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Evaluation of the root zone water quality model for predicting water and NO_3–N movement in an Iowa soil[1]

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Abstract

Evaluation of computer models with field data is required before they can be effectively used for predicting agricultural management systems. A study was conducted to evaluate tillage effects on the movement of water and nitrate–nitrogen (NO_3–N) in the root zone under continuous corn (*Zea mays L.*) production. Four tillage treatments considered were: chisel plow (CP), moldboard plow (MP), no-tillage (NT), and ridge-tillage (RT). The root zone water quality model (RZWQM: V.3.25) was used to conduct these simulations. Three years (1990–1992) of field observed data on soil water contents and NO_3–N concentrations in the soil profile were used to evaluate the performance of the model. The RZWQM usually predicted higher soil water contents compared with the observed soil water contents. The model predicted higher NO_3–N concentrations in the soil profile for MP and NT treatments in comparison with CP and RT treatments, but the magnitude of simulated NO_3–N peak concentrations in the soil profile were substantially different from those of the observed peaks. The average NO_3–N concentrations for the entire soil profile predicted by the model were close to the observed concentrations except for ridge tillage (percent difference for CP=+5.1%, MP=+12.8%, NT=+18.4%, RT=−44.8%). Discrepancies between the simulated and observed water contents and NO_3–N concentrations in the soil profile indicated a need for the calibration of plant growth component of the model further for different soil and climatic conditions to improve the N-uptake predictions of the RZWQM.

Keywords: Modeling; Groundwater pollution; Tillage practices; RZWQM; Nitrate–nitrogen

1. Introduction

Several studies have confirmed the presence of agricultural chemicals in groundwater in Iowa and other North Central region states of the United States (Hallberg et al., 1985; Gish et al., 1991; Spalding et al., 1989; Parsons and Witt, 1988). Nitrate–N is the most common agricultural chemical found in the groundwater. Parsons and Witt (1988) have also reported on the presence of 73 pesticides in the groundwater of 34 states.

Nitrogen fertilizers and pesticides applied to the soil surface prior to and immediately after the planting operation are particularly susceptible to loss through

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surface runoff or leaching to groundwater through the soil profile. Tillage practices modify the physical and hydraulic properties of the soil, and therefore, affect the amounts of water and chemicals moving both over and through the soil water (Blevins et al., 1990). For example, tillage disrupts macropores (structural cracks, worm or root holes), whereas no-tillage systems allow macropore networks to develop and persist. These macropores may act as preferential pathways for rapid movement of water and/or chemicals in the solution phase. Conservation tillage systems often reduce surface water contamination because soil erosion and water runoff are reduced. At the same time, concern is raised that conservation tillage may increase groundwater contamination because of increased infiltration. This shows a clear need for evaluating the impacts of different tillage systems on the subsurface movement of water and chemicals.

Several studies have been conducted that focus on experimentally determining tillage effects on soil and water quality (Kanwar et al., 1991; Brinsfield et al., 1987; Weed, 1992), but little work has been done on simulating tillage effects on the subsurface water and chemical movement and comparing these predictions with observed data (Singh and Kanwar, 1995). The root zone water quality model (RZWQM, V. 3.25) developed by USDA-ARS (1992) has not yet been evaluated for its predictions for NO_3–N concentrations in the soil profile. Therefore, this study was designed to evaluate the latest version of the RZWQM to simulate water and NO_3–N movement through the vadose zone under four tillage systems, namely chisel plow, moldboard plow, no-tillage, and ridge tillage and compare the simulations with the observed data. Soil properties selected to characterize different tillage systems were bulk density (BD), residue cover, and macroporosity (MP).

2. Materials and methods

2.1. A brief overview of RZWQM

The RZWQM (V.3.25) has been developed to simulate the movement of water, nutrients, and pesticides over and through the root zone of a unit area. It is primarily a one-dimensional model designed to simulate conditions at a representative point (unit area) in a field. The model can be used as a tool for assessing the impacts of alternative agricultural management strategies on the subsurface environment. These alternatives include evaluation of management plans on a field-by-field basis, different levels of conservation tillage, surface sealing effects, and water quality impacts of irrigation and methods of fertilizer and pesticide application. The root zone water quality model consists of six subsystems or processes that define the simulation program: physical, plant growth, soil chemical, nutrient, pesticide, and management processes.

2.1.1. Physical processes

Physical processes include interrelated hydrological processes such as infiltration, chemical transport during infiltration, transfer of chemicals to runoff during rainfall, water and chemical flow through macropore channels and their absorption by the soil matrix, soil hydraulic properties estimation from BD and 33 or 1500 kPa water content, heat flow, evapotranspiration, root water-uptake and soil water redistribution, and chemical transport during redistribution. Soil surface evaporation and plant transpiration are calculated by using a form of the Penman–Monteith equation (Decoursey, 1992) that enables each component to be separately identified based on an energy-transfer approach. These daily evaporation and transpiration rates are impacted by continuously changing soil and cover conditions brought about by tillage, residue accumulation, plant growth, and soil water movement.

2.1.2. Plant growth processes

The plant growth model predicts the relative response of plants to changes in environment. Environmental change can be manifested either as normal variations in climatic variables or by differences in management practices. The model simulates carbon dioxide assimilation, carbon allocation, dark respiration, periodic tissue loss, plant mortality, root growth through the soil profile, transpiration, and nitrogen (N) uptake.

2.1.3. Soil chemical processes

Soil chemical processes include soil inorganic chemical processes, nutrient processes, chemical transport, and pesticide processes. The inorganic processes include bicarbonate buffering, dissolution and precipitation of calcium carbonate, gypsum, and aluminum hydroxide; ion exchange involving bases and aluminum; and solution chemistry of ion-pair complexes. The chemical state of the soil is characterized by soil pH, solution concentration of the major ions, and adsorbed cations on the exchange complex. The model is capable of handling soil solution chemistry across a wide range of soil pH.

