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Prediction of NO3-N losses with subsurface drainage water from manured and UAN-fertilized plots using GLEAMS

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Keywords
GLEAMS, Swine manure, Nitrate-nitrogen, Water quality

Disciplines
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PREDICTION OF NO_3-N LOSSES WITH SUBSURFACE DRAINAGE WATER FROM MANURED AND UAN-FERTILIZED PLOTS USING GLEAMS

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ABSTRACT. *Excessive application of swine manure to a field over long durations can increase nitrate-nitrogen (NO_3-N) leaching as a result of accumulation of more nutrients in the root zone than the subsequent crops may need. The objective of this study was to use the GLEAMS (V.2.1) model to compare measured versus simulated effects of swine manure application with urea-ammonium-nitrate (UAN) on subsurface drain water quality from beneath long-term corn (Zea mays L.) and soybean (Glycine max L.) plots. Four years (1993-1996) of field data from an Iowa site were used for model calibration and validation. The SCS curve number and effective rooting depth were adjusted to minimize the difference between simulated percolation below the root zone and measured subsurface drain flows. Model predictions of percolation water below the root zone followed the pattern of measured drain flow data, giving an average difference of 10%, and –5% between predicted and measured values for manured and UAN-fertilized plots, respectively, for four years from 1993 to 1996. Model simulations for overall NO_3-N losses with percolation water were comparable to measured NO_3-N losses with subsurface drain water giving an average difference of 20% for manured plots. The model overpredicted NO_3-N losses, particularly for soybean on plots, which received manure in the previous year. Predicted NO_3-N losses with subsurface drainage from fertilized plots were much lower than measured values with an average difference of –32%. The best fit line with zero intercept showed correlation coefficients of 0.73 and 0.66 between monthly predicted and measured NO_3-N losses with subsurface drain flows for manured and UAN-fertilized plots for four years from 1993 to 1996, respectively. The results of the study show that the N-transformation processes and the associated rate factors based on soil temperature and soil water levels may need to be refined for consistent simulation of NO_3-N losses with subsurface drainage water when fertilized with either swine manure or UAN for corn production.*
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The rapid growth in size of swine facilities in Iowa has resulted in a steady increase in animal waste production, with manure production ranging from 1 to 10 kg/day/hog depending on the hog's size, type, and ration. Currently, 28.4 million tons of liquid swine manure are gathered in pits annually in Iowa (Midwest Plan Service, 1993; Iowa Agricultural Statistics, 1996). This situation has encouraged farmers to apply higher rates of swine manure on agricultural lands, but continuous application of manure to a field over a long duration may result in the accumulation of more nutrients in the root zone than subsequent crops need. Some nutrients, especially nitrogen in the form of nitrate (NO_3), is highly mobile and may leach to groundwater or to the tile drainage network. Nitrate contamination of groundwater is a major concern in hog-producing areas, and additional information quantifying the impact of swine manure application on water quality is needed (Kanwar et al., 1995; Gangbazo et al., 1997; Gupta et al., 1997).

Freshly excreted manure has nitrogen in the organic form that is converted to ammonium-nitrogen after application to the soil or during storage. Because ammonium is adsorbed to the soil particles, it generally does not leach from the root zone, but may volatilize as ammonia gas depending on the soil environment and its mode of application. Soil microbes convert ammonium to NO_3, which is highly soluble and can move easily with the soil water. In wet soils, NO_3 may contaminate groundwater through percolation or may be lost as nitrogen gas as a result of denitrification. These N-transformation processes are influenced by environmental and management variables, which determine the potential for contamination (Yoon et al., 1994). Therefore, it is imperative to quantify these N-transformation scenarios to minimize N losses.

