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Simulating Nitrogen Management Effects on Subsurface Drainage Water Quality*

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ABSTRACT

Increased level of NO_3-N in the drinking water supplies is a major health concern these days. The long-term effects of actual nitrogen (N) fertilizer management practices are not well understood. The use of computer models allows the simulation of different N management practices on a long-term basis and their related effects on water quality. The RZWQM (Root Zone Water Quality Model, Version 3.0) was used to simulate the long-term (1978–1992) impacts of N management practices (single N applications at 50, 100, 150, and 200 kg per ha; and single and split N applications at 150 and 200 kg per ha) on NO_3-N losses with subsurface drain flows and crop yields under two tillage systems (moldboard plow (MB) and no till (NT)). Simulations conducted in this study were based on input parameters calibrated by Singh et al. *(*J. Environ. Qual., in press*) for NO_3-N transport to subsurface drains. However, calibration of some additional parameters was required in this study for long-term simulations. The long-term climatic data and soil properties data for these simulations were obtained from a water quality research site at Nashua, Iowa.*

The results of this study showed that increasing rates of N applications (50, 100, 150, and 200 kg per ha) resulted in increased NO_3-N losses with subsurface drain flows and increased crop yields. However, increasing rates of NO_3-N losses and crop yields were not linearly proportional with increasing rates of N applications. These trends were similar for both MB and NT treatments. Also, NO_3-N losses and crop yields were not

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significantly different under single and split N applications at both 150 and 200 kg per ha levels of application. The single N application of 150 kg per ha was considered the best N application practice as the simulated NO_3-N losses under this practice were reduced considerably (40.3% less in MB and 52.4% less in NT) when compared with the single N application of 200 kg per ha. At the same time, the reduction in crop yields at 150 kg per ha single N application was very small (5.9% reduction under MB and about 6.1% under NT) when compared with the crop yields at 200 kg per ha single N application. This study also shows that RZWQM can be used successfully in evaluating similar N management schemes for other geographic regions of the world by utilizing site-specific data on soils, geological features, crops, and climatic parameters such as rainfall and evaporation.

INTRODUCTION

Contamination of soil and water resources due to agricultural chemicals is considered to be one of the most serious environmental concerns requiring immediate attention of scientists, policy makers, farmers, chemical manufacturers, and water consumers. The increased applications of plant nutrients in agricultural production systems, through the use of inorganic fertilizers, potentially contribute more nutrients to water resources because plants cannot absorb all the nutrients applied. One pollutant, nitrate nitrogen (NO_3-N), is of particular concern in the corn-belt region of the USA where extensive use of nitrogen (N) is made in corn production. The excess N (remaining in the system after plant use) becomes available for leaching through the soil profile and polluting the groundwater. Increased levels of NO_3-N in the drinking water supplies present health-related concerns.

Pollution of drinking water resources and other aquatic environments by agricultural chemicals is a complex environmental problem that not only poses serious human health concerns but also causes the deterioration of natural habitats and loss of biodiversity. The objective of agricultural water pollution control efforts should be to protect the water quality of aquatic environments by limiting the chemical losses from agricultural production systems. This can be achieved by reducing the chemical inputs in the crop production systems, making these systems more efficient in utilizing the chemicals, and accelerating the breakdown of harmful chemicals remaining in the system into unharmful byproducts. Mathematical models can provide cost-effective, time-saving, and environmentally safe tools for analyzing the mechanisms and interactions involved in the movement of chemicals both in surface and subsurface environments. Estimation techniques or deterministic models simulating the water and chemical movement processes could be used to assess the magnitude of water pollution in larger watersheds. Mathematical models can also be helpful in determining the impacts of agricultural management practices (chemical management, crop management, residue management, tillage management, etc.) on water quality and sustainability of agricultural production systems. Kanwar *et al.* (1988) demonstrated the use of computer simulation models to simulate the effects of agricultural practices on NO_3-N loss with drainage water.

Artificial drainage is an absolute necessity to farm some of the nation's most productive lands for corn and soybean production. Without good artificial drainage, not only is the timeliness of planting and harvesting hindered, but complete crop failures may occur in wet years. The use of subsurface drainage systems to remove excess soil water from these watersheds is also increasing the chances of removing NO_3-N through subsurface drains and polluting surface water resources as subsurface drainage water is eventually discharged to rivers and streams. Because it is difficult to study a large number of combinations of N fertilizer management and crop rotation practices in a large watershed, the use of computer simulation to estimate the impacts of different management practices on NO_3-N losses is one of the best alternatives we have. Therefore, the objective of this study was to use the RZWQM (Root Zone Water Quality Model; USDA-ARS, 1995) to evaluate the effects of N fertilizer management practices (single and multiple N applications) on the losses of NO_3-N with subsurface drainage water from agricultural watersheds and crop production. Input data from an experimental site near Nashua, Iowa, was used for model simulations. The overall objective of this study was to determine whether by using site-specific soil, geological, crop, and climatic data, RZWQM is able to predict NO_3-N losses with subsurface drainage water and crop production. Therefore, it is essential to verify the model performance at different experimental sites where observed data are available. Several investigators have used the RZWQM to simulate water table fluctuations (Johnsen *et al.*, 1995), subsurface drain flows, and its quality (Singh *et al.*, 1995, 1996*a*, in press), crop yields, and evapotranspiration (Farahani *et al.*, 1995; Nokes *et al.*, 1995), and the characteristics of macropore flow and its impacts on water quality (Ahuja *et al.*, 1993).

A BRIEF OVERVIEW OF THE RZWQM

Hydrological processes

This section describes some of the components of RZWQM dealing with water movement through a soil profile. The water flow process in the

RZWQM is divided into two phases: (1) infiltration into the soil matrix and macropores (pores having diameter equal to or greater than 0.5 mm) and macropore–matrix interaction during rainfall or irrigation, modeled by using the Green–Ampt approach (Green and Ampt, 1911; Ahuja, 1983); and (2) 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 the walls of the macropore channels. A detailed account of water management processes is given in the technical documentation of RZWQM (USDA-ARS, 1995).

