde, 1963) as applied by Skaggs (1978). This equation is intended to correct for the 2-D effects of tile drainage by estimating this flux at the center point between two parallel drains. The depth of the water table is defined as the depth at which the pressure head is nonnegative, assuming the heads change linearly between numerical nodes. The calculated drainage rate is satisfied either through a point sink term in the Richard's equation for redistribution, or by drainage through a distributed sink extending from the top of the water table to two soil layers below the tile drain. Thus, model estimates of the depth of the water table are given at the midpoint between drains.

The RZWQM requires knowledge of the soil physical and hydraulic properties (some of which can be estimated by the model), rainfall data, and evapotranspiration rates. Soil physical properties include: horizon delineation, bulk density, particle density, porosity, and texture. Soil hydraulic properties include Brooks-Corey parameters (Brooks and Corey, 1964) of soil water content-matric suction relationship and the unsaturated hydraulic conductivity-matric suction relationship. The hydraulic properties can either be specified for each horizon or can be estimated by the model (based on the knowledge of soil physical properties and 1/3 bar or 1/10 bar water suction). To calculate tile drainage rates, it also requires knowledge of the depth to the drain, drain spacing, effective drain radius, and lateral saturated hydraulic conductivity (assumed equal to the vertical saturated hydraulic conductivity if the former is unknown). This version of RZWQM (V.2.5) did not have a freeze-thaw component so the model cannot be run for winter period for the sites where freezing-thawing is an important component of weather cycle.

FIELD EXPERIMENTS AND INPUT DATA NEEDS

Observed subsurface drain flow data were collected from a water quality site at Iowa State University's Northeast Research Center (NERC) near Nashua, IA (Kanwar et al., 1993a). The following sections describe the experimental site, measured subsurface drain flow data, and the input data needed for simulations.

Description of the Experimental Site and Observed Subsurface Drain Flow Data

The continuous corn plots at this study site are located on Kenyon, Readlyn, and Floyd soils with 2 to 3% organic matter. Kenyon is classified as fine-loamy, mixed, mesic, Typic Hapludoll, Floyd as fine loamy, mixed, mesic Aquic Hapludoll, and Readlyn as fine loamy, mixed, mesic Typic Hapludoll. These soils have seasonally high water tables and benefit from subsurface drainage. Sixty meters of pre-Illinoian till units overlie a carbonate aquifer. However, in some areas bedrock is near the surface. The site has 36, 0.4-ha experimental plots with fully documented tillage and cropping records for the past 14 yr. Tile lines were installed about 1.2-m deep at 28.5-m spacings in 1979. Each 0.4-ha plot has one tile line passing through the middle of the plot and there is a tile line at each of the plot borders. The middle tile lines of all the plots were intercepted and connected to individual sumps in December 1988 for measuring subsurface drainage and collecting water samples for chemical analysis. A detailed description of the automated subsurface drain-monitoring system is given by Kanwar and Baker (1991). Cumulative subsurface drain flows were monitored for each plot on alternate days. Subsurface drain flows for the missing days were linearly interpolated from the cumulative subsurface drain flows values on the days before and after.

Long-term tillage studies (three replications of each tillage treatment) were initiated at this site in the fall of 1977 to evaluate the effects of CP, MB, NT, and RT systems on subsurface drainage water quantity and quality.

Model Input Data

Climatic Data

The model requires daily input values of air temperature (minimum and maximum), wind speed, short wave radiation, and relative humidity. All the daily climate data were available for the Nashua weather station except wind speed and pan evaporation. When the data on wind speed are missing, the model assumes a wind speed of 100 km/d.

The model requires values of surface albedos for dry and wet soil, mature crop and residue, and sunshine fraction as input. These albedos provide the base value of energy reflectance from these surfaces. The albedos are modified as environmental conditions change. Surface albedos were taken from Jury et al. (1991).

The model requires input of rainfall data as breakpoint rainfall data. If a given rainfall event is plotted as cumulative rainfall vs. time, each point where there is a substantial change in slope (representing a change in rainfall intensity) will represent a breakpoint. For the simulations for 1990, 1991, and 1992, hourly rainfall data from the Nashua weather station were acquired and following procedure was used to get an approximate breakpoint rainfall data from hourly rainfall data. Cumulative rainfall was plotted as a function of time for each rainfall event and breakpoints were recorded wherever there was a substantial change in the slope of the cumulative rainfall vs. time curve. Therefore the time increments for the breakpoint rainfall data were equal to or more than 1 h. It should be noted that this approximation procedure could cause underestimation of peak rainfall intensities. For the period when hourly rainfall data were not available (due to equipment malfunction), daily rainfall values were obtained from the NERC nonrecording rain gage observations. A similar rain event (approximately equal in magnitude) was selected from hourly rainfall data for the Nashua weather station. The pattern of this hourly rainfall was used to estimate breakpoints for the missing rainfall event. Total rainfall for 1990, 1991, and 1992 (DOY 70-300) were 102.2, 84.8, and 65.0 cm, respectively.