In addition to field and lab experiments, the use of computer models also provides an opportunity to evaluate the response of soil and water resources to several different farming practices in an efficient and cost-effective way. Kanwar et al. (1983) developed a computer model to simulate major water and N transport processes occurring in a typical agricultural watershed during the crop growth period. DRAINMOD (Skaggs, 1978) was extended as DRAINMOD-N (Breve et al., 1997) for predicting various N transformations and uptake processes in subsurface-drained soils. The scientists of USDA-ARS developed the CREAMS model (Knisel, 1980) to evaluate nonpoint

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source pollution from field-scale agricultural areas. Saleh et al. (1994) evaluated the DRAINMOD-CREAMS model with an incorporated nutrient submodel. CREAMS was later modified to develop GLEAMS (Knisel, 1993) with an enhanced hydrology component, a component for the vertical flux of pesticide, and a component for plant nutrients. Shirmohammadi et al. (1998) reported that GLEAMS was capable of simulating drainage discharge and NO_3-N and dissolved-P losses reasonably well in a structured soil. Stone et al. (1998) reported that GLEAMS simulated groundwater NO_3-N concentrations with mean residuals (simulated-observed) of ±1.3 mg/L and ±19 mg/L, respectively, for a corn/wheat/soybean rotation field and for a bermuda grass field sprayed with swine waste. GLEAMS is now a field-scale water quality model that has hydrology, erosion, pesticide, and nutrient submodels. A detailed description of GLEAMS can be found in Leonard et al. (1987) and Knisel (1993).

Although computer models can be useful tools for developing waste management systems and solving soil and water problems, they must be validated using field experimental data. GLEAMS has been validated for poultry manure application (Yoon et al., 1994; Minkara et al., 1995), but no validation studies have been conducted for swine manure application under a corn-soybean cropping sequence. Therefore, this study presents evaluation of the GLEAMS model for simulation of NO_3 losses with subsurface drainage water with the following objectives:

- Calibrate and validate the GLEAMS model for prediction of NO_3 losses with subsurface drainage water from corn-soybean rotation plots fertilized with liquid swine manure.
- Compare the simulations of the model with corn-soybean rotation plots fertilized with a urea-ammonium nitrate (UAN) solution.

Field Experiments and Input Data

The field experiment providing calibration and validation data for this study was located at Iowa State University's Northeast Research Center near Nashua, Iowa. The corn-soybean rotation plots are located on a predominantly Kenyon silty clay loam and Readlyn fine loamy soil with 4 to 5% organic matter (Kermit, 1995). Kenyon and Readlyn are classified as fine-loamy, mixed, mesic *Typic Hapludolls*. These soils have seasonally high water tables and benefit from subsurface drainage. Subsurface drains were installed in 1979 at 1.2 m depth and 28.5 m spacing. Pre-Illinoian glacial till units 60 m thick overlie a carbonate aquifer used for water supply in the area. The site has thirty-six, 0.4-ha plots with fully documented tillage and cropping records for the past 19 years. Each plot has an independent drainage sump for measuring subsurface drainage and collecting water samples for chemical analysis (Kanwar and Baker, 1991). Drainage water sampling frequency averaged three times a week during subsurface drainage flow. The current field study was initiated in the fall of 1992 to monitor NO_3 leaching losses through subsurface drain flows beneath corn-soybean rotation plots fertilized with either swine manure or UAN fertilizer whenever corn was grown. Four years (1993-1996) of data on subsurface drain flows and NO_3-N concentrations in the water from six rotation plots (plots no. 11, 23, 27 manured and 12, 17, 34 fertilized with UAN) were selected to calibrate and validate the GLEAMS (version 2.1) model for NO_3-N simulations. The Nashua site has seven different crop management systems, allocated to 36 plots under a randomized block design (fig. 1). System 3 (plots no. 12, 17, 34) and system 5 (plots no. 11, 23, 27) were selected because these two systems are under the same tillage, herbicide, and crop rotation treatments except N-management practices, for which this study was designed.

Model Input Data

The model was run for continuous simulations from 1 January 1993 through 31 December 1996 to minimize the effects of parameter estimation at the beginning of each year and to simulate various soil water and N transformation processes continuously throughout that period. Local weather and management data were generally available and were used for the simulation.

Meteorological Data

GLEAMS requires mean daily air temperature and daily precipitation data. It uses mean daily temperature to determine whether precipitation is rain or snow. The hydrology subroutine requires mean monthly maximum temperature, minimum temperature, solar radiation, wind speed, and dew point data. For locations where this information is not available, it can be found for more than 1,000 U.S. locations in the Climate Generator (CLIGEN) database associated with the model (Richardson and Nicks, 1990). For this study, daily rainfall and temperature data were available from an on-site weather station, but mean monthly data for solar radiation, dew point, and wind speed were not available, so they were taken from the database for a station near Osage, Iowa, which is located about 40 km from the experimental site.