Subsurface drainage is also included in RZWQM Version 3.0 (USDA-ARS, 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 2D effects of subsurface drainage by estimating the drain flux at the center point between two parallel drains. Thus, model estimates of the water table depth are given at the midpoint between drains. The depth of the water table is defined as the depth at which the pressure head is non-negative. 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.

The RZWQM requires knowledge of the soil's 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 the relationships between soil water content and matrix suction and between unsaturated hydraulic conductivity and matrix suction. 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 33 kPa or 10 kPa water suction). To calculate subsurface drain flow rates 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 otherwise unknown).

NO_3-N transport processes

The NO_3-N transport through the soil profile during infiltration is simulated by using a sequential partial displacement and mixing approach in 1 cm layer increments, based on the concept of miscible displacement. The soil solution is displaced sequentially across 1 cm soil increments for each infiltration step. Because the volume of flow during an infiltration step is always less than the mesopore (pores having diameter less than 0.5 mm) soil water content of a 1 cm increment (usually less than half), displacement of the solution in this increment is only partial. Mixing is allowed to occur within all mesopores of an increment after each displacement step. Thus, this two-stage process simulates miscible displacement in the mesopores. During redistribution, NO_3-N in solution moves with water from one depth increment to another, including upward movement due to evaporation.

Transport of NO_3-N within the saturated zone is calculated using miscible displacement in the mesopores only, similarly to method described above. After initial infiltration and NO_3-N transport has occurred within a time step, the flux of water from the top of the water table to the bottom of the profile is displaced sequentially across 1 cm increments, mixing with the NO_3-N concentration in the mesopore of each increment. The NO_3-N loss with subsurface drainage from each layer within the contribution zone is calculated by multiplying the NO_3-N concentration in the layer by the drainage volume out of that layer. The contribution zone or distributed sink is defined as a part of the saturated zone (extending from the top of the water table to about 30 cm below the tile line) which contributes water for the subsurface drainage. Finally, the overall weighted NO_3-N concentration in subsurface drainage is calculated by dividing the total NO_3-N loss by the total volume of subsurface drainage.

Nutrient and plant growth processes

The nutrient processes define carbon (C) and nitrogen (N) transformations within the soil profile. In RZWQM, an organic matter/nitrogen submodel is used for C and N cycling in the soil system. 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 forms. A multipool approach is used for organic matter cycling. Process rate equations are based on chemical kinetic theory and controlled by microbial population size and environmental parameters such as soil temperature, pH, water content, and salinity.

The plant growth model predicts the relative response of plants to changes in the environment. Environmental changes can be manifest either as normal variations in climate 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, water and N uptake, and transpiration. A population development model was coupled with the plant growth model to form a generic crop-production system that simulates both plant growth and phenological development. A detailed description of nutrient and plant growth processes can be found in the technical documentation of the RZWQM (USDA-ARS, 1992).

EXPERIMENTAL SITE

The input data used for model simulations were obtained from an experimental site located at Iowa State University's Northeast Research Center in Nashua, Iowa. This site was located mainly on Kenyon, Readlyn, and Floyd soils with 3 to 4% organic matter. The experimental site is characterized by seasonally high water tables and benefits from subsurface drainage. Subsurface drains were installed about 1.2 m deep at 28.5 m spacing in 1979. Long-term tillage practices were established at this site in the fall of 1977 to investigate the impact of tillage and crop management practices on water quality and crop yields. Each field plot at this site has one subsurface drain passing through the middle of the plot, and a subsurface drain at each of the two borders. The middle subsurface drains of all the plots were intercepted for measuring subsurface drainage flows and collecting water samples for chemical analyses (Kanwar *et al.*, 1991, 1993).

SIMULATION STUDY AND METHODOLOGY

Singh *et al.* (in press) calibrated and evaluated the NO_3-N transport and plant growth components of the RZWQM (Version 3.0) in an earlier study using three years (1990–1992) of experimental data on NO_3-N losses with subsurface drain flows and crop yields. They calibrated and evaluated the model for four different tillage systems (chisel plow, moldboard plow, no till, and ridge till) under continuous corn production. This study was designed to simulate long-term (1978–1992) effects of various N application options (single and multiple) on crop yields and NO_3-N losses with subsurface drain flows by using the hydrological parameters previously calibrated by Singh *et al.* (in press). A list of these parameters is given in Table 1. Several additional parameters in the RZWQM required calibration for long-term simulations. These parameters included the snowmelt coefficient, macroporosity, albedos, and various plant growth parameters. Table 2 gives a list of these parameters and their calibrated values. The impact of N application options on NO_3-N losses with subsurface drain flows and crop yields were simulated under two different tillage practices, namely, moldboard plow (MB) and no tillage (NT) under continuous corn production.

TABLE 1
A List of Calibrated Hydrological Parameters for Each Plot

Plot number	*Soil type*	*Tillage treatment*	*LKsat* (mmh^{-1})	*DP* ($m^3\ m^{-3}$)
25	Kenyon	NT	31.0	0.20
14	Readlyn	NT	31.0	0.20
31	Floyd	NT	32.0	0.20
Average			31.3	0.20
35	Readlyn	MB	23.0	0.18
13	Floyd	MB	23.0	0.19
22	Readlyn	MB	23.0	0.18
Average			23.0	0.18

CP = chisel plow; MB = moldboard plow; NT = no tillage; RT = ridge tillage; LKsat = lateral saturated hydraulic conductivity; DP = effective drainable porosity.