Soil Properties Data

A 2.52-m deep soil profile was considered for model simulations. This profile was divided into seven to nine soil horizons depending on the information gathered from soil survey reports for Kenyon, Readlyn, and Floyd soils (USDA-SCS, 1982). For each horizon, physical soil properties, for example, soil bulk density (BD), porosity (estimated by BD and a particle density of 2.65 Kg/m^3), and particle-size distribution were used as input to the model. Soil bulk densities for the surface horizon, and particle-size distribution for all the horizons were experimentally measured. Singh (1994) described the detailed methodology of these measurements. Bulk densities for the rest of the horizons were taken from Sharpley and Williams (1990). Among soil hydraulic properties, only soil water content at 33 kPa suction (Θ_{33kPa}) for each soil horizon was taken from Sharpley and William (1990) and specified as input. All other hydraulic properties, such as saturated/unsaturated hydraulic conductivity, effective porosity, and bubbling pressure, were estimated by the model based on BD, Θ_{33kPa}, and texture data. Tables 1, 2, and 3 show selected soil properties for Kenyon, Floyd, and Readlyn soils as a function of horizon.

Table 1. Selected soil properties for Kenyon, Floyd, and Readlyn soil as a function of horizons, used as input for subsurface drainage simulations.

Horizon no.	Depth, m	Bulk density, Mg/m^3	Porosity, m^3/m^3	Particle size dist, %† sand	silt	clay
		Kenyon soil				
1	0.0-0.20	1.36†	0.49	38	42	20
2	0.20-0.41	1.53	0.43	41	34	25
3	0.41-0.50	1.55	0.42	42	32	26
4	0.50-0.69	1.60	0.40	43	30	27
5	0.69-0.89	1.65	0.38	44	28	28
6	0.89-1.23	1.70	0.36	44	31	25
7	1.23-1.67	1.75	0.34	44	31	25
8	1.67-2.52	1.75	0.34	44	31	25
		Floyd soil				
1	0.0-0.43	1.29*	0.51	30	44	26
2	0.43-0.58	1.40	0.47	33	42	26
3	0.58-0.85	1.45	0.45	54	22	24
4	0.85-1.15	1.58	0.40	47	29	24
5	1.15-1.40	1.70	0.36	35	40	25
6	1.40-1.53	1.70	0.36	35	40	25
7	1.53-2.52	1.75	0.34	35	40	25
		Readlyn soil				
1	0.0-0.20	1.34*	0.49	31	43	26
2	0.20-0.30	1.45	0.45	31	43	26
3	0.30-0.43	1.45	0.45	37	38	25
4	0.43-0.54	1.50	0.43	37	38	25
5	0.54-0.68	1.60	0.40	55	24	21
6	0.68-0.89	1.65	0.38	46	28	26
7	0.89-1.10	1.70	0.36	46	28	26
8	1.10-1.50	1.70	0.36	46	28	26
9	1.50-2.52	1.70	0.36	46	28	26

† Experimentally measured (Singh, 1994).

Plant Growth Variables and Parameters

RZWQM uses a generic plant growth model to simulate corn growth. Default values of plant growth parameters were used for the generic growth model, as recommended in the RZWQM user manual. Planting and harvesting days, number of plantings, planting depth, planting density, harvesting efficiency, etc., are input to the model and were based on the actual field information collected at the research site.

Tillage Management Variables

RZWQM needs tillage related information to simulate tillage effects on soil properties (bulk density, macroporosity, hydraulic properties, and residue incorporation). This information mainly consists of date of tillage, tillage implement used, depth of tillage, tillage intensity, etc. Simple approximate relations are adopted in the tillage management component of the RZWQM to describe changes in soil properties. The extent of these changes depends on the depth and intensity of tillage operation. The algorithm used for the tillage induced bulk density changes is adopted from USDA- Water Erosion Prediction Project (WEPP) model (Alberts et al., 1989). In the RZWQM macroporosity change is assumed to be equal to that of bulk density but in the opposite direction. As a result of tillage, soil bulk density is decreased and population of macropores increased within the tilled zone. The tilled zone is assumed to reconsolidate with time as a function of rainfall energy and amount received after tillage. Tillage-related information was obtained from field staff at the Nashua Water Quality site and specified as input to the model.

Table 2. A list of calibrated parameters for each plot and total observed and predicted subsurface drain flows for 1990.