2.1.4. Nutrient processes

The nutrient processes define carbon (C) and N transformations within the soil profile. Given initial levels of soil humus, crop residues, other organics, and NO_3–N and ammonium (NH_4–N) concentrations, the model simulates mineralization, nitrification, immobilization, denitrification, and volatilization of appropriate N. A multi-pool approach is used for organic matter cycling. Transformation rate equations are based on chemical kinetic theory, and are controlled by microbial population density and other environmental variables such as soil temperatures, pH, water content, and salinity. Levels of soluble nutrients are used in estimating crop growth, nutrient extraction in surface runoff, and movement through and below root zone.

2.1.5. Management processes

The management submodel consists of a description of management activities influencing the state of the root zone. It includes typical tillage practices (e.g. plowing, ridging, chiseling, and no-tillage) for most crop rotations and the impact of these tillage practices on surface roughness, BD, and micro- and macroporosity. The timing of typical management practices such as fertilizer and pesticide applications, irrigation, planting densities and timing, primary tillage, cultivation, and harvest operations are functions of soil water conditions. Algorithms to describe BD reconsolidation as a function of time, rainfall, and tillage have been adopted and modified from the USDA-water erosion prediction project (WEPP) model. In RZWQM, it is assumed that tillage changes soil bulk density and macroporosity, and incorporates plant residues into the soil. The macroporosity change is assumed to be equal to that of bulk density in absolute percentage, but in the opposite direction (Rojas et al., 1992).

2.2. Study site

The study site for which these simulations were performed was located on a predominantly Kenyon loam (fine-loamy, mixed, mesic, Typic Hapludoll) soil with 3–4% organic matter at Iowa State University's Northeast Research Center, Nashua, IA (Table 1). These soils have seasonally high water tables and benefit from subsurface drainage. A 15 ha field experiment with 36, 0.4 ha plots was established on this site in 1977, and was later used to investigate tillage effects on surface and subsurface water quality. Tillage treatments included chisel plow (CP), moldboard plow (MP), no-tillage (NT), and ridge tillage (RT) systems. Details on the field experiments are given by Kanwar et al. (1983).

There were three replications of each tillage treatment on 0.4 ha plots. Each plot has one subsurface drain passing through the middle of the plot which was

Table 1
Soil properties for different soil horizons used as input for RZWQM simulations on a Kenyon loam in Iowa

Horizon number	Depth (cm)	$\Theta_{33\ \mathrm{kPa}}$[a] ($cm^3/cm^3$)	Bulk density[a] (g/cm^3)	Porosity (cm^3/cm^3)	Organic carbon[b] (%)	Particle size distribution[b] (%)		
						Sand	Silt	Clay
1	0–20	0.30	1.36	0.49	2.0	38	42	20
2	20–41	0.27	1.52	0.43	0.8	41	34	25
3	41–50	0.26	1.55	0.42	0.6	42	32	26
4	50–69	0.28	1.60	0.40	0.4	43	30	27
5	69–89	0.28	1.65	0.38	0.3	44	28	28
6	89–123	0.26	1.70	0.36	0.2	44	31	25
7	123–167	0.28	1.75	0.34	0.1	44	31	25

[a] Taken from Sharpley and William (1990). $\Theta_{33\ \mathrm{kPa}}$=soil water content at a tension of 33 kPa.

[b] Experimentally measured (Singh, 1994). No-tillage was done for 15 years before start of these experiments.

intercepted and connected to individual sumps for measuring subsurface drainage and collecting water samples for chemical analyses (Kanwar et al., 1993).

2.2.1. *Collecting soil samples for water content and NO_3–N analyses*

Three sets of 180 cm long soil cores were collected from each plot in 1990, 1991, and 1992. The first set of cores (collected in April or May) represented the beginning of the growing season, the second set (collected in September) represented the middle of the growing season, and the third set (collected in October or early November) represented the end of the growing season. The exact dates of sampling are given in Table 2 for each year. To collect soil samples, a zero contamination hand-sampler was used to remove 180 cm long, 2.5 cm diameter cores. As the sampler was pushed into the soil, each core slid into a clean liner made of PETG (polyethylene, terephthalate, glycol modified) plastic to protect the sample from contamination. After removing the sampler, we plugged the resulting opening in the soil with bentonite clay granules. These samples were frozen promptly after collection. Three cores were collected from each plot for each sampling date. Soil cores for the same plot were composited after they were sectioned into a set of samples. In 1990, the cores were divided into sections representing 0–10, 10–20, 20–30, 30–45, 45–60, 60–90, 90–120, 120–150 cm depths. Soil samples for 150–180 cm depth were discarded. In 1991, cores were divided into sections representing 0–10, 10–20, 20–30, 30–45, 45–60, 60–100 cm depths. Soil samples for 100–180 cm depth were discarded. In 1992, the cores were divided into sections representing 0–10, 10–20, 20–30, 30–45, 45–60, 60–90, 90–120 cm depths. Again soil samples for 120–180 cm depth were discarded. Composited samples were analyzed for soil water and NO_3–N con-

Table 2
Dates of tillage, planting, chemical application, and harvesting for simulation runs of RZWQM on a Kenyon loam in Iowa[a]

Date	Day of year	Activity
1990		
18 April	108	Applied 202 kg N/ha to most continuous corn plots
2 May	122	Planted corn
30 May	150	Early summer soil sampling
25 September	268	Late season soil sampling
1 October	274	Corn harvest
30 October	303	Post harvest soil sampling
7 November	310	Moldboard and chisel plow tillage
1991		
11 May	131	Preplant soil sampling
14 May	134	Applied 202 kg N/ha to most continuous corn plots
27 May	147	Planted corn
18 June	169	Early summer soil sampling
23 September	266	Late season soil sampling
8 October	274	Corn harvest
13 November	317	Post harvest soil sampling
1992		
2 April	93	Moldboard and chisel plow tillage
29 April	120	Preplant soil sampling
1 May	121	Applied 202 kg N/ha to most continuous corn plots
5 May	126	Planted corn
23 June	175	Early summer soil sampling
18 September	262	Late season soil sampling
14 October	288	Corn harvest
21 October	295	Post harvest soil sampling
10 November	315	Moldboard and chisel plow tillage

[a] Adapted from Kanwar et al. (1993).

centrations. Soil water was measured by weighing a sample of soil, drying it at 105°C for 24 h, reweighing the cooled sample, and calculating the soil water as the percentage water on dry soil basis. For NO_3–N analysis, a weighed sample of wet soil was mixed with 2 N potassium chloride (KCl). This mixture was shaken for 1 h, then filtered. The resulting filtrate was analyzed with a Lachat Model AE ion analyzer. A detailed methodology of collecting and analyzing soil samples is given by Weed (1992). A statistical analysis on the observed NO_3–N concentrations was performed to test the effects of tillage on concentrations for all the three years.