TABLE 2
A List of Additional Hydrological, Nutrient, and Plant Growth Parameters and Their Calibrated Values

Description of parameter	*Calibrated value*
Snowmelt infiltration vs. runoff coefficient	0.50
Macroporosity	1%
Albedo	
Dry soil	0.27
Wet soil	0.16
Crop at maturity	0.26
Fresh residue	0.8
Maximum N uptake rate (g per plant per day)	2.0
Amount of biomass needed to obtain leaf area index of 1.0	10.0
Normal maximum root system depth (m)	2.0
Coefficient of Arrhenius equation for denitrification	1.0E + 12
Coefficient for Arrhenius o.m. decay equations	
(a) for fast decaying soil o.m.	2.5E−07
(b) for medium decaying soil o.m.	5.0E−08
(c) for slow decaying soil o.m.	4.5E−10

Model inputs

Climatic data

The model requires daily input values of air temperature (minimum and maximum), wind speed, pan evaporation or short wave radiation, and relative humidity. Daily climatic data, except wind speed and pan evaporation, obtained from Charles City weather station (about 5 miles from Nashua) were used for long-term simulations (1978–1992). When the data on wind speed are missing, the model assumes a wind speed of 100 km per day.

The model requires values of surface albedos for dry and wet soil, mature crop and residue, and sunshine fraction as input. The albedos provide the base value of energy reflectance from these surfaces. The albedos are made sensitive to surface wetness and roughness effects, and are modified as environmental conditions change. Initial estimates of surface albedos were taken from Jury *et al.* (1991) and calibrated for local conditions. The model uses a modified Shuttleworth and Wallace (1985) approach to calculate the daily potential (evapotiauspination) ET. Actual crop transpiration and soil evaporation are determined by the ability of the soil to deliver the potential rates.

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. Hourly rainfall data were available for Nashua weather station for the period 1990–1992. Hourly rainfall data were converted into breakpoint rainfall data. The detailed methodology of converting hourly rainfall data into breakpoint rainfall data is given by Singh (1994). The daily rainfall data were obtained from the Charles City weather station for the period 1978–1989. The daily rainfall data were converted into breakpoint rainfall data, assuming a uniform rainfall distribution over a 4 h period.

Soil properties data

A 1.75 m deep soil profile was considered for model simulations. This profile was divided into six to eight soil horizons depending on the information gathered from soil survey reports for Kenyon, Readlyn, and Floyd soils (USDA-SCS, 1982). For each horizon, data on 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 inputs to the model. Soil bulk density for the surface horizon and particle size distribution at various depths of the profile were experimentally measured. Singh (1994) described the detailed methodology of these field measurements. Among soil hydraulic properties, only the soil water content at 33 kPa suction (Q_{33kPa}) for each soil horizon was taken from Sharpley and Williams (1990) and specified as input. All other hydraulic properties, such as saturated and unsaturated hydraulic conductivities, effective porosity, and bubbling pressure, were estimated with the model based on BD, Q_{33kPa}, and texture data.

Information on field operations

Dates of planting, harvesting, fertilizer application, and tillage operations are needed as inputs to the model. Table 3 shows the dates of various farm operations for the research site in a given year.

TABLE 3
Dates of Farming Operations for Long-Term Simulations

Dates relative to planting	*Activity*
30 days before planting	Primary tillage (MB only)
2 days before planting	Secondary tillage (MB only)
10 days before planting	Single N Application
10 days before and 20 days after planting	Split N Application
0 days (5 May)	Planting
15 days after planting	Cultivation
155 days after planting	Harvesting

Initial and boundary conditions
The initial water table depth was set equal to 1.2 m. The depth of the impermeable layer was assumed to be 1.75 m, a reasonable assumption for this site. Initial soil hydraulic and physical properties were used as inputs in the input file once observed values were available for these properties.

RZWQM also requires the input of initial organic matter and microorganism pools, soil water temperature, aqueous chemistry, and pesticide kinetic pool profiles. In actual conditions, after some time, all these values tend to reach steady values in the soil. In the present version of RZWQM, one of the options is to create a file that provides equilibrium values for these different parameters, which are used as initial conditions for the simulations. These files were obtained by running the model iteratively, for each plot separately, for 15 years. Three iterations were performed using the final values of the different parameters from an iteration as initial values for the next iteration. Reading the initial values from this file solved the problem of initializing the model when observed data are not available.

These binary files were created when considering a single application of 200 kg N per ha, 10 days after planting — considered to be the typical N application scheme in the corn belt region.

Additional calibrated parameters

The snowmelt component is a new feature in Version 3.0 of RZWQM. This component allows the user to run continuous simulations through the winter for different years. It is a clear advantage, once it avoids reinitiating the model every spring, when in most of the cases observed initial data are not available for all the years. The percentage of snowmelt that infiltrates the soil surface and the percentage of snowmelt that becomes part of the runoff were calibrated for our conditions. To calibrate this parameter, several simulations were conducted considering different values for this percentage. The value that gave a better prediction between the observed and simulated subsurface drain flow volumes was selected as an input to the model. For this study, this percentage was set at 50%.

To adjust the model to continuous simulations, albedo values (for dry and wet soil, crop at maturity and fresh residue) were calibrated. To calibrate the albedo, several combinations of values for dry and wet soil albedos, crop at maturity albedo, and fresh residue albedo were used for simulations. All these values were within the limit values cited in the literature. The combination of values that gave a better estimation of evapotranspiration was selected as the calibrated parameter. The macroporosity was also calibrated. With all other input values of the model defined, different values for macroporosity were used for simulation. The calibrated value for macroporosity was selected as being the one that gave the best estimation of the volume of subsurface drain flows. All these values are listed in Table 2.

N application scenarios

Simulations were conducted for a period of 15 years (1978–1992) to investigate the long-term impacts of various N application scenarios on NO_3-N losses with subsurface drain flows and crop yields. These N application scenarios were evaluated for two different tillage treatments, namely MB and NT. Each tillage treatment consisted of three replicated field plots. Therefore, simulations were also conducted separately for each replicated plot under a given tillage treatment using soil properties from each plot.

To consider improvement in the efficiency of N fertilizer use by plants and to reduce NO_3-N losses through drainage waters, two N fertilizer management schemes were evaluated. The first management scheme included four different N application rates (50, 100, 150, and 200 kg per ha) for continuous corn production. Survey data for one area of intensive row-crop production in Iowa show that the fertilization rate for corn increased from 115 to 181 kg per ha from 1970 to 1979 (Kanwar *et al.*, 1988). N fertilizer was assumed to be applied at these rates one week before planting date. The average N application rate in Iowa has gone down to 144 kg per ha in the past few years.