Plot no.	Soil type	Tillage treat.	LKsat, mm/h	EP, m^3/m^3	Predicted flow, mm	Observed flow, mm	Percent diff.
6	Readlyn	RT†	29.0	0.20	236.0	231.0	+2.5
36	Kenyon	RT	25.0	0.18	133.0	121.0	+9.9
32	Floyd	RT	28.0	0.20	212.6	222.0	−4.2
AVG			27.3	0.19	193.9	191.0	+1.4
SD			2.1	0.01	54.0	61.0	
25	Kenyon	NT	31.0	0.20	245.2	270.0	−9.2
14	Readlyn	NT	31.0	0.20	266.7	282.0	−5.4
31	Floyd	NT	32.0	0.20	232.3	258.0	−9.9
AVG			31.3	0.20	248.0	270.0	−8.1
SD			0.6	0.00	18.0	12.0	
35	Readlyn	MB	10.0	0.17	64.2	59.0	+8.5
13	Floyd	MB	23.0	0.19	125.4	117.0	+7.1
22	Readlyn	MB	22.0	0.18	101.6	98.0	+3.7
AVG			18.3	0.18	97.0	91.0	+6.6
SD			7.23	0.01	31.0	30.0	
26	Kenyon	CP	30.0	0.20	225.2	227.0	−0.8
21	Readlyn	CP	30.0	0.20	202.4	194.0	+4.3
5	Readlyn	CP	25.0	0.18	138.0	128.0	+7.8
AVG			28.3	0.19	188.3	183.0	+2.7
SD			2.9	0.01	45.0	50.0	

† CP = chisel plow; MB = moldboard plow; NT = no-tillage; RT = ridge-tillage. AVG = average; SD = standard deviation.

Table 3. A summary of total observed and predicted subsurface drain flows for 1991 and 1992.

			Results for 1991			Results for 1992		
Plot no.	Soil type	Tillage treat.	Predicted flow, mm	Observed flow, mm	Percent difference	Predicted flow, mm	Observed flow, mm	Percent difference
6	Readlyn	RT	267.0	303.0	−11.9	134.0	99.0	+35.3
36	Kenyon	RT	230.0	298.0	−22.8	74.0	112.5	−34.2
32	Floyd	RT	287.0	377.0	−23.8	125.0	99.0	+26.6
AVG			261.3	326.0	−19.9	111.0	103.0	+7.8
SD			29.0	44.0		32.3	7.8	
25	Kenyon	NT	321.0	301.0	+6.6	187.0	213.9	−12.5
14	Readlyn	NT	272.0	345.0	−21.1	174.2	165.0	+5.4
31	Floyd	NT	281.0	361.0	−22.1	185.0	259.0	−28.5
AVG			291.0	336.0	−13.4	182.0	213.0	−14.6
SD			26.0	31.0		7.0	47.0	
35	Readlyn	MB	104.0	161.0	+35.4	56.0	99.0	−43.4
13	Floyd	MB	179.0	224.0	−20.0	90.0	159.0	−43.4
22	Readlyn	MB	183.0	169.0	+8.2	86.0	75.0	+14.6
AVG			155.3	185.0	−16.0	77.3	111.0	−30.3
SD			44.5	34.0		18.6	43.0	
26	Kenyon	CP	308.0	311.3	−1.1	143.0	154.3	−7.1
21	Readlyn	CP	243.0	289.0	−16.0	144.0	130.0	+10.8
5	Readlyn	CP	202.0	215.0	−6.0	106.0	100.0	+6.0
AVG			251.0	271.0	−7.4	131.0	128.0	+2.3
SD			53.0	50.0		22.0	27.0	

CP = chisel plow; MB = moldboard plow; NT = no-tillage; RT = ridge-tillage; AVG = average; SD = standard deviation.

MODEL SIMULATIONS AND EVALUATIONS

Boundary and Initial Conditions

To simulate fluctuating water table conditions, an impermeable layer was assumed at a depth of 2.52 m, which is a reasonable assumption for this site. Deep seepage through this impermeable layer was assumed to be equal to zero. The upper boundary of the soil profile system being modeled was characterized by infiltration and evaporation rate at the surface layer.

Initial soil water content and temperature of the soil profile were needed as input to the model for subsurface drain flow simulations. Initial soil water content was set equal to Θ_{33kPa} (field capacity), but was adjusted in the subsequent simulations to begin the subsurface drain flows at approximately the same time subsurface drain flows actually began in the field. Initial water table depth was set equal to 1.2 m (equal to depth of tile drains). The initial temperature profile was adopted from Hillel (1982) for the spring season.