2.3. Simulation procedure and data input needs

All of the measured input parameter values used in the model simulation were either measured in the field or were taken from previously conducted research at this site. Input parameter values for which no data were available were estimated by using the databases provided in the RZWQM's user manual (USDA-ARS, 1992b). Thus, only on-site input data or estimates derived by the model were used in the simulations. Movement of water and NO_3–N was simulated under CP, MP, NT, and RT treatments. A unit gradient was assumed for the lower boundary condition for all the simulation runs.

For model simulations, a variable-depth-increment scheme (layer thickness ranging from 1 cm at the top to 15 cm at the bottom) was used as described in the technical documentation of RZWQM (USDA-ARS, 1992a). The profile depth simulated was 1.67 m. Seven soil-horizons for Kenyon loam soil were delineated for model input. Soil profile information was collected from soil survey report of Butler County, IA (USDA-SCS, 1982). The respective soil properties were used as inputs for each of these horizons.

2.3.1. Soil properties data

Bulk density and macroporosity for the surface horizon (0–20 cm) were determined experimentally as a function of tillage for Kenyon soil (Table 3). Skopp (1981) defined macroporosity as the portion of soil porosity that provides preferential flow paths where water or chemical mixing and transfer between adjacent pore sizes is limited. Macroporosity of top-soil was investigated from the infiltration experiments conducted at 0, 30, 60, and 90 mm tensions at the study site. As infiltration measurements at different tensions were made under approximately steady-state conditions, macropore conductivity was determined as the difference between the ponded infiltration rate and the infiltration rate at 30 mm tension. Based on this assumption, macroporosity for the top-soil was determined (Table 3) by applying Poiseulle's equation using the assumptions of laminar flow and cylindrical macropores as described by Watson and Luxmoore (1986). Macroporosity is estimated by assuming that pores are of the minimum radius corresponding to the lower limiting tension of 30 mm, and therefore, represent maximum values. For subsequent horizons, bulk density values were taken from the soils database of Sharpley and William (1990), and a macroporosity of 0.01% was assumed for these horizons. Total porosity for each horizon was calculated from bulk density and

Table 3
A list of input soil properties for the surface horizon (0–20 cm) and their values for different tillage systems in RZWQM simulations on a Kenyon loam in Iowa

Soil property	CP	MP	NT	RT
Bulk density (g/cm^3)	1.41	1.38	1.50	1.38
Porosity (cm^3/cm^3)	0.47	0.48	0.43	0.48
Macroporosity (cm^3/cm^3)	0.00015	0.00025	0.0003	0.0003
Residue pools (µg/g)				
Slow pool	450	700	140	310
Fast pool	700	1000	215	480
Residue cover (Mg/ha)[a]	3.8	0.6	6.2	5.0

CP – chisel plow; MP – moldboard plow; NT – no-tillage; RT – ridge tillage.

[a] Residue cover was assumed constant during the season.

an assumed value of 2.65 g/cm^3 for particle density. Other soil properties such as 33 kPa water content ($\Theta_{33\ \mathrm{kPa}}$), 1500 kPa water content ($\Theta_{1500\ \mathrm{kPa}}$), and pH for the Kenyon soil were also taken from Sharpley and William (1990). Tables 1 and 3 list major soil properties used as input parameters in the model. All other hydraulic properties such as K_{sat}, effective porosity, and bubbling pressure, were estimated by the model based on soil texture, BD, and $\Theta_{33\ \mathrm{kPa}}$ values.

Experimentally measured values of soil texture were used as inputs to the model. Soil heat properties (dry volumetric heat capacity and heat conductivity) were estimated by using soil texture data as described by Jury et al. (1991) and were used as inputs to the model. Actual tillage (mode of tillage, depth of tillage, amount of residue at surface), planting, fertilizer application, and harvest dates were used as inputs to the model and are shown in Table 2.

2.3.2. Weather data

Daily meteorological data, including minimum and maximum temperature, wind speed, radiation, relative humidity, and pan evaporation, are required by the model as inputs. All the daily meteorological data except wind speed and pan evaporation were available for the Nashua weather station. These data were obtained from Taylor (1992). Daily evaporation was estimated by the model by using short-wave radiation as the energy input to the evaporation algorithm. When wind speed is missing, the model assumes a wind speed of 10 km/day.

The RZWQM accepts rainfall in the form of breakpoint rainfall data to incorporate the effects of rainfall intensity on the subsurface movement of water and chemicals. Breakpoints represent breaks or changes in slope in the cumulative rainfall versus time plot. For this study, hourly rainfall data for the Nashua weather station were obtained from Taylor (1992). For each rainfall event, cumulative rainfall was plotted as a function of time. Breakpoints were recorded at every point where there was a significant change in the slope. For the periods when hourly rainfall data were not available, daily rainfall was recorded and breakpoints were noted from a rainfall event of similar magnitude for which hourly rainfall data were available.

The model also requires values of surface albedos for dry and wet soil, mature crop and residue, and sunshine fraction, as input. Surface albedos were taken from Jury et al. (1991). Sunshine factor is estimated based on latitude information provided as input to the model.

2.3.3. Plant growth variables and parameters

The 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. Tillage specific data on 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.

2.3.4. Initial conditions

Initial conditions specified for the simulations consisted of pH, initial soil water content and temperature, soil inorganic chemistry variables (CEC, fractions of exchangeable ions, etc.), organic matter pools, microorganisms pools, solution chemistry, gas pools, and initial NO_3–N concentrations in the soil profile.