The second N fertilizer management scheme included multiple (or split) applications of N fertilizer at different times during the crop growing season for continuous corn production. In this management scheme, two different amounts of N fertilizer (150 and 200 kg per ha) were considered to be applied in two split applications. For example, 150 kg per ha of N fertilizer was considered to be applied in two applications of 75 kg per ha each (the first application was made 10 days before planting and the second application was made 20 days after planting). Similarly, 200 kg per ha of N fertilizer was considered to be applied in two applications of 75 and 125 kg per ha (the first application was made 10 days before planting and the second application was made 20 days after planting).

Statistical analysis

The results of simulations were statistically analyzed for significant differences, using the t test for all pairs of values, and considering an overall probability level of 0.05 (Steel and Torrie, 1980). The t test was conducted on differences between the values of each pair of data, considered to be the average of three replications. The null hypothesis tested stated that the mean of the population of differences was zero. Using this method, the variability attributed to different years will no longer be considered.

RESULTS AND DISCUSSION

Effects of N application rates on NO_3-N losses and crop yields

Figure 1 shows the effects of N application rates on NO_3-N losses (average of three replications under each tillage treatment) with subsurface drainage water under MB and NT treatments. As expected, NO_3-N losses increased with increasing rates of N application under both tillage (MB and NT) treatments. These differences were significantly different (t test, 95% confidence interval), with an exception of 50 kg N per ha when compared to 100 kg N per ha for the MB treatment. However, the rate of increase in NO_3-N losses with subsurface drain flows was not linearly proportional to the rate of increase in N applications. For example, NO_3-N losses doubled when N application was increased from 50 to 100 kg per ha. But NO_3-N losses in subsurface drain flows almost tripled when N application was increased from 100 to 150 kg per ha. This non linear trend was the same order under both MB and NT treatments. Figure 2(a) and (b) presents relationships between NO_3-N application rates and the cumulative NO_3-N losses with subsurface drain flows, for MB and NT systems, respectively. Data for the 15 years period are displayed in these figures. These plots also show there is a non linear relationship between these two variables. This was observed for both MB and NT treatments. Figure 1 also shows that NO_3-N losses with subsurface drain water at 50 and 100 kg per ha were almost zero except fot the first couple of years at the beginning of the simulation. At 50 and 100 kg N per ha application rates, most applied N was probably used by plants and therefore was not available for leaching. The NO_3-N losses in the beginning of the simulation (at 50 and 100 kg N per ha application rates) indicate that NO_3-N leaching was probably due to initial NO_3-N present in the profile.

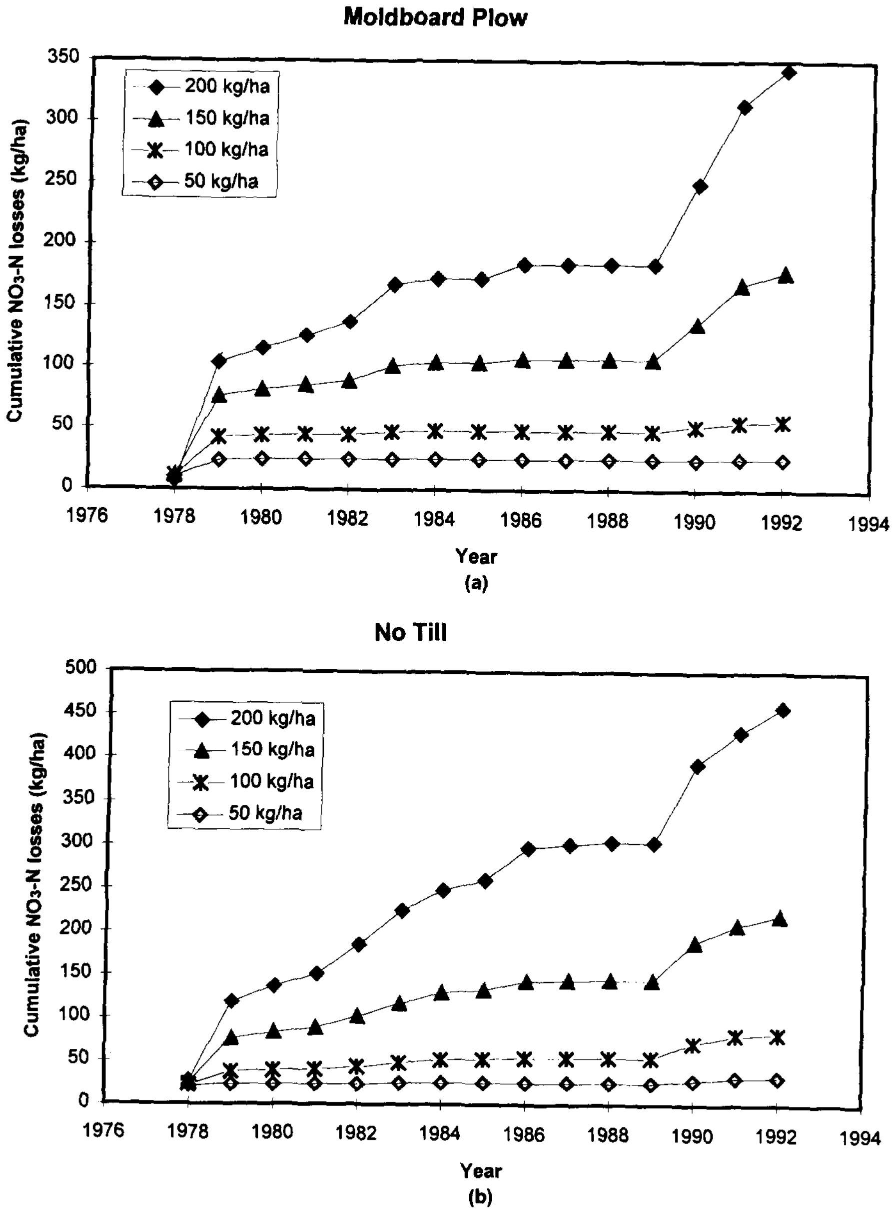

Fig. 1. Effects of NO_3-N application rates on NO_3-N losses with subsurface drain flows for (a) moldboard plow and (b) no-till systems