Model Calibration

The subsurface drainage component of the model was calibrated by using the measured daily subsurface drain flow data from the year 1990, a year with sustained subsurface drain flows. Calibration was done for 12 continuous corn plots on a plot-by-plot basis (four different tillage systems, CP, MB, NT, and RT, with three replications under each tillage system). The criterion used for calibrating the model was to minimize the difference between the measured and predicted cumulative subsurface drain flows for a period covering the entire growing season of 1990 (Day of Year-DOY 70–300; 11 March–27 October). A trial and error procedure was used to determine the best values of two main soil hydraulic parameters: effective porosity, EP – defined as difference between soil water content at saturation and soil water content at field capacity ($\Theta_s - \Theta_{33kPa}$), and lateral saturated hydraulic conductivity, LKsat. Relative sensitivity of EP and LKsat was found to be largest in a sensitivity analysis done by Singh (1994). Subsurface drainage response of the model was sensitive to EP, initial water content, and LKsat in a decreasing order. The EP was varied by changing the Θ_{33kPa}. The values for Θ_{33kPa} reported by Sharpley and Williams (1990) ranged from 0.22 to 0.29 m^3/m^3 for Kenyon, 0.29 to 0.17 m^3/m^3 for Readlyn soil. Calibrated values of Θ_{33kPa} in these simulations ranged from 0.32 to 0.14 m^3/m^3. LKsat affected the peak subsurface drain flows while the EP affected the entire shape of the subsurface drain flow hydrograph. First, EP was calibrated to match the shape of the simulated subsurface drain flow hydrographs with the observed subsurface drain flow hydrographs. Next, LKsat was calibrated to adjust the subsurface drain flow peaks and total subsurface drain flow volume. Sometimes matching the total subsurface drain flows required small readjustments in EP values. This procedure was continued until the shapes of simulated and observed subsurface drain flow hydrographs were in reasonable agreement and simulated total subsurface drain flows were within 10% of observed total subsurface drain flows.

Initial water content of the soil profile had a significant effect on subsurface drain flows. First, initial water content was set equal to Θ_{33kPa}, but in subsequent trials initial water content for the unsaturated soil profile was adjusted to make sure that simulated subsurface drain flow began approximately at the same time subsurface drain flow actually began in the field.

Model Testing and Evaluations

To test the ability of the model to predict system response, the model was evaluated with measured subsurface drain flow data for 1991 and 1992 for all four tillage systems, again, on a plot-by-plot basis. Initial water content in the soil profile was adjusted for these simulations in the same manner as in case of 1990 simulations. The rest of the input data were kept the same as for 1990 simulations. Simulations were conducted from DOY 70 to 300 for both 1991 and 1992. These dates cover the entire growing season for these years.

RESULTS AND DISCUSSION

Table 2 shows cumulative simulated and observed subsurface drain flows for the calibration year 1990 and

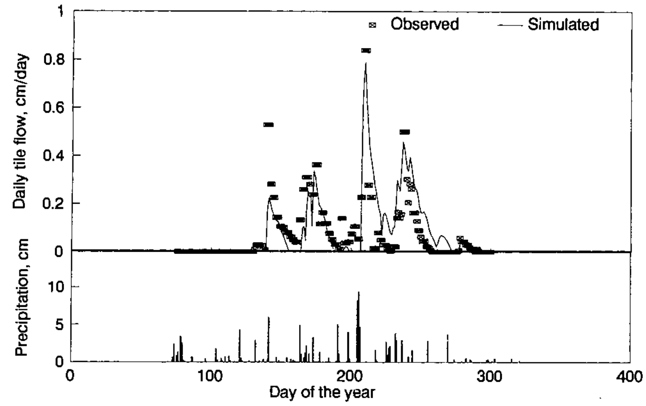


Fig. 1. Simulated and observed tile flows for plot 21 (chisel plow), 1990.

calibrated values for parameters EP and LKsat for 12 continuous corn plots under CP, MB, NT, and RT tillage treatments. Calibrated LKsat values were the highest for NT plots (average LKsat 31.3 mm/h) and lowest for MB plots (average LKsat being 18.3 mm/h). LKsat could be considered as an effective conductivity accounting for macropores in the soil system. Therefore, higher LKsat values for NT plots may be attributed to higher macroporosity under NT plots compared with other tillage treatments. Calibrated EP values ranged from 0.17 to 0.20 m^3/m^3. Table 2 also shows that simulated subsurface drain flows with calibrated LKsat and EP values were within 10% of observed flows. Standard deviations for predicted subsurface drain flows within a given tillage system were comparable with those for observed subsurface drain flows.

Figure 1 shows a typical example of the measured vs. predicted daily subsurface flows for the growing season of 1990 for a chisel plow plot. Similar graphs were made for individual plots but are not shown here due to space limitation. Observed and predicted values of subsurface drain flows generally agreed, although peak subsurface drain flows were usually underpredicted. The RZWQM predicted peak subsurface drain flows at approximately the same time they were actually observed in the field for a given plot and also predicted zero flow within a few days after the subsurface drains actually stopped flowing. Some of the discrepancy between the predicted and observed timings of peak flows could be due to (i) the error involved with the linear interpolation of observed cumulative subsurface drain flow data and (ii) approximation of breakpoint rainfall data from hourly rainfall data. Given the fact that a high degree of spatial variability exists under actual field conditions, the model predictions were encouraging.