Except for pH, organic matter pools, initial soil water content, and NO_3–N concentration profiles, default values provided in the model were used. Soil pH values for different tillage practices were taken from soil test results (Karlen et al., 1991). Organic matter values were obtained from Nashua soil report (Table 1) and were divided into slow (60%), medium (35%), and fast (5%) pools as described in RZWQM user's manual (USDA-ARS, 1992b). Initial water contents were specified as $\Theta_{33\ \mathrm{kPa}}$. The values for $\Theta_{33\ \mathrm{kPa}}$ were taken from soil database of Sharpley and William (1990) and were the same for all the tillage systems. Initial NO_3–N concentrations for 1990 were obtained from model calibration. Initial NO_3–N concentrations for 1991 and 1992 were specified as the observed concentrations in the soil samples at the end of October 1990 and 1991, respectively. A careful review of the soil sample data revealed that NO_3–N concentration profiles at the end of October 1990 were quite similar to those of the pre-fertilizer application concentrations in the spring of 1991, indicating little change in NO_3–N concentration profiles through the 1990–1991 winter period. Initial soil NO_3–N concentrations for simulation runs for 1990 are provided in Table 4.

Table 4
Initial NO_3–N concentrations in the soil profile for simulation runs for all tillage treatments for 1990

Horizon	NO_3–N concentration (μg/kg)			
	Chisel plow	Moldboard plow	No-tillage	Ridge-tillage
1	15	24	15	20
2	6	11	5	5
3	8	13	5	6
4	11	18	5	8
5	13	18	6	11
6	15	15	7	13
7	9	3	7	10

3. Results and discussion

3.1. Comparison between simulated and observed soil water contents

Figs. 1–3 show both observed and simulated volumetric water contents in the soil profile on Julian Day (JD) 150 (May 30) for 1990, JD 266 (September 23) for 1991 and JD 119 (April 29) for the year 1992, respectively. These figures represent the sampling dates at the beginning and middle of crop season for these years when the sampling was done. Figs. 1–3 show that predicted soil water contents by the RZWQM were usually close to the observed soil water contents except for JD 266 in 1991 for the MP tillage system. Also, the difference between observed

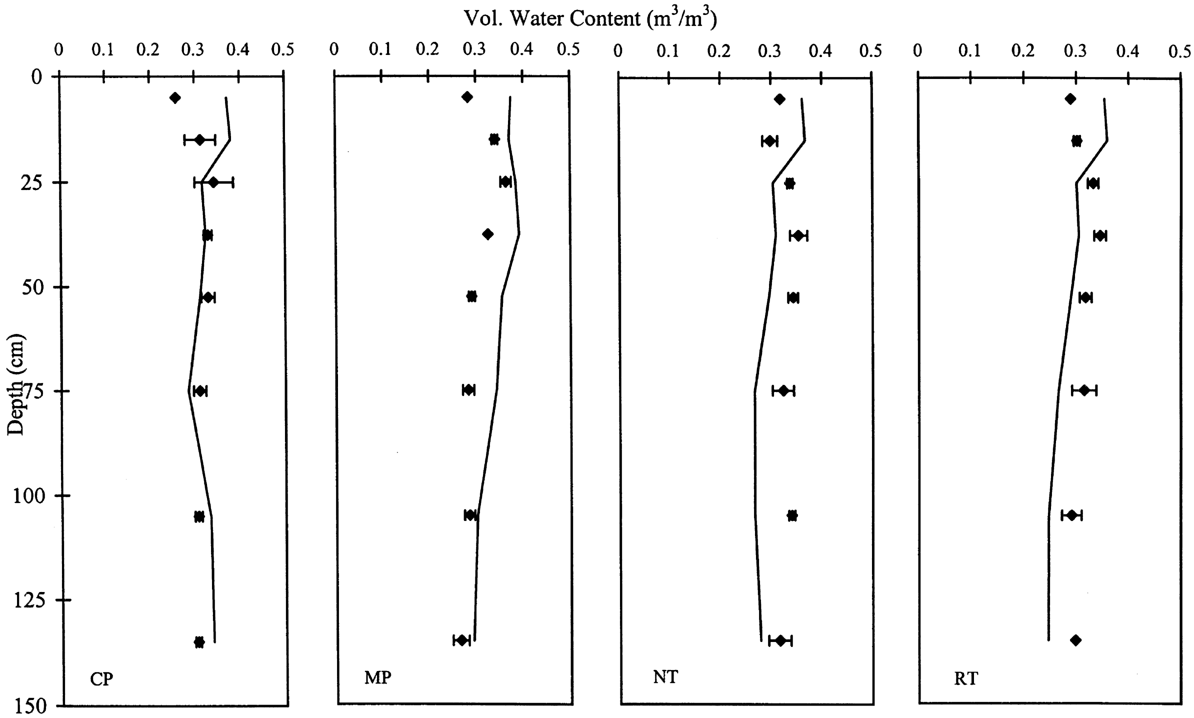

Fig. 1. Simulated (lines) and observed (points) water contents for soil profile for day 150 for 1990 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