Similarly, Fig. 3 shows the effects of NO_3-N application rates on crop yields under MB and NT treatments. Again, all differences were significant between treatments (*t* test, 95% confidence interval). This figure shows that crop yields increased with increasing N application rates. The rate of increase

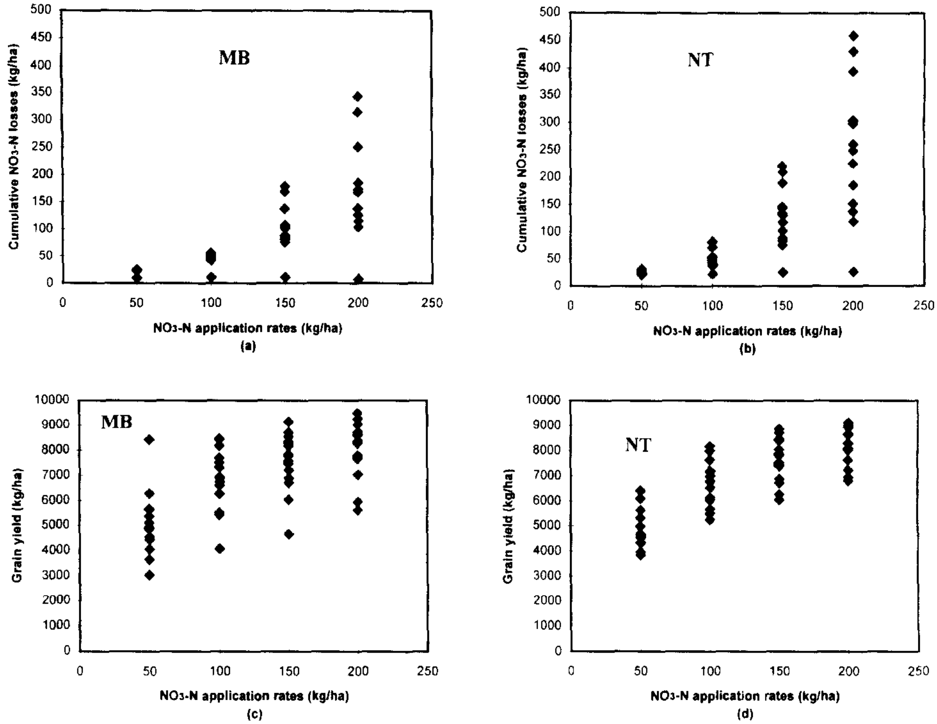

Fig. 2. Relationship between NO_3-N application rates and cumulative NO_3-N losses in subsurface drain flows, and yield, for moldboard plow (MB) and no till (NT) systems: (a) cumulative NO_3-N losses vs. NO_3-N application rates for MB; (b) cumulative NO_3-N losses vs. NO_3-N application rates for NT; (c) grain yield vs. NO_3-N application rates for MB; (d) grain yield vs. NO_3-N application rates for NT.

in crop yields was not linearly proportional to the rate of increase in N applications. For example, crop yields increased substantially (as much as by 60%) under both MB and NT systems when N application was increased from 50 to 100 kg per ha. But the increase in crop yield was much smaller when N application rates were increased from 100 to 200 kg per ha in 50 kg per ha increments. This nonlinear trend is also shown in Fig. 2(c) and (d), where NO_3-N application rates were plotted against grain yield.

Effects of split N applications on NO_3-N losses and crop yields

The effects of single and split application of 150 kg N per ha on NO_3-N losses with subsurface drain flows under MB and NT treatments are presented in Fig. 4. Similar results are presented in Fig. 5 for a total N application of 200 kg per ha. These figures show that there was no significant difference (*t* test, 95% confidence interval) between NO_3-N losses under single and split N