The coefficient of determination (CD) was calculated by plotting observed vs. predicted flows for individual field plots. Pooled subsurface drain flow data from all three replicated field plots within a given tillage system were used for this purpose. The best fit line for observed vs. predicted tile flows was compared with 1:1 line. An example of best fit line for pooled observed vs. predicted subsurface drain flows for three chisel plow plots and

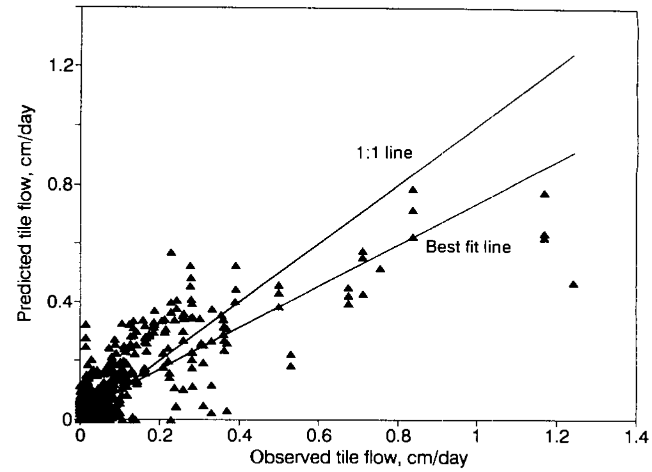


Fig. 2. An example of best fit line for pooled observed vs. predicted tile flow data (chisel plow, 1990).

its comparison with 1:1 line is shown in Fig. 2. Table 4 shows the intercept (C), CD, and slope (M) for the individual simulation runs and for pooled data for a given tillage system. The CD values for 1990 simulations (pooled data) ranged from 0.51 to 0.68. The slope of best fit lines ranged from 0.57 to 0.71 (all of them being statistically smaller than 1.0− slope of 1:1 line) indicating underestimation of subsurface drain flows by the RZWQM. A careful visual observation of the best fit lines for the pooled data (e.g., Fig. 2) revealed that few points at the end of best fit lines dominate the estimate of slope for the best fit line. The best fit line through the rest of the data, excluding few points on extreme right, usually showed a slope of approximately 1.2. Data points at the end of best fit line in Fig. 2 in fact represent peak drainage outflows. Underestimation of peak flows by the RZWQM could be due to the fact that there was no macropore flow contribution in the simulations (macropore flow was not considered in these simulations) which might have been an important part of observed peak flows. At the same time overestimation of drainage

Table 4. Intercept (C), coefficient of determination (CD), and slope (M) of best fit lines for observed vs. predicted tile flow plots.

Plot no.	Tillage treatment	1990 C	1990 CD	1990 M	1991 C	1991 CD	1991 M	1992 C	1992 CD	1992 M
6	RT†	0.04	0.58	0.57	0.02	0.70	0.74	0.02	0.71	1.2
36	RT	0.01	0.66	0.87	0.02	0.68	0.60	0.01	0.65	0.74
32	RT	0.03	0.45	0.57	0.03	0.81	0.62	0.02	0.78	1.1
Pooled data	RT	0.03	0.53	0.62	0.03	0.73	0.65	0.02	0.69	1.0
25	NT	0.04	0.55	0.54	0.03	0.80	0.88	0.04	0.44	1.1
14	NT	0.04	0.62	0.60	0.01	0.77	0.75	−0.01	0.78	1.6
31	NT	0.03	0.40	0.61	0.03	0.64	0.67	0.0	0.61	1.1
Pooled data	NT	0.04	0.51	0.57	0.03	0.72	0.76	0.02	0.56	1.1
35	MB	0.02	0.51	0.58	0.01	0.66	0.58	0.00	0.62	0.77
13	MB	0.01	0.63	0.71	0.00	0.82	0.85	−0.02	0.71	1.2
22	MB	0.02	0.55	0.69	0.02	0.67	0.85	0.02	0.45	1.2
Pooled data	MB	0.01	0.58	0.68	0.01	0.70	0.76	0.00	0.54	1.1
26	CP	0.05	0.58	0.51	0.04	0.78	0.73	0.01	0.77	1.1
21	CP	0.03	0.61	0.75	0.02	0.74	0.73	0.02	0.34	1.3
5	CP	0.02	0.60	0.76	0.01	0.86	0.89	−0.01	0.60	1.6
Pooled data	CP	0.03	0.68	0.71	0.02	0.78	0.77	0.01	0.55	1.2

† CP = chisel plow; MB = moldboard plow; NT = no-till; RT = ridge-till.