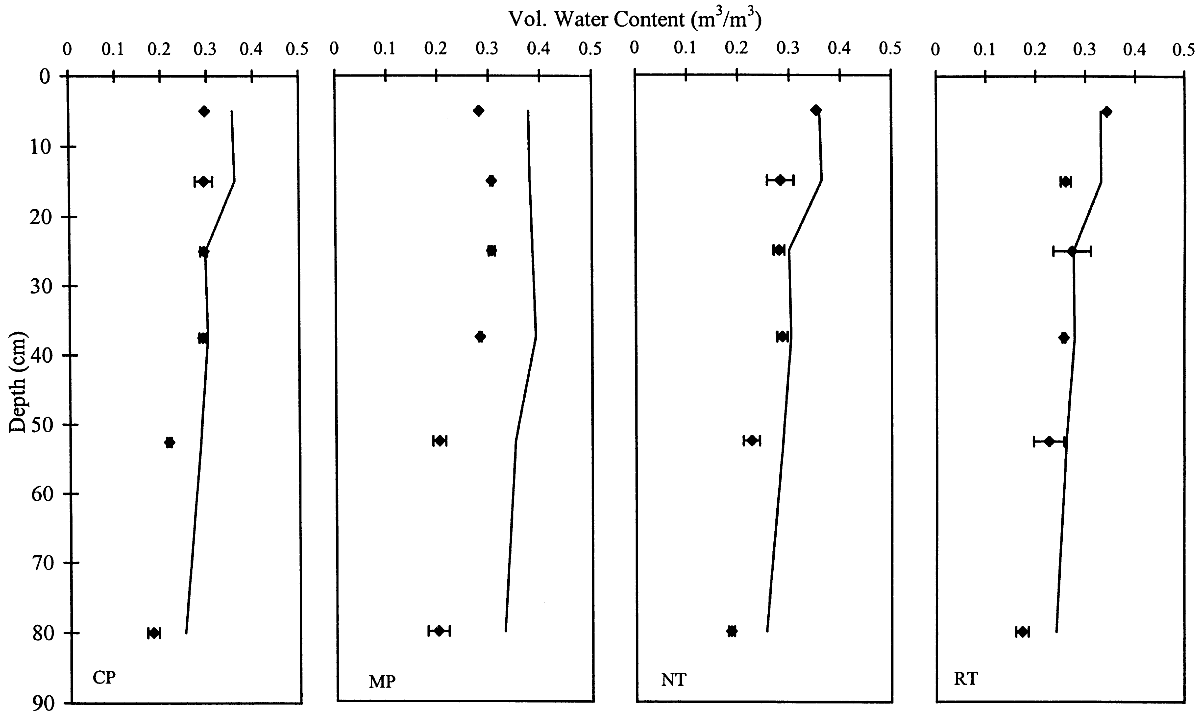

Fig. 2. Simulated (lines) and observed (points) water contents for soil profile for day 266 for 1991 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

and simulated values generally decreased with the increase in soil depth for all dates for all three years with few exceptions (Figs. 1–3). Simulated water content profiles on JD 150 for 1990 show that the MP treatment had a higher soil water content at all depths in comparison with NT, CP and RT treatments. On the other hand, the observed soil water content profiles on JD 150 showed no consistent pattern (Fig. 1).

For MP tillage system, the model predicted 33% higher soil water contents than the observed values for the year 1991.

For 1992, the model predictions were close to the observed data for JD 119 (Fig. 3). The simulated water contents for soil profile were slightly higher for all tillage treatments except for the NT system. Observed soil water content data showed more distinction between tillages in surface layers (maximum water content was observed for the NT and RT treatments). This difference gradually decreased with depth. On the average, the soil profile water contents predicted by the RZWQM followed the observed trend reasonably well. However, simulated soil water contents did not show any distinct effects between the tillage treatments. Similar trends were observed for other dates for which water contents were simulated in 1990, 1991 and 1992 (not shown).

One of the possible causes of difference between simulated and observed soil water content in the soil profile is the soil macroporosity. Soil macroporosity is not only affected by tillage systems, but also by changing weather conditions. Some other factors affecting the water movement through the soil profile could be inconsistencies between estimated and actual rainfall intensities, discrepancies between estimated and actual values of some of the soil properties, taking average of water contents over a depth and assuming at one point, errors in root water extraction procedures of the model, and finally, unaccounted spatial variability in soil properties, which plays a major role in the subsurface water and solute transport.

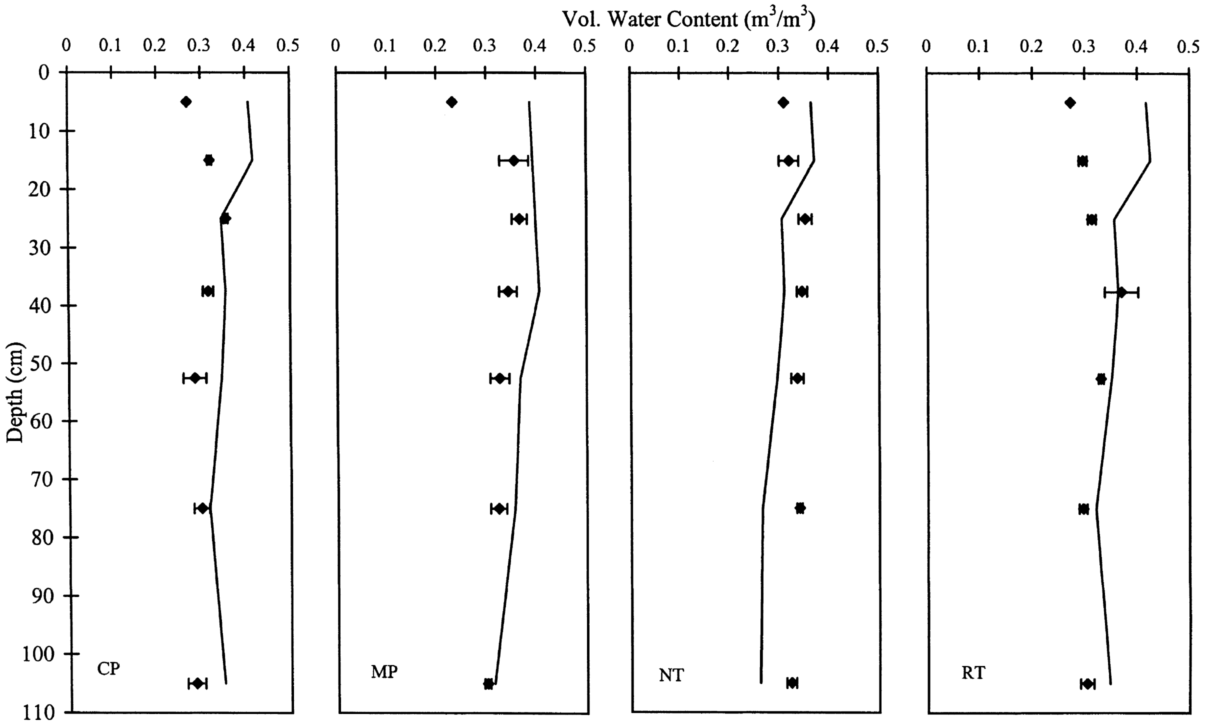

Fig. 3. Simulated (lines) and observed (points) water contents for soil profile for day 120 for 1992 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

3.2. Comparison between predicted and observed soil NO_3–N concentrations

The model was run from Julian day (JD) 91 (April 1) to JD 335 (November 30) covering the crop growing seasons of 1990, 1991, and 1992. Simulated NO_3–N concentrations for different days of the growing seasons were compared with observed data and are discussed in the following paragraphs.