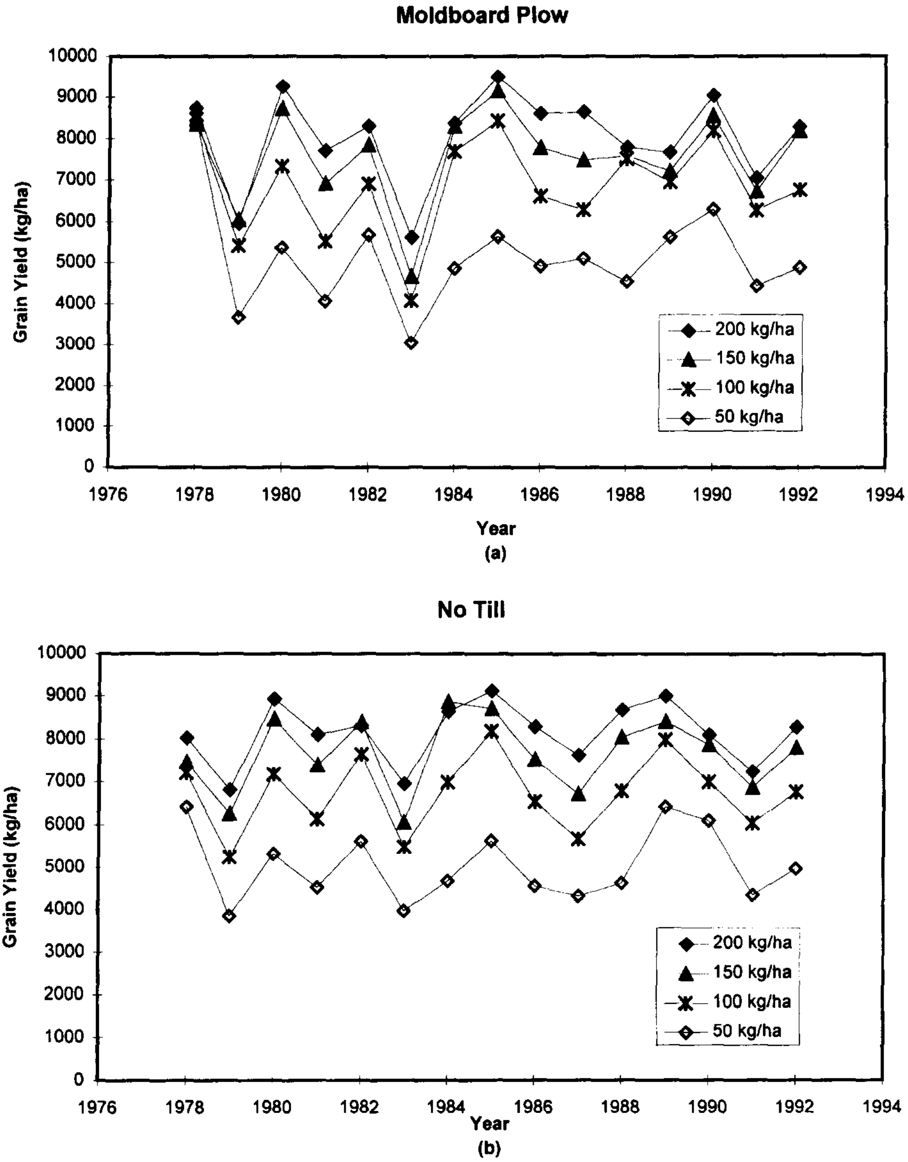

Fig. 3. Effects of NO_3-N application rates on corn yields under (a) moldboard plow and (b) no till systems for 15 years (1978–1992) of continuous corn production.

applications for either 150 or 200 kg per ha of total N application, with the exception of 200 kg per ha under MB where a significantly higher NO_3-N loss was observed in split application contrary to what was expected. The unexpected higher NO_3-N losses under split applications compared to single N application were probably due to the rainfall events immediately after the

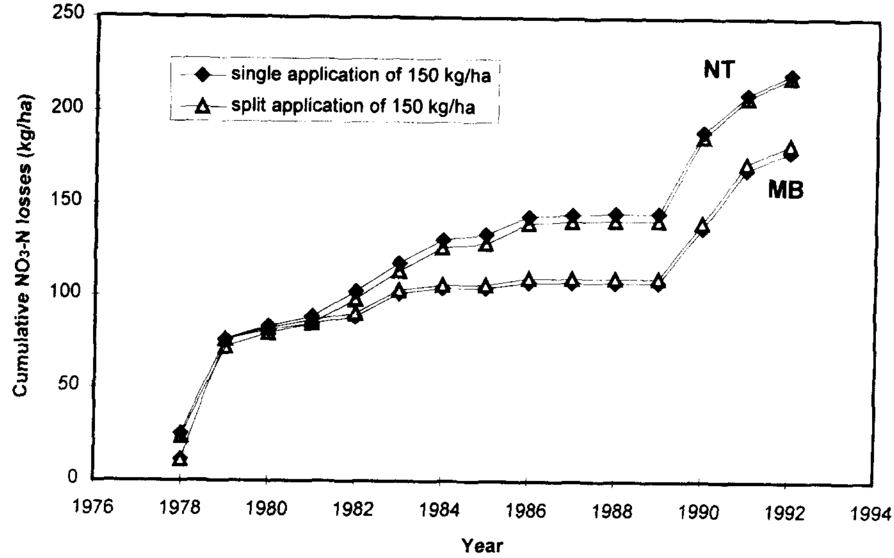

Fig. 4. Effects of single and split N application of 150 kg N per ha on NO_3-N losses with subsurface drain flows for moldboard plow and no till systems.

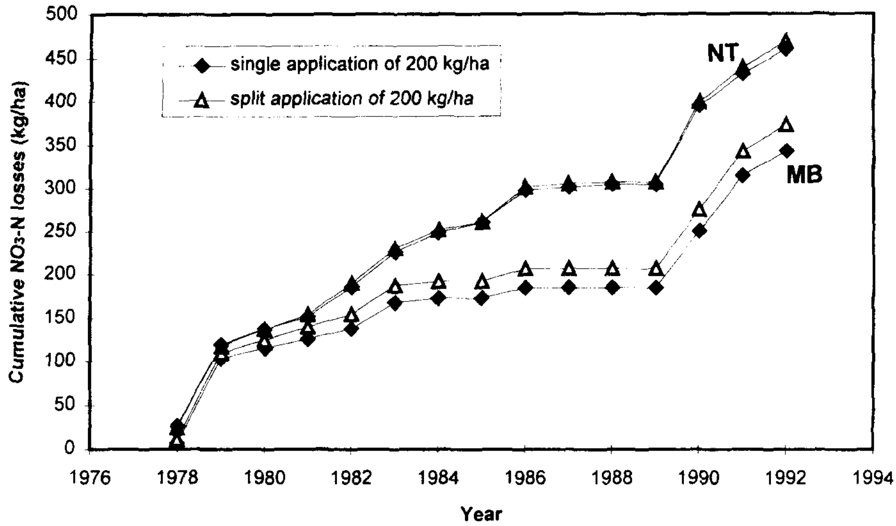

Fig. 5. Effects of single and split N application of 200 kg N per ha on NO_3-N losses with subsurface drain flows for moldboard plow (MB) and no till (NT) systems.

second nitrogen application in some of the years. Also, these trends were similar for both MB and NT tillage treatments.