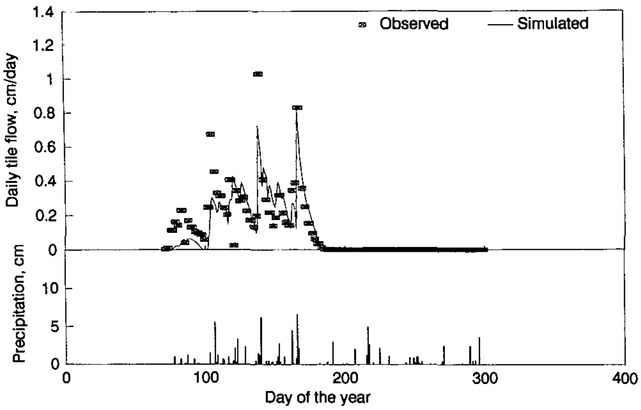
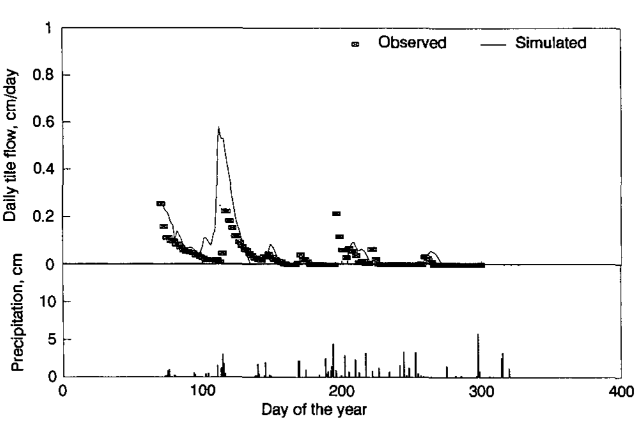


Fig. 3. Simulated and observed tile flows for plot 21 (chisel plow), 1991.

outflows in the smaller range could have been a result of underestimation of rainfall intensities due to approximation of breakpoint rainfall data from hourly data and consequently underestimation of run-off.

Table 3 gives a summary of total observed and predicted subsurface drain flows for 1991 and 1992. Figures 3 and 4 give examples of daily simulated and observed subsurface drain flows for a CP plot, respectively, for 1991 and 1992.

Predicted daily subsurface drain flows for 1991 (Fig. 3) showed a pattern similar to observed subsurface drain flows. However, subsurface drain flow peaks were usually underpredicted several times. Total subsurface drain flows were also underpredicted except for plot no. 22 (MB), 35 (MB), and 25 (NT). Percent difference between mean predicted and observed total subsurface drain flows were 19.9, 13.4, 16, and 7.4% for RT, NT, MB, and CP systems, respectively (Table 3). Again, standard deviations for predicted drainage outflows were comparable with those for observed drainage outflows within a given tillage system. The CD values (Table 4) for observed vs. predicted daily subsurface drain flows for 1991 (pooled data) ranged from 0.70 to 0.78. Slopes of best fit lines for pooled subsurface drain flow data ranged from 0.65 to 0.77 and were again statistically smaller than 1.0 (slope of the 1:1 line). Visual observation of the best fit lines showed a pattern similar to those for 1990 data, that is, overestimation of tile flows in the smaller flow range and overestimation in the larger flow range. The possible reasons for this are discussed earlier.



Simulated daily subsurface drain flows for 1992 (Fig. 4) followed the trend of observed subsurface drain flows reasonably well. Percent difference between mean predicted and observed total were 7.8, 14.6, 30.3, and 2.3% for RT, NT, MB, and CP systems, respectively. The CD values for observed vs. predicted pooled drainage outflow data (Table 4) ranged from 0.54 to 0.69 for 1992. The slopes of best fit lines for pooled data ranged from 1.0 to 1.2 and were not statistically different from 1.0 except for CP system (Table 4). It seems that in 1992 macropore flow contribution was not significant in measured peak tile flows so that peak flows were not underestimated by the model for this year.

Simulated results agreed with observed trends for 1990 and 1991 regarding the tillage effects on subsurface drain flows. For example, maximum simulated subsurface drain flows occurred under NT and minimum flows occurred under MB treatments, similar to the trends in observed subsurface drain flows. For 1992, simulated tillage effects on subsurface drain flows were similar to 1990 and 1991 simulations, but the observed tillage effects were not consistent with previous years. In 1992, maximum observed flow occurred under NT treatment and minimum observed flow occurred under RT treatment. In fact, observed total flows under RT, CP, and MB were not substantially different from each other in 1992. The year 1992 was a relatively dry year with mostly low-intensity rainfall events. Therefore, in 1992 preferential flow was probably not generated as much as in 1990 and 1991, thus minimizing the tillage effects on measured subsurface drain flows. As expected, the model's response was consistent from year to year regarding tillage effects on subsurface drain flows according to calibration done for 1990 data. However, observed tillage effects were not consistent from year to year. This inconsistency indicates that besides the rainfall pattern there are other factors affecting the subsurface drainage trends on a yearly time scale; for example, changing soil hydraulic properties, especially macroporosity. Soil macroporosity is not only affected by tillage systems, but also by changing weather conditions. Other factors that could have contributed to the difference in observed and simulated subsurface drain flow patterns were: groundwater flux due to natural gradient, deep seepage, inaccuracies involved in the estimation of breakpoint rainfall data.