Figs. 4–7 show predicted and observed NO_3–N concentrations (mg/l) in the soil profile for 1990, 1991, and 1992, respectively. Observed NO_3–N concentrations in the soil profile showed no clear pattern regarding tillage effects on NO_3–N concentrations, although MP and RT treatments generally showed higher NO_3–N concentrations in comparison with NT and CP treatments. But this trend was not consistent for every year. Observed NO_3–N concentrations for the MP system were consistently higher and for NT system consistently lower for all the years. For JD 150 of year 1990, MP treatment had the highest NO_3–N concentration in the soil profile among all tillage treatments (Fig. 4), while NT treatment had the lowest NO_3–N concentration on JD 266 of year 1991 (Fig. 6). Minimum NO_3–N concentrations in the soil profile usually occurred under the NT treatment (considering all soil samples for all the years). For JD 119 of year 1992, CP treatment had the lowest NO_3–N concentrations and RT had the highest NO_3–N concentrations (Fig. 7). Statistical analysis on observed NO_3–N concentrations was performed to test the significance of differences between tillage treatments for each date of soil sampling (Table 5). A detailed discussion on these observed values is provided by Weed (1992).

Simulated NO_3–N concentrations were more or less in the same range as those of observed concentrations for JD 150 for the year 1990 (Fig. 4). The maximum percent difference between predicted and observed NO_3–N concentrations for the entire soil profile was −19% for the NT system (Table 5). But the model predicted substantially higher NO_3–N concentrations

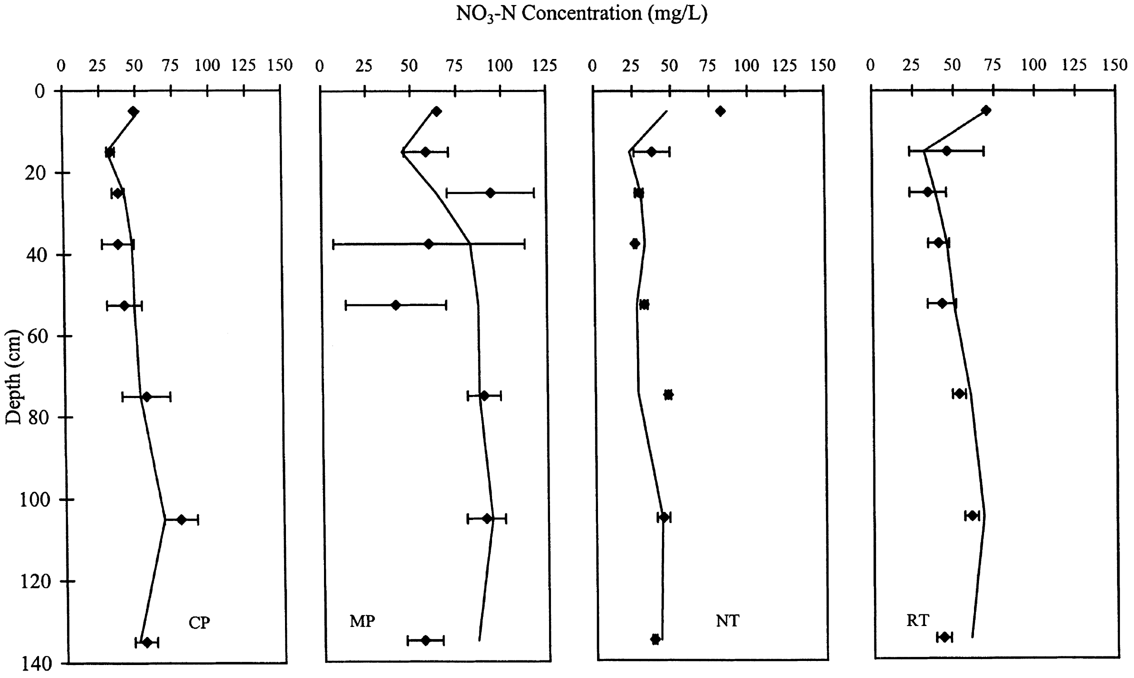

Fig. 4. Simulated (lines) and observed (points) NO_3–N concentrations for soil profile for day 150 for 1990 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