Figures 6 and 7 present results on crop yields under single and split application of 150 and 200 kg N per ha, respectively. There was no significant

TABLE 4
Average Crop Yields under Single Application of 200 and 150 kg N per ha

Year	*MB*			*NT*		
	Single 200 kg per ha	*Single 150 kKg/ha*	*% difference*	*Single 200 kg per ha*	*Single 150 kg per ha*	*% difference*
1978	8 730	8 346	4.40	8 022	7 453	7.10
1979	5 960	6 046	−1.44	6 811	6 255	8.15
1980	9 256	8 717	5.82	8 923	8 461	5.18
1981	7 720	6 911	10.48	8 100	7 383	8.84
1982	8 310	7 851	5.52	8 310	8 389	−0.96
1983	5 624	4 668	17.00	6 951	6 052	12.93
1984	8 372	8 292	0.96	8 634	8 860	−2.61
1985	9 495	9 153	3.60	9 116	8 705	4.51
1986	8 605	7 790	9.47	8 288	7 524	9.21
1987	8 645	7 490	13.36	7 630	6 713	12.02
1988	7 797	7 595	2.60	8 676	8 045	7.27
1989	7 681	7 225	5.94	9 000	8 410	6.55
1990	9 040	8 554	5.38	8 100	7 877	2.76
1991	7 052	6 727	4.60	7 237	6 869	5.08
1992	8 288	8 186	1.23	8 281	7 807	5.73
Average	8 038	7 570	5.93	8 139	7 623	6.12

effect (*t* test, 95% confidence interval) of split application on crop yields at both 150 kg per ha or 200 kg per ha levels of N application. This trend was the same under MB and NT treatments. These results indicate that split N applications do not have any positive affect on crop yields when applied at total 150 and 200 kg N per ha rates.

The best N management scenario

Based on the results of several simulations as explained earlier, one N application scenario (single application of 150 kg N per ha) proved to be the best N management scenario. The effects of the best N application scheme and a typical N application scheme in the cornbelt (single application of 200 kg per ha 10 days before planting) on NO_3-N losses with subsurface drain flows and on crop yields are compared for both MB and NT tillage treatments in Figs 8 and 9, respectively. Similar results are presented in tabular form in Tables 4 and 5. Tables 4 and 5 show that single application of 150 kg N per ha resulted in about 6% average reduction in crop yield (5.9% reduction under MB and about 6.1% under NT) when compared with the crop yields under a higher application rate of 200 kg N per ha. The differences between the crop yields for 200 and 150 kg N per ha application rates were significantly different (*t* test, 95% confidence interval); whereas the NO_3-N losses with subsurface drain flows under 150 kg N per ha were much smaller (40.3% lower under MB and 52.4% lower under NT) compared to a single application rate of 200 kg N per ha. Again, these differences were significantly different (*t* test, 95% confidence interval) for MB and NT tillage

TABLE 5

Average NO_3-N Losses with Subsurface Drain Flows under Single Application of 200 and 150 kg N per ha

Year	*MB*			*NT*		
	Single 200 kg per ha	*Single 150 kg per ha*	*% difference*	*Single 200 kg per ha*	*Single 150 kg per ha*	*% difference*
1978	7.22	11.33	−56.97	26.39	25.15	4.68
1979	96.35	64.46	33.10	92.37	50.85	44.96
1980	11.24	5.45	51.53	18.35	7.50	59.11
1981	10.62	3.80	64.22	14.26	5.11	64.16
1982	12.01	3.56	70.38	33.92	13.54	60.09
1983	30.23	12.55	58.50	40.26	15.28	62.04
1984	4.82	2.77	42.61	23.23	12.94	44.31
1985	0.00	0.00	0.00	11.46	3.00	73.78
1986	11.94	3.16	73.55	37.49	9.95	73.45
1987	0.00	0.00	95.45	3.49	1.10	68.53
1988	0.00	0.00	0.00	2.97	0.80	72.84
1989	0.00	0.00	0.00	0.00	0.00	0.00
1990	65.82	29.97	54.47	90.36	43.96	51.35
1991	63.88	31.36	50.91	36.79	20.12	45.31
1992	28.74	9.78	65.99	28.55	11.13	61.02
Average	22.85	12.16	40.25	30.66	14.59	52.38

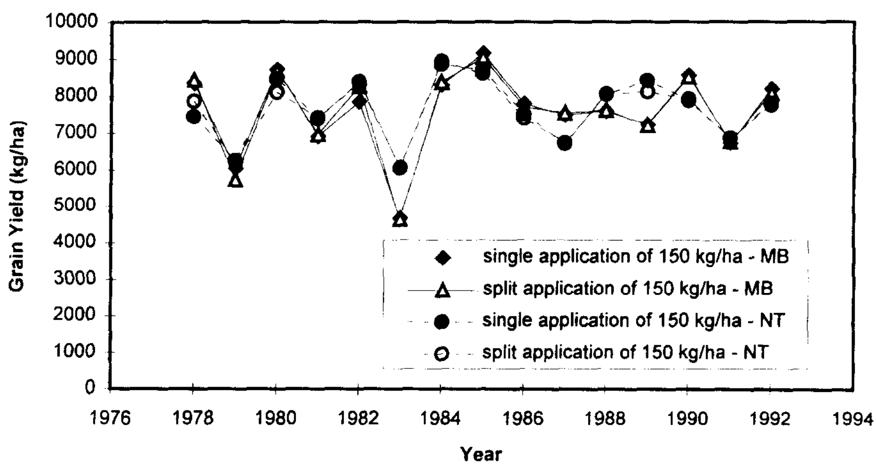

Fig. 6. Effects of single and split N application of 150 kg N per ha on corn yields under continuous corn production for 15 years (1978–1992), for moldboard plow (MB) and no till (NT) systems.

systems. This simulation study thus shows that NO_3-N losses in the subsurface drain flows can be effectively reduced, without substantially hampering crop production, by applying a reduced amount of N. Even though not shown by the results of this study, the use of split N application may reduce the NO_3-N losses to groundwater under certain conditions (if no rainfall occurs immediately after the N application). This study also shows that

