Simulated Effects of Fertilizer Management on Nitrate Loss with Tile Drainage Water for Continuous Corn

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ABSTRACT

A computer simulation model was used to estimate the impact of different fertilizer management practices for continuous corn production on the loss of nitrate-nitrogen with tile drainage water. Simulations using historical weather data were conducted for seven consecutive growing seasons for a location in Iowa. Currently, nitrogen management by most farmers in Iowa can be represented by a single application (usually NH_3-N) of about 150 kg/ha. Management schemes tested to improve the efficiency of nitrogen use include fertilizer application rates, and timing and the number of applications. Model results indicate that lower application rates and multiple applications significantly decrease nitrate-nitrogen losses in both wet and dry years.

INTRODUCTION

The efficient management of water and nitrogen is very important to agriculture in areas of artificially drained soils; a deficiency of available N often limits corn yields while an excess can be an environmental quality concern. Inefficient management of nitrogen fertilizers can result in the loss of N through denitrification and leaching, an economic loss to the farmer and potential for surface and groundwater pollution. Further, efficient fertilization is important to minimize energy input in crop production.

The fate of nitrogen fertilizer applied to tile drained agricultural fields has been researched (Baker and Johnson 1981; Gambrell et al., 1975a; Gambrell et al., 1975b; Gast et al., 1978). Baker and Johnson (1977) reported that artificial drainage would be expected to increase the movement of nitrate from agricultural fields even in years when no additional fertilizer was applied. A field study from North Carolina shows that poorly drained soils with high water tables lose less nitrate to drainge waters than do naturally well-drained soils (Gambrell et al., 1975b) because of denitrification of nitrate in the subsoil of poorly drained soils. Skaggs and Gilliam (1981) found that the amount of nitrate that leaves the field through subsurface drainage waters can be reduced by using controlled drainage during the winter months and during the growing season.

Management of nitrogen fertilizers applied to soils to avoid leaching losses and to increase efficiency of nitrogen use may be directed in either of two directions. One management objective would be to adopt practices that will minimize losses of nitrate-nitrogen from the crop root zone by leaching. A second goal would be to minimize denitrification losses and thus maximize the use of applied fertilizer. The latter objective seems practical and is not completely independent from the first objective, but is not discussed in this paper.

To determine the impact of current fertilizer application rates on nitrate losses in drainage water, a field study was conducted by Baker et al. (1975), and Baker and Johnson (1981). The results obtained from those studies were used to develop and calibrate a computer simulation model of the soil-plant-water-climate system to a particular set of field conditions (Kanwar et al., 1983). The constraints of financial resources make it difficult to study a large number of combinations of practices by having a large scale field experiment; therefore, the field-calibrated computer simulation model was used to estimate the impact of different fertilizer management practices on the loss of nitrate-nitrogen in tile drainage water.

The overall objective of this study is to define the effects of various nitrogen management practices for continuous corn production on the loss of nitrate-nitrogen with tile drainage water from agricultural watersheds. Fertilizer application rates, timing, and the number of applications were simulated for a location in Iowa. The results provide a basis for maximizing the efficiency of nitrogen use for the given crop production system.

SIMULATION STUDY

Computer Simulation Model

A hydrologic and nitrogen transport simulation model developed by Kanwar et al. (1983) was used to study the impact of different fertilizer management practices on the loss of nitrogen with tile drainage water in an artificially drained area. Inputs to the computer simulation model include daily precipitation; daily open-pan evaporation; dates of planting, harvest, and fertilization; amount of fertilizer; and soil-water relationships. Outputs from the model consist of water table depths, surface runoff, discharge at the tile, concentration of nitrate in the effluent, and nitrogen uptake by plants. This model can be used for the comprehensive analysis of soil water and nitrate transport in an agricultural field.

The hydrologic and nitrogen transport components of the simulation model were calibrated and tested by use of seven years of tile flow and the drainage water nitrate concentration data from field experiments conducted at the Iowa State University's Agronomy and Agricultural Engineering Research Center near Boone, Iowa. A summary of the comparison between measured and predicted tile flows and nitrogen losses for seven years, as

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TABLE 1. COMPARISON OF MEASURED AND PREDICTED ANNUAL TILE FLOW AND NITRATE DISCHARGE FOR 7 YEARS