Soil Data

Clay, silt, sand fractions, porosity, field capacity, wilting point, and hydraulic conductivity data were taken from Singh (1994). Based on the soil properties, experimental plots were classified in the hydrologic soil group A according to the user's manual (Knisel, 1993). The root zone was divided into four horizons based on textural data. Physical and hydraulic properties of each soil horizon within the six plots are presented in table 1. The SCS curve numbers (CN2) for hydrologic soil group A were selected initially from the user's manual and were calibrated for plots 11 and 23 with a slope of 1%, and for plot 27 with a slope of 4%. The calibrated model from manured plots was tested for the UAN plots using measured data from plots of 12 and 34, which have slopes of 1% and 3%, respectively.

Management Practices

A chisel plow was the primary tillage tool used for the six selected plots in this study. Tillage was done in the fall of each year immediately after harvesting the crop. The secondary tillage operations were one or two field cultivations in the spring performed by a field/row cultivator. Dates of all the management activities, such as planting, harvesting, tillage, and fertilizer applications, are given in table 2. UAN was applied two times during the

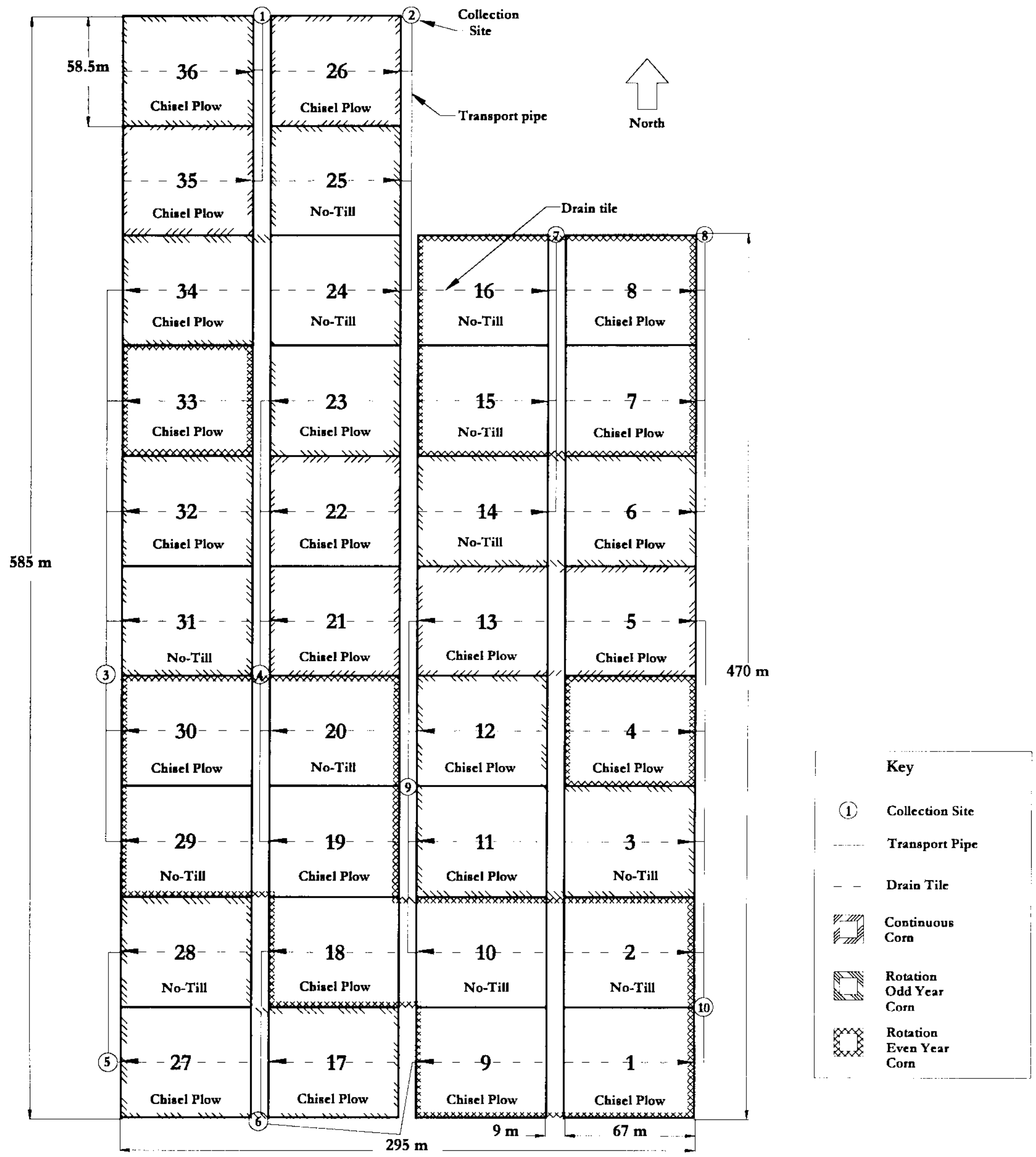


Figure 1–Plot layout at Nashua, Iowa, water quality site.

Table 1. Soil physical properties used as inputs to the GLEAMS hydrology file (from Singh, 1994)

	Physical Properties				Hydraulic Properties			
Soil Depth (mm)	Clay (%)	Silt (%)	Sand (%)	Organic Matter (%)	Porosity	Field Capacity	Wilting Point	Hydraulic Conductivity (mm/h)
Plots No. 11*, 12, 34, 27*								
0-200	20	42	38	4.0	0.49	0.30	0.14	12.7
200-690	26	32	42	2.0	0.44	0.25	0.14	12.0
690-890	28	28	44	1.0	0.38	0.19	0.14	12.0
890-1200	25	31	44	0.1	0.35	0.20	0.14	12.0