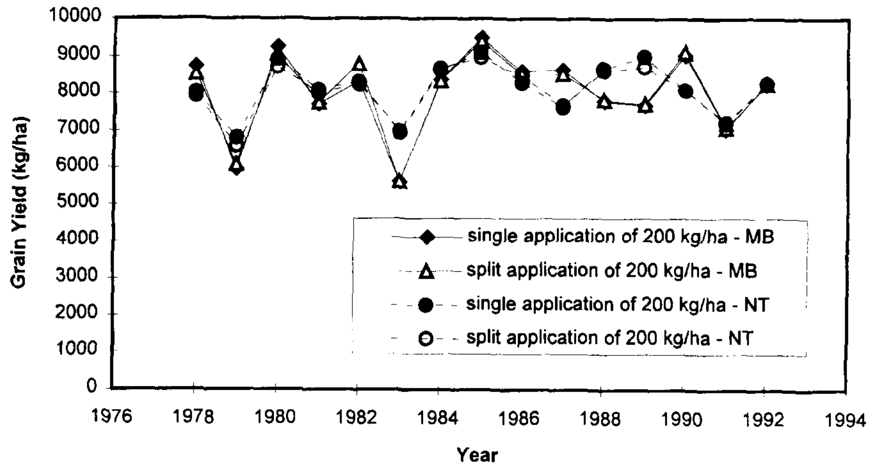

Fig. 7. Effects of a single and split N application of 200 kg N per ha on corn yields for 15 years of continuous corn production under moldboard plow (MB) and no till (NT) systems.

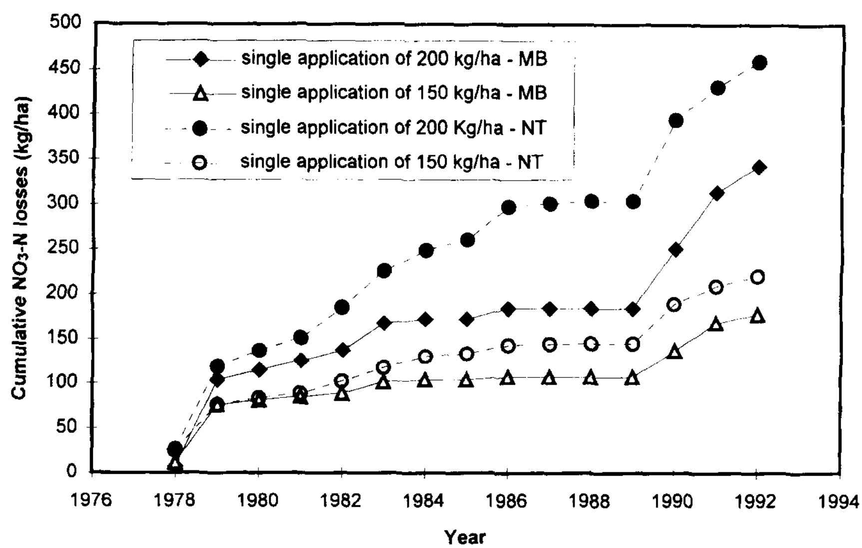

Fig. 8. Comparison between 150 and 200 kg N per ha in single applications on NO_3-N losses with subsurface drain water under moldboard plow (MB) and no till (NT) systems.

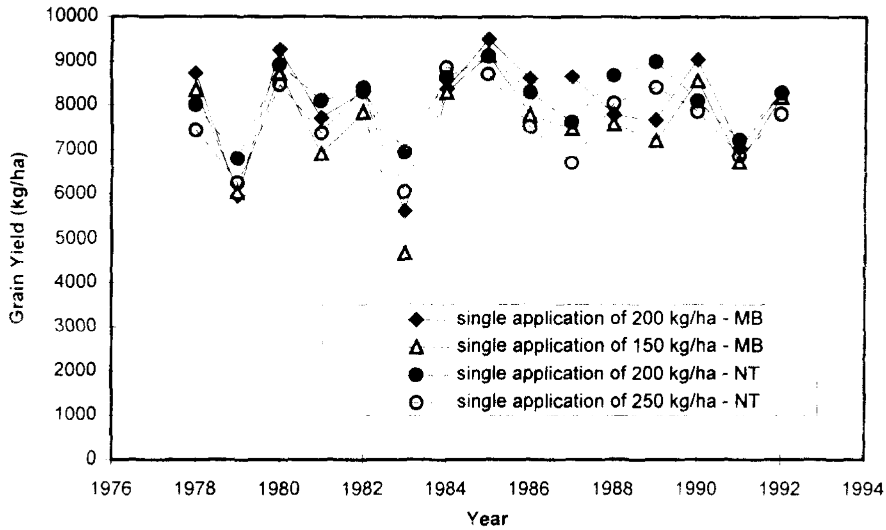

Fig. 9. Comparison between 150 and 200 kg N per ha in single applications on corn yields under moldboard plow (MB) and no till (NT) systems.

RZWQM can be effectively used in developing similar N management schemes for other geographic regions by utilizing site-specific soil, geological, crop, and climatic data.

CONCLUSIONS

This study resulted in the following conclusions:

(1) Increasing rates of N applications (at 50, 100, 150, and 200 kg per ha) resulted in increased NO_3-N losses with subsurface drain flows and increased corn yields. The increased amounts of NO_3-N losses with subsurface drain water and increased crop yields were not linearly proportional to the increasing rates of N application.

(2) The single and split N applications at rates of 150 and 200 kg N per ha, respectively, did not significantly affect the NO_3-N losses and corn yields.

(3) The single N application rate of 150 kg per ha resulted in the best N application scenario, as the simulated NO_3-N losses with subsurface drainage water under this scenario were reduced significantly (40.3% lower losses under MB and 52.4% lower losses under NT) when compared to the single application of 200 kg N per ha. At the same time, the reduction in crop yields at 150 kg per ha of single N application was

not significant (5.9% reduction under MB and about 6.1% under NT) when compared with the crop yields at 200 kg N per ha.

(4) RZWQM can be used successfully in the testing and evaluation of different N management schemes for other geographic regions by utilizing site-specific data on soils, geological conditions, crops, and climatic parameters.

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