Year	Crop	Fertilizer application rate, kg/ha	Precipitation (cm) April through November	Tile flow			Nitrogen loss		
				Measured, cm	Predicted, cm	Error, %	Measured, kg/ha	Predicted, kg/ha	Error, %
1970	corn	112	84.50	9.37	10.77	+ 14.9	14.9	18.5	+ 24.2
1972	corn	112	83.16	17.03	15.80	- 7.2	40.9	29.9	- 26.9
1973	soybean	0	93.01	30.31	31.33	+ 3.4	50.0	57.7	+ 15.4
1974*	corn	100	86.21	19.21	20.28	+ 5.6	30.1	38.5	+ 27.9
1975	soybean	0	64.01	15.92	15.27	- 4.1	38.5	31.9	- 17.1
1976	corn	90	43.18	8.10	7.62	- 5.9	20.9	16.4	- 21.5
1978	corn	90	83.49	11.07	10.00	- 9.7	20.6	19.0	- 7.8
Average		72	76.79	15.86	15.87	+ 0.1	30.84	30.27	- 1.8

*Calibration year.
1971 and 1977 planted to oats

reported by Kanwar et al. (1983), is given in Table 1. Simulations presented in this paper were conducted by using weather and soils data from the Agronomy and Agricultural Engineering Research Center near Boone, Iowa.

Weather, Soil, and Crop Input Data

Simulations were conducted using 1972 through 1978 weather data. The year 1972 was used as the first year of simulation (with low antecedent soil moisture and low initial N) to establish the soil profile data for the model. Monthly variations in precipitation patterns for the growing seasons (April thru November) are shown in Fig. 1. Daily precipitation, open-pan evaporation, and soil temperatures were taken from the local weather data collection station at the reseach center.

Simulations were conducted on Clarion-Webster soils, which are naturally poorly drained soils. Soil moisture, hydraulic conductivity characteristics, and other physical properties used as inputs in the model were taken from Campbell and Johnson (1975). Data on field capacity and wilting point were taken from Shaw et al. (1972). The data on initial soil water content are needed as inputs for the model. Initial soil water contents for 1972 also were taken from Shaw et al. (1972). Thereafter, the soil moisture contents at the end of each simulation year were carried over to the beginning of the next simulation year. (The assumption is made that the soil will be frozen for most of the period between the end of each simulation year and the beginning of the next simulation year).

May 15 and October 15 were taken as planting and harvesting dates for the corn crop, respectively. Other

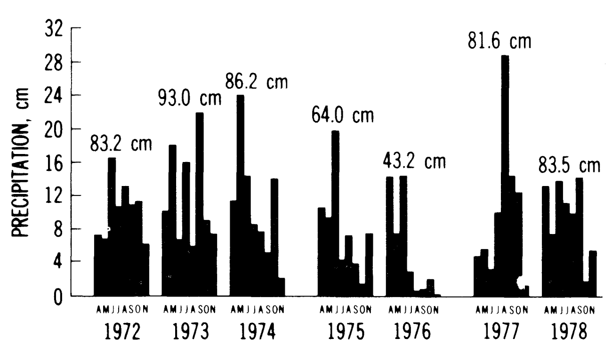

Fig. 1—Monthly precipitation patterns at Ames, Iowa for months of April through November. Eight months total precipitation is given above each precipitation pattern.

crop input data such as the distribution of the root system, crop development ratios, and crop stress factors are given by Kanwar et al. (1983).

Drainage System Input Data

The model calculates the daily tile flow rates using Hooghoudt's steady-state equation. Deep percolation is considered to occur through a nearly impermeable layer and is estimated by the application of Darcy's law. Therefore, the data on depth of tiles, tile spacings, depth to impermeable layer, saturated hydraulic conductivities, thickness of the nearly impermeable layer, and the initial water table depth are needed for simulation. The initial water table depth for the first year of simulation, 1972, was taken at 150 cm.

Surface runoff is calculated by using the SCS equation (Mockus, 1972). Other data on surface and subsurface drainage parameters are summarized by Kanwar et al. (1983).

Nitrogen Input Data

In the model, transport of nitrogen in the soil profile occurs in the form of NO_3-N by the processes of diffusion, dispersion, and mass flow. The values of the diffusion and dispersion coefficients were taken as 1 cm^2/day and 0.4 cm, respectively. Nitrogen uptake (mg/cm^2) by the crop is calculated as a product of evapotranspiration (cm) from the soil profile, nitrate concentration of soil layers (mg/cm^3), and a factor for approximating the transpiration from each layer. It is assumed that 60% of the evapotranspiration from the top 30 cm of soil profile is transpired, and the rest evaporated. Therefore, the value of the factor, F, was taken as 0.6. The value of this factor was taken as 1.0 for the bottom 120 cm of the 150 cm soil profile.