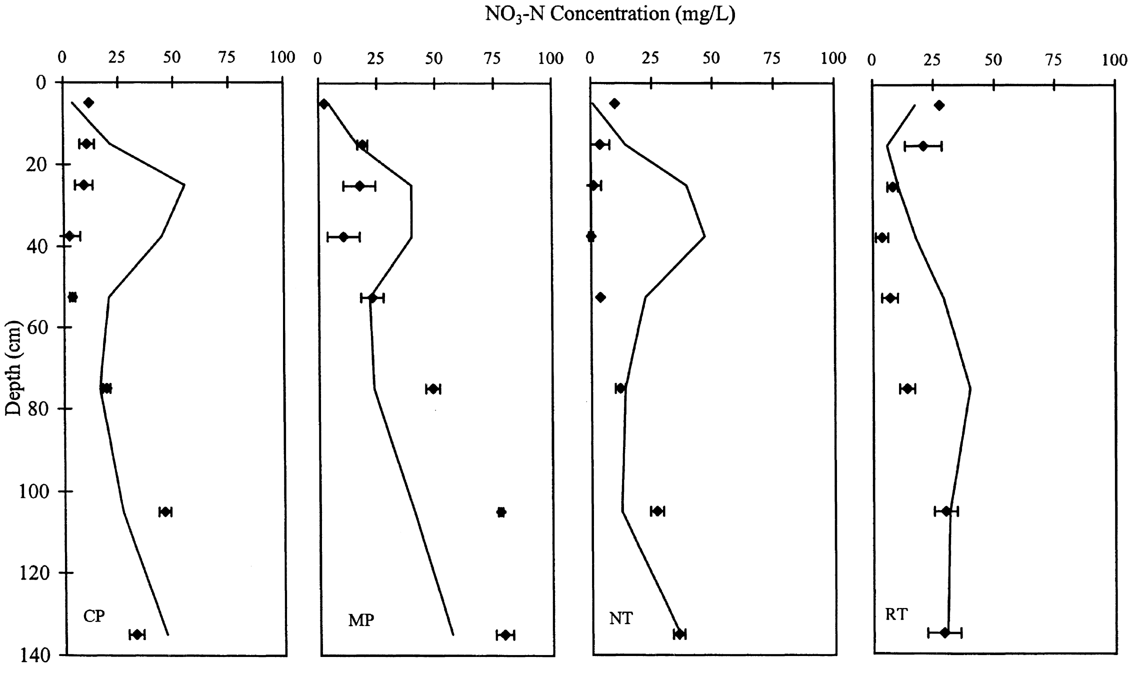

Fig. 5. Simulated (lines) and observed (points) NO_3–N concentrations for soil profile for day 268 for 1990 (error bars show the standard deviation); CP – chisel plow, MP –moldboard plow, NT – no-tillage, RT – ridge tillage.

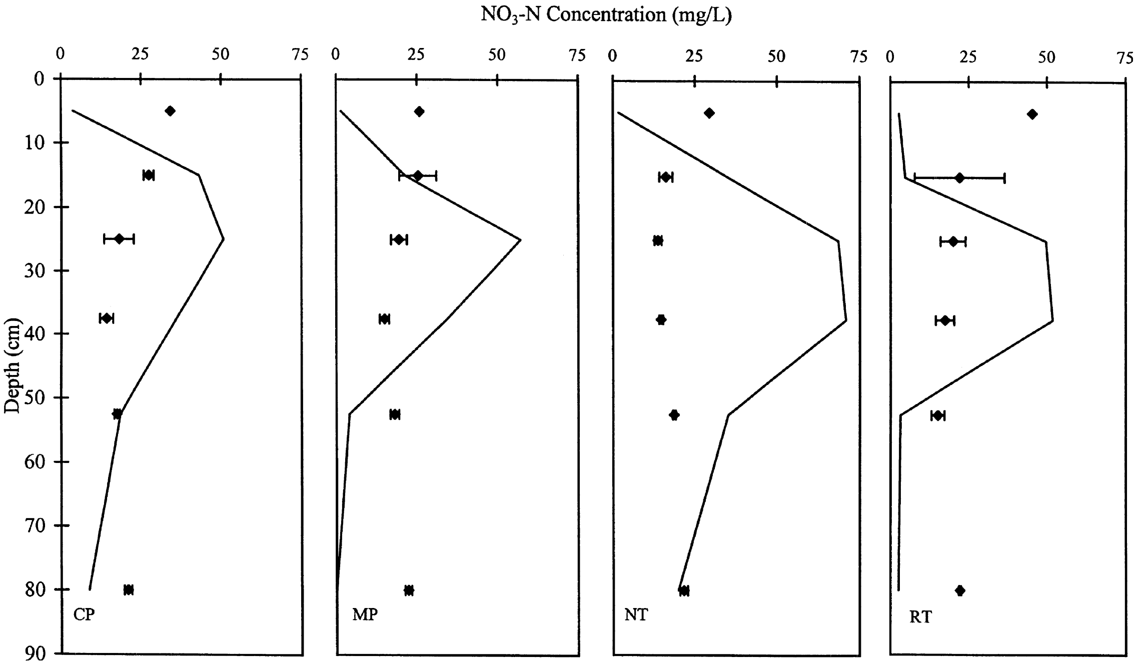

Fig. 6. Simulated (lines) and observed (points) NO_3–N concentrations for soil profile for day 266 for 1991 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

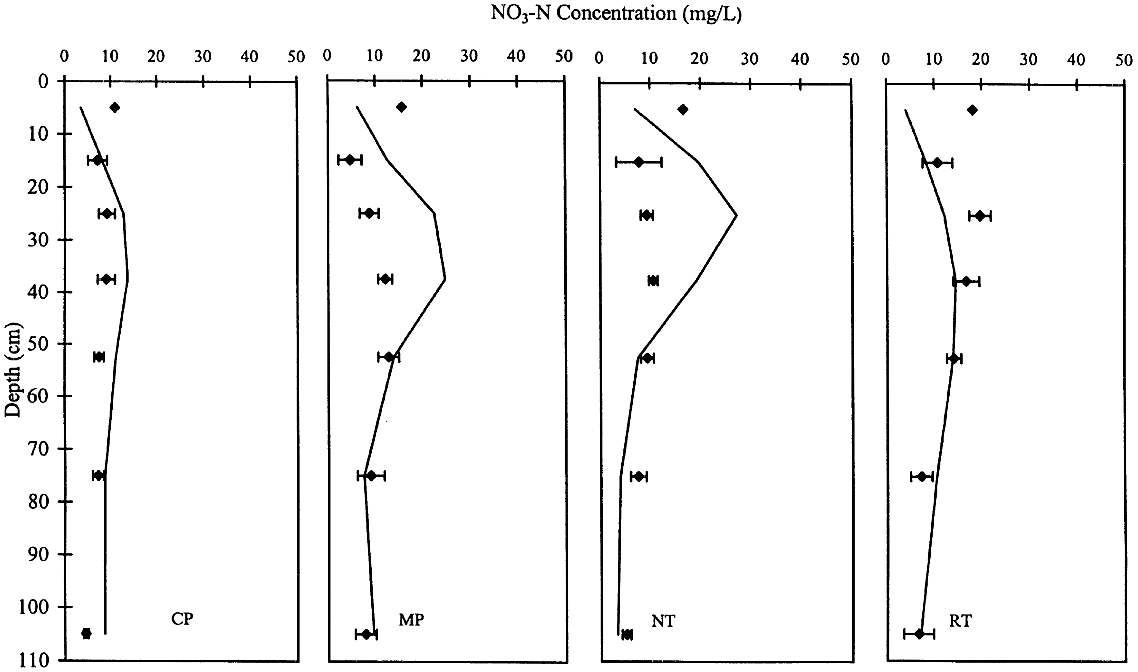

Fig. 7. Simulated (lines) and observed (points) NO_3–N concentrations for soil profile for day 120 for 1992 (error bars show the standard deviation); CP – chisel plow, MP – moldboard plow, NT – no-tillage, RT – ridge tillage.