Plots No. 23*, 17								
0-200	26	43	31	4.0	0.49	0.29	0.13	12.7
200-540	24	36	40	2.0	0.44	0.25	0.13	12.0
540-890	24	26	50	1.0	0.38	0.19	0.13	12.0
890-1200	26	28	46	0.1	0.35	0.20	0.13	12.0

* Manured plots.

Table 2. Seasonal management activities at the study site

Corn		Soybean		
1993	1995	1994	1996	Activities
15 Nov*	17 Nov*	-	-	Fall application of manure
20 Nov	22 Nov	20 Nov	19 Nov	Primary tillage
14 May	15 May	-	-	Preplant UAN injected (28 kg/ha)†
17 May	16 May	17 May	30 May	Planting
21 July	14 June	-	-	Cultivation
7 July	22 June	-	-	Sidedress UAN injected (123.5 kg/ha)†
1 Sept	7 Sept	2 Sept	5 Sept	Approximate maturity
25 Oct	22 Sept	6 Oct	8 Oct	Harvesting

* Fall of the preceding year.
† Urea ammonium nitrate solution (UAN)-fertilized plots.

growing season for the UAN-fertilized plots (12, 17, 34) with rates and dates of applications given in table 2. Weed control was achieved by herbicide application (Band Dual + Extrazine for corn and Lasso + Pursuit for soybean). Swine manure was applied in the fall prior to planting corn the following spring. No manure or UAN-fertilizer was applied for soybean crops. Average characteristics and nutrients applied from swine manure to plots 11, 23, and 27 are given in tables 3 and 4, respectively.

Plant Growth Variables and Parameters

Corn and soybeans were grown during the study period of 1993-1996. Maximum rooting depth of 1200 mm for corn and 1000 mm for soybean were calibrated to fit model simulations of percolation to measured subsurface drain flow data. Corn was grown in 1993 and 1995; whereas, soybeans were grown in 1994 and 1996 on these six plots. Crop characteristics data required by the model, such as leaf area index, crop height, dry matter ratio, C:N ratio, and N:P ratio, were taken from the model database. Measured yield for both crops (table 5) was also used as input to the model.