In the nitrogen tranport model, all NO_3-N predicted to be taken up by plants was assumed to be permanently removed from the system. The nitrogen which is returned to the soil in the stalks is assumed to be organic and becomes a part of the potentially mineralizable nitrogen pool. The NO_3-N uptake sub-model within the nitrogen transport model, could not be verified because field data were not available.

April 1 of each year was set as the starting day for the model simulation, and the initial NO_3-N concentrations for all the soil layers considered in the model are needed as inputs. Initial values of NO_3-N concentrations in the soil profile were estimated for 1972. A total of about 72 kg N/ha was used in the model as initial residual NO_3-N in the upper 150 cm of the soil profile for 1972; then the residual NO_3-N at the end of each simulation period was carried over to the beginning of the next simulation year. Also, a total of about 80 kg/ha of inorganic nitrogen annually is estimated to be input in the top 30 cm of the soil profile because of mineralization from organic nitrogen during the growing season. The mineralization rate is high in spring and occurs in the top two layers of the soil (net mineralization rate of 0.0042 mgN/day/cm^2 for each layer from April 15 to June 3). A mineralization rate of 0.00116 mgN/day/cm^2 for each of the top two layers is assumed for days from April 1 to April 14 and June 4 to Oct. 31. This is only slightly less than the mineralization rate estimate of 84 kg N/ha used by Watts and Martin (1981).

Fertilizer Management

To consider improving the efficiency of nitrogen use, six fertilizer management schemes were simulated involving three rates, and two timings for continuous corn production. Three fertilizer application rates of 75, 150, and 225 kg N/ha, were used in the simulation study (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 N/ha from 1970 to 1979; Baker and Johnson, 1981). For the first timing scheme, nitrogen fertilizer (anhydrous NH_3) was assumed to be applied to the soil after three consecutive days without rain, any time after April 1.

The second timing scheme included multiple applications of nitrogen fertilizer at different times during the growing season for continuous corn production. In this management scheme, the same amounts of fertilizer (75, 150, and 225 kg/ha) were applied in three applications. Three applications of 25 kg/ha each (75 kg/ha total); 50 kg N/ha each (150 kg/ha total); and 50, 75 and 100 kg N/ha (225 kg/ha total) were assumed to be applied in the first week of April, June and July, after a period of three days without rain.

RESULTS AN DISCUSSION

Simulated Effects of Fertilizer Application Rate on NO_3-N Loss

The simulated effects of fertilizer applications rates on total NO_3-N loss with tile drainage water for the simulated growing seasons (1973 to 1978) are given in Fig. 2 for single N fertilizer application rates increasing from 75 to 225 kg N/ha. It is clear from this figure that the larger NO_3-N leaching losses are associated with large application rates of nitrogen fertilizers. Also, total NO_3-N leaching losses increase as the cumulative tile flows for the season increase.

Fig. 3 summarizes the simulated effects of fertilizer application rates on the total leaching loss of NO_3-N and NO_3-N uptake by plants. From Fig. 3, it is shown that, for the year 1972, the first year of simulation, the computed total leaching loss during the growing season was not substantially increased by the additional fertilizer, however, residual nitrogen in the soil profile increased considerably by the end of each simulation period of eight months (initial residual nitrogen in the soil profile was considered constant for all application rates for the year 1972). The major effect of this left-over