Table 5
A summary of average observed and predicted NO_3–N concentrations for entire soil profile for 1990 (0–150 cm), 1991 (0–100 cm), and 1992 (0–120 cm)

Year	Concentration (mg/l)			
	CP[a]	MP	NT	RT
May 1990				
Observed	48.42b	69.32a	42.06b	48.62b
Predicted	42.74	76.05	34.18	52.96
% Difference	−11.73	+9.71	−18.73	+8.93
September 1990				
Observed	16.97b	34.76a	11.58b	17.54b
Predicted	29.36	30.42	23.21	22.78
% Difference	+73.01	−12.48	−100.04	+29.87
May 1991				
Observed	31.96a	28.99b	25.07b	29.86b
Predicted	24.15	24.67	26.42	18.10
% Difference	−24.43	−14.90	+5.38	−39.38
September 1991				
Observed	22.01a	20.98a	19.02a	23.69a
Predicted	26.79	19.75	38.50	19.10
% Difference	+21.71	−5.86	−102.42	−19.37
April 1992				
Observed	7.93b	10.10b	9.45b	13.25a
Predicted	9.48	13.80	12.45	9.98
% Difference	+19.54	+36.63	+31.74	−24.67
September 1992				
Observed	5.85a	2.49b	4.05b	0.85b
Predicted	10.12	11.47	10.99	0.48
% Difference	+72.99	−360.64	−171.36	−43.52

Tillage averages (observed data) followed by dissimilar letters (a, b or c) are significantly different at the 0.05 level overall.
[a] CP – chisel plow; MP – moldboard plow; NT – no-tillage; RT – ridge tillage.

under CP and NT treatments in comparison with the MP and RT treatments, usually at upper soil depths, for JD 268 of the year 1990 (Fig. 5). The reason for NO_3–N bulging in the NT plots around 20–30 cm could be that flow is bypassed through macropores and nitrate is not leached down to lower depths. The NT system tends to have better network of macropores compared to other tillage systems. On the other hand, for JD 268, simulated NO_3–N concentration profiles for different tillage treatments were more or less similar to the depth of below 60 cm (Fig. 5). For deeper soil horizons CP, MP and NT treatments showed substantially lower NO_3–N concentrations in comparison with RT treatment for JD 268. Usually, the predicted peak NO_3–N concentrations occurred within the same depth increments for all tillages (Figs. 6 and 7) except for RT system (Fig. 5). A comparison of observed and predicted peak NO_3–N concentrations in the soil profile (Figs. 5–7) shows that the model generally overpredicted maximum NO_3–N concentrations for all tillage treatments. However, the model predictions for the later part of 1992 season were not close to the observed values. Figs. 4 and 7 also show that simulated NO_3–N concentrations at all depths were close to the observed values in the beginning of the crop season but overpredicted for the later part of the season (Figs. 5 and 6). This could be due to lower N-uptake calculations by the model. This shows a need for further calibration of the model for better calculations of N-uptake by plants.

Discrepancies between simulated and observed NO_3–N concentrations indicate a need for evaluation and validation of various N-transformation processes for different tillage systems to improve the predictions for the hydrologic and plant growth components of the model. Also, poor predictions of NO_3–N concentrations for 1992 could be due to weather conditions as early part of 1992 was dry and model could not simulate the movement of water very well, which could be responsible for poor predictions for NO_3–N concentrations in the soil profile. Besides poor predictions of water movement, there could be improper simulation of mineralization rate of organic N, which in turn will affect the simulations of NO_3–N. Tillage practices also affect the residue pools (Table 2). Default values as suggested in the User's manual of RZWQM were used for model simulations. Field measured values of these residue pools could improve the model predictions of NO_3–N in the soil profile.

The model fails to simulate tillage effects clearly on water and NO_3–N movement in the soil profile. The reason for this could be because the model used only bulk density as a tillage specific input parameter. Also, field measured data for bulk density and macroporosity were available only for the 0–20 cm soil profile. Soil bulk density and macroporosity below the 20 cm soil profile was adopted from literature for the similar type of soil. Therefore, the likely reason for poor simulations of tillage effects on NO_3–N is that inputs to the model concerning tillage induced changes in soil physical properties were inadequate.

4. Summary and conclusions

Evaluation of the root zone water quality model was done to simulate water and NO_3–N movement through the vadose zone under four different tillage practices utilizing field-measured soil properties. Based on the results of this study, model predictions were not satisfactory. The model needs improvements in its nutrient component before it can be used as a predicting tool for agricultural management. The following conclusions were made from this study:

1. RZWQM usually predicted higher soil water contents than observed in the field. Both observed and simulated values did not show any distinct tillage effect on soil water contents for all the three years.
2. Although the average predicted NO_3–N concentrations were usually within the range (one standard deviation) of observed NO_3–N concentrations, the model generally overpredicted maximum NO_3–N concentrations in the soil profile for all the treatments.
3. The model predictions indicate a need for improvement in the crop growth and nutrient components of the model as well as their evaluation and validation for different tillage practices. Incorporating the effect of tillage practices on soil physical properties other than bulk density, can make these improvements. Since model heavily relies on residual pools, there is a need to estimate these pools accurately for each tillage system.

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