Consideration also needs to be given to the spatial variability in soil properties even on a plot scale. If a field plot is located on two or more different soil types (which was the case for many field plots) predicting subsurface drainage response based on the major soil type may also contribute to some differences in the observed and simulated subsurface drain flows. Although the model is capable of showing a good response to rainfall pattern, it does not take into account the spatial variability in soil properties. The temporal changes in the soil properties due to tillage practices are incorporated in the RZWQM but weather-induced changes in the soil properties are not incorporated.

SUMMARY AND CONCLUSIONS

The RZWQM (Version 2.5) was calibrated by minimizing the differences between the cumulative predicted and observed subsurface drain flows and shapes of subsurface drain flow hydrographs for four tillage systems (CP, MB, NT, and RT) for 1990. Parameters calibrated were LKsat and EP. There was generally a good agreement between the observed and predicted daily subsurface drain flows. Time of peak flows as well as beginning and ending of simulated subsurface flows agreed well with the observed subsurface drain flow data. Coefficient of determination (CD) between observed and predicted subsurface drain flows ranged from 0.51 to 0.68 for 1990 simulations. Slopes of the best fit lines for observed and predicted subsurface drain flows were statistically smaller than 1.0 (slope of 1:1 line) mainly due to underestimation of peak flow rates by the model. Macropore flow was not considered in these simulations which might have been an important factor in peak flow events in the actual field conditions.

Performance of the RZWQM was evaluated by predicting subsurface drain flows for 1991 and 1992 under four different tillage systems by using the calibrated parameters. For both years, simulated daily subsurface drain flows followed the trends of observed flows reasonably well. However, peak flows were usually underpredicted for 1991. Coefficient of determination (CD) between the observed and predicted daily subsurface drain flows ranged from 0.70 to 0.78 for 1991 and from 0.54 to 0.69 for 1992.

Simulated tillage effects on subsurface drain flows (maximum under NT and minimum under MB) for 1991 and 1992 were consistent with those for calibrated year 1990. However, observed tillage effects for 1992 were not consistent with those in 1990 and 1991, indicating a change in soil hydraulic properties, especially macroporosity, from year to year. Some other possible causes of discrepancies between observed and predicted subsurface drain flows could be: groundwater flux due to natural gradient, deep seepage, inaccuracies involved in the estimation of breakpoint rainfall, and spatial variability in actual field conditions.

The overall evaluation of the RZWQM indicates that the model has the capability of predicting subsurface drain flows satisfactorily for different soil and weather conditions.

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REFERENCES

Ahuja, L.R. 1983. Modeling infiltration into crusted soils by the Green-Ampt approach. Soil Sci. Am. J. 47:412–418.

Alberts, E.E., M.A. Weltz, and F. Ghidley. 1989. Growth components. Chap. 8. *In* L.J. Lane and M.A. Nearing (ed.) USDA-Water Erosion Prediction Project: Hillslope Version. NSERL Rep. 2. USDA-ARS, West Lafayette, IN.

Baker, J.L., and H.P. Johnson. 1976. Impact of subsurface drainage on water quality. p. 91–98. *In* 3rd Natl. Drainage Symp., Chicago. 13–14 Dec. 1976. ASAE, St. Joseph, MI.

Baker, J.L., and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10:519–522.

Bouwer, H., and J. van Schlifgaarde. 1963. Simplified method of predicting the fall of water table in drained land. Trans. ASAE 6(4):288–291, 296.

Brooks, R.H., and A.T. Corey. 1964. Hydraulic properties of porous media. p. 1–15. *In* Hydrology Paper 3. Colorado State Univ., Ft. Collins.

Burwell, R.E., G.E. Schuman, K.E. Saxton, and H.G. Heineman. 1976. Nitrogen in subsurface discharge from agricultural waters. J. Environ. Qual. 5:325–329.

Celia, M.A., E.T. Bouloutaas, and R.L. Zarba. 1990. A general mass-conservative numerical solution for the unsaturated flow equation. Water Resour. Res. 26:1483–1496.

Duffy, J.C., C. Chung, C. Boast, and M. Franklin. 1975. A simulation model of biophysiochemical transformation of nitrogen in tile drained corn belt soils. J. Environ. Qual. 4:477–486.

Dutt, G.R., M.J. Shaffer, and W.J. Moore. 1972. Computer simulation model of dynamic bio-physiochemical processes in soils. Arizona Agric. Exp. Stn. Tech. Bull. 196.

Gast, R.G., W.W. Nelson, and G.W. Randall. 1978. Nitrate accumulation in soils and loss in the tile drainage following nitrogen application to continuous corn. J. Environ Qual. 7:258–262.

Gold, A.J., and T.L. Loudon. 1982. Nutrient, sediment, and herbicide losses in tile drainage under conservation and conventional tillage. ASAE Paper 82-2549. ASAE, St. Joseph, MI.

Green, W.H., and G.A. Ampt. 1911. Studies on soil physics. 1. Flow of air and water through soils. J. Agric. Sci. 4:1–24.