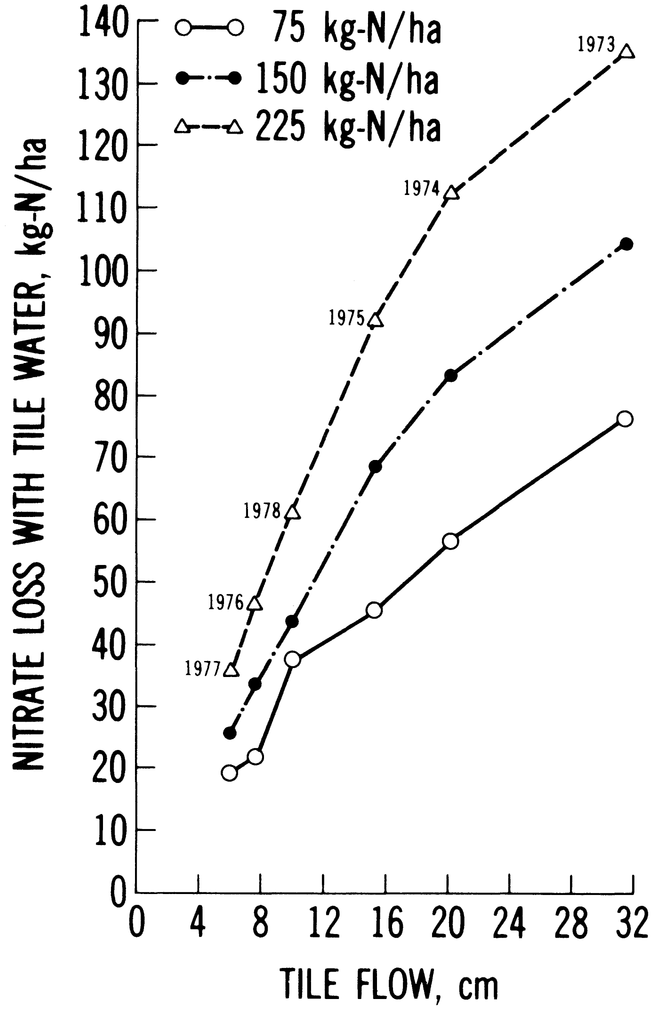

Fig. 2—Total seasonal NO_3-N leaching loss as a function of fertilizer application rates (applied in a single application) and total seasonal tile flows (April through November) for continuous corn production for the years 1973 to 1978. Years for each season are shown above the simulated data points.

residual nitrogen is the potential for increased leaching loss during the spring of the following year. The effect of the increased fertilizer application rate on leaching loss is very evident for the year 1973 (Fig. 3). The leaching loss of NO_3-N was increased by 59.1 kg/ha (77% increase) when the single application rate was increased from 75 to 225 kg N/ha.

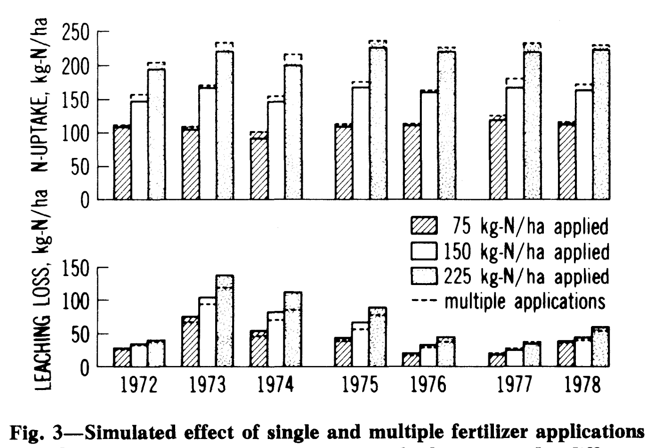

Fig. 3—Simulated effect of single and multiple fertilizer applications on NO_3-N leaching loss and nitrogen uptake by corn under different precipitation patterns for continuous corn production.

The simulated effects of the three fertilizer rates for seven years of continuous corn production are summarized in Table 2. When the fertilizer rate for a single application was increased from 75 to 150 kg/h (a 100% increase), the NO_3-N leaching loss was increased by an average of about 38% and nitrogen uptake was increased by about 47%. But when the fertilizer application rate was increased by 200% (75 to 225 kg/ha), the NO_3-N leaching loss increased by 83%, and nitrogen uptake increased by 98%.

Effect of Multiple Fertilizer Applications on NO_3-N Leaching Losses and Plant Uptake

Fig. 3 shows the comparison of single and multiple fertilizer applications on the calculated NO_3-N leaching loss with tile drainage water and NO_3-N uptake by the plants. NO_3-N leaching loss depends on many factors, such as the amount of fertilizer applied, the method and time of fertilizer applications, and amount of nitrogen present in the soil profile at the beginning of the simulation, therefore, Fig. 3 presents the combined effects of the factors for seven consecutive growing seasons. Multiple applications resulted in greater plant uptake and lesser NO_3-N load in tile drainage water. Plant uptake increased 2% to 9% when multiple applications of fertilizer were applied as compared with a single application of the same amount. The NO_3-N loss with tile drainage water was decreased as much as 23% when multiple applications were applied.

Table 2 compares the simulated annual averages of NO_3-N uptake by plants, and NO_3-N leached under three different application rates for single and multiple applications for seven years of continuous corn production. This table shows that a decrease of 9% to 13% in the NO_3-N leached can occur when multiple applications are used as compared with applying fertilizer in a single application. About 7% increase in nitrogen uptake by plants can be obtained when fertilizer is applied in multiple applications.

Effect of Tile Drainage on NO_3-N Leaching Losses

The relationship between NO_3-N leaching losses with tile drainge water and annual tile flow is given in Fig. 2. Nitrogen leaching loss during any growing season depends on the removal of excess water by tile drains and the amount of fertilizer applied (the effect of excessive fertilization probably will not be realized for at least a year). Larger NO_3-N losses are associated with higher application rates. Also, NO_3-N leaching losses increased with increased tile flow, except for 1972 when leaching losses were not high. This may be due to two facts. First, 1971 was a very dry year, and the moisture content in the soil profile on the beginning day of simulation for 1972 was very low. Second, the amount of residual NO_3-N in the soil profile was comparatively lower at the start of the 1972 year (because the area was under oats during 1971). These two facts together may have decreased the residual NO_3-N available for leaching and plant uptake for the year 1972. Fig. 2 shows that even for 150 kg N/ha of fertilizer application, nitrate losses of 70 to 95 kg/ha might be possible if tile flows exceed 16 cm and enough residual nitrogen buildup takes place in the soil profile during continuous corn production.

TABLE 2. COMPARISON OF ANNUAL AVERAGES OF THE SIMULATED RESULTS UNDER SINGLE AND MULTIPLE NITROGEN FERTILIZER APPLICATIONS WITH DIFFERENT APPLICATION RATES FOR SEVEN YEARS OF CONTINUOUS CORN PRODUCTION.

Application rate (kg/ha)	Single application*		Multiple application†	
	NO_3-N loss with tile water, kg/ha	Plant N uptake, kg/ha	NO_3-N loss with tile water, kg/ha	Plant N uptake, kg/ha
75.0	40.3	108.6	36.2	114.7
150.0	55.7	159.7	50.8	171.4
225.0	73.9	214.9	64.2	227.0

* One application in the first week of April.
† Three applications in the first weeks of April, June, and July.

Effect of Rainfall Pattern

Fig. 3 gives the comparison of simulated NO_3-N leaching loss and nitrogen uptake for the seven consecutive years of weather record for six fertilizer management practices. For years 1973 and 1974, the annual tile flow increase resulted in a greater NO_3-N loss with tile drainage water. The average NO_3-N in the soil profile is affected greatly by the rainfall pattern.

For the year 1974 excess rain fell in April, May, and June; the NO_3-N immediately began to move downward in the soil profile, resulting in larger leaching losses. Thus, the available nitrogen was moved below the root zone, and corn plants at that stage could not use the displaced nitrogen. Rapid uptake was delayed, which resulted in the least uptake of nitrogen for that year relative to the seven years of the simulation period (Fig. 3).

The year 1975 was a relatively dry year with annual rainfall of 64.0 cm; but more than 40 cm of rainfall occurred in April, May, and June, resulting in more than 85% of the tile flow for this year occurring in these three months. More tile flow (15.3 cm) occurred in 1975 than in 1978 (10.0 cm), when rainfall totaled 83.5 cm.

The rainfall pattern for 1977 was unique (with a rainfall of 81.6 cm). Because 1976 was a very dry year (annual rainfall of only 43.2 cm), the initial moisture content of the soil profile was very low for the beginning of 1977. Also during 1977 less than 30% of the annual rainfall occured in the first four months of the growing season, and tile did not flow until October, which resulted in very little NO_3-N loss and relatively more nitrogen uptake by corn. The year 1977 was the only year when multiple fertilizer applications resulted in more NO_3-N loss with tile water.

This shows that the rainfall pattern has a major impact on the leaching of NO_3-N in tile-drained areas, and management practices for nitrogen applications are needed to meet the unpredictable weather conditions.

CONCLUSIONS

This simulation study resulted in the following conclusions:

1. For all years, the greater nitrogen uptake and NO_3-N leaching losses were associated with the highest fertilizer application rate of 225 kg N/ha. Nitrogen uptake increased by more than 95% and NO_3-N leaching loss increased about 80% when the fertilizer application rate was increased from 75 to 225 kg/ha for continuous corn production.

2. Multiple fertilizer applications increased nitrogen uptake by about 2 to 9% and decreased NO_3-N loss up to 23% depending upon the rainfall pattern, and the amount and time of fertilizer application (during an

(continued on page 1404)

Simulated Effects of Fertilizer Management

(continued from page 1399)

unusual rainfall year, multiple applications actually slightly increased leaching losses).

3. NO_3-N leaching losses depend on the amount of residual nitrogen present at the beginning of the simulation, and precipitation pattern.

4. There is a considerable delay (up to 1 yr) between the time of increased fertilization at the soil surface and the time that the quality of subsurface drainage water is affected.

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