Hillel, D. 1982. Introduction to soil physics. Academic Press, New York.

Johnsen, K.E., H.H. Liu, J.H. Dane, L.R. Ahuja, and S.R. Workman. 1995. Simulating fluctuating water tables and tile drainage with a modified root zone water quality model and a new model WAFLOWM. Trans. ASAE 38(1): 75–83.

Jury, W., W.R. Gardner, and W.H. Gardner. 1991. Soil physics. John Wiley & Sons, New York.

Kanwar, R.S., and J.L. Baker. 1991. Long term effects of tillage and reduced chemical application on the quality of subsurface drainage and shallow groundwater. *In* A.B. Bottcher (ed.) Proc. of the Conf. on Environmentally Sound Agriculture, Orlando, FL. 16–18 Apr. 1991. ASAE, St. Joseph, MI.

Kanwar, R.S., J.L. Baker, and D.G. Baker. 1988. Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. Trans. ASAE 31:453–460.

Kanwar, R.S. J.L. Baker, and J.M. Laflen. 1985. Nitrate movement through soil profile in relation to tillage system and fertilization application method. Trans. ASAE 28:1802–1807.

Kanwar, R.S., H.P. Johnson, and J.L. Baker. 1983. Comparison of simulated and measured nitrate losses in the tile effluent. Trans. ASAE 5:1451–1457.

Kanwar, R.S., D.L. Karlen, T.S. Colvin, W.W. Simpkins, and V.J. McFadden. 1993a. Evaluation of tillage and crop rotation effects on groundwater quality – Nashua Project. A completion report prepared for Leopold Center for Sustainable Agriculture. Iowa State Univ., Ames.

Kanwar, R.S., D.E. Stoltenberg, R. Pfiffer, D. Karlen, T.S. Colvin, and W.W. Simpkins. 1993b. Transport of Nitrate and pesticide to shallow groundwater system as affected by tillage and crop rotation practices. p. 270–273. *In* Proc. of Conf. on Agricultural Research to Protect Water Quality. Soil and Water Conserv. Soc., Ankeny, IA.

Kirkham, D. 1958. Seepage of steady rainfall through soils into drains. Trans. Am. Geophys. Union 39:892–908.

Logsdon, S.D., R.R. Allmaras, L. Wu, J.B. Swan, and G.W. Randall. 1990. Macroporosity and its relation to saturated hydraulic conductivity under different tillage practices. Soil Sci. Soc. Am. J. 54: 1096–1101.

Scotter, D.R., L.K. Heng, L.J. Horne, and R.E. White. 1990. A simplified analysis of soil water flow to a mole drain. J. Soil Sci. 41:189–198.

Sharpley, A.N., and J.R. Williams (ed.). 1990. EPIC-Erosion Productivity Impact Calculator. User manual. USDA-ARS Tech. Bull. 1768. U.S. Gov. Print. Office, Washington, DC.

Shuttleworth, W.J., and J.S. Wallace. 1985. Evaporation from sparse crops—an energy combination theory. J. R. Meteor. Soc. III:839–855.

Singh, P. 1994. Characterizing tillage and simulating the movement of water and NO_3-N in the vadose zone by using Root Zone Water Quality Model. Paper 1. *In* Modification of Root Zone Water Quality Model (RZWQM) to simulate the tillage effects on subsurface drain flows and NO_3-N movement. Ph.D. diss. Iowa State University, Ames (Diss. Abstr. 94-24259).

Singh, P., R.S. Kanwar, and M.L. Thompson. 1991. Measurement and characterization of macropores by using AUTOCAD and automatic image analysis. J. Environ. Qual. 20:289–294.

Skaggs, R.W. 1978. A water management model for shallow water table soil. Rep. no. 134. Water Resources Res. Inst., North Carolina State Univ., Raleigh.

Taylor, D.D., and G.W. Thomas. 1977. Lysimeter measurements of nitrate and chloride losses from soil under conventional and no-tillage corn. J. Environ. Qual. 6:63–66.

USDA-ARS. 1992a. Root Zone Water Quality Model (RZWQM) V. 1.0. Technical Documentation. GPSR Tech. Rep. 2. USDA-ARS Great Plains Systems Res. Unit, Ft. Collins, CO.

USDA-ARS. 1992b. Root Zone Water Quality Model (RZWQM) V. 1.0. User's Manual. GPSR Tech. Rep. 3. USDA-ARS Great Plains Systems Research Unit, Ft. Collins, CO.

USDA-SCS. 1982. Soil Survey of Butler County, IA. USDA, SCS in cooperation with Iowa Agric. and Home Econ. Exp. Stn., Coop. Ext. Serv., Iowa State Univ., Ames and the Dep. of Soil Conserv., State of Iowa.

Workman, S.R., and R.W. Skaggs. 1990. PREFLOW: A water management model capable of simulating preferential flow. Trans. ASAE 33:1939–1948.