Initial Conditions

GLEAMS requires input of initial conditions for various soil horizons. Crop residue from 1992 was estimated to be 1000 kg/ha for the 1993 season. Total nitrogen content, potentially mineralizable nitrogen, total phosphorous, and phosphorous concentration data for each soil horizon were not available, so default values of the model were used. The model estimates total nitrogen and potentially mineralizable nitrogen from organic matter data provided for each horizon (table 1). The manure characteristics given in table 3 were used as input to the model. Table 4 gives the actual amount of various nutrients applied using swine manure. The soil NO_3-N concentrations for the beginning date of simulation were not available, so the approach of Shirmohammadi et al. (1998) was adopted. The initial estimates for NO_3-N concentrations (1 mg/kg) for each soil horizon were adjusted as input for 1993 to make sure that the initial NO_3-N concentrations of the subsurface flow matched with the measured NO_3-N concentrations. The use of measured crop yield data improved the simulations of NO_3-N losses with subsurface drainage water.

Model Calibration and Evaluation

Soil characteristics vary from point to point within a field and perhaps within a plot. The measured set of soil physical properties at a certain point within a field may not represent the entire field. Errors could also be introduced during the simulation process. The most likely error is the sampling error, which considers the soil properties of one point as representative of the whole field; i.e., lacking the incorporation of spatial variability of soil characteristics within a field. A second error could be introduced by the set of equations representing the soil and water flow and N-transformation processes that may not adequately represent the field. Therefore, calibrations of key parameters of the model such as Effective Rooting Depth (RD) and SCS curve number (CN2) were critical. These calibrations were made to fit the model-predicted water percolation losses below the root zone to the measured subsurface drain flow data of 1993 for six plots. The subsurface drains have been installed at 1.2 m depth. The data collected for subsurface drain flows can give a good estimate of percolation losses because the fields are subjected to seasonally high watertable. An impermeable layer in the soil profile of the study area has been reported at a depth of 2.52 m by Singh (1994). The hydrologic component of the model was calibrated first by adjusting CN2 and RD. Efforts were made to keep parameters within the acceptable range as specified in the user's manual (Knisel, 1993). The CN2 parameter controls the runoff, and RD controls the evapotranspiration values. These two parameters were adjusted to fit the model percolation to the measured subsurface drain flow data. The calibrated parameters for each plot and both crops of corn and soybean are given in tables 6 and 7, respectively. A trial and error procedure was used to find the best set of values for these two parameters that could simulate the model's percolation as subsurface drainage flow with minimum difference between the measured and simulated values. After the calibration process, the model was run continuously for four years from 1993 to 1996.

Table 3. Characteristics of swine manure applied to corn and used as input to the model

Characteristics	Fall 1992	Fall 1994
Avg application amount (mm)	2.70	4.60
Depth of injection (mm)	254.00	254.00
Total solids (%)	6.21	6.73
Total N content (%)	0.54	0.49
Organic N content (%)	0.25	0.04
Ammonia content (%)	0.04	0.06
Phosphorous content (%)	0.21	0.21
Organic phosphorous content (%)	0.04	0.03
Organic matter content (%)	0.14	0.14

Data expressed on wet weight basis.

Table 4. Application rates of N, P_2O_5, and K_2O for corn-soybean rotation plots from swine manure applications for 1993 and 1995

Characteristics	1993	1995
N	73	195
P_2O_5	53	78
K_2O	71	104

Table 5. Measured corn-soybean yield (Mg/ha) used as input to the model

	Corn		Soybean	
Plots	1993	1995	1994	1996
11*	5.7	5.4	3.2	3.9
23*	5.9	5.7	3.2	3.9
27*	5.2	5.7	3.3	3.9
12	7.0	3.6	3.3	3.6
17	7.2	3.8	3.1	3.8
34	6.1	3.7	3.1	3.7

* Manured plots.

Table 6. Calibrated parameters and results from GLEAMS simulations for corn

			Corn			
			1993 (percolation, mm)		1995 (percolation, mm)	
Plot No.	SCS Curve No.	Effective Rooting Depth (mm)	Observed	Predicted	Observed	Predicted
11*	77	1200	337	273	75	153
23*	77	1200	319	273	97	152
27*	91	1200	128	142	27	51
12	77	1200	376	306	127	153
17	94	1200	66	64	15	25
34	77	1200	365	305	103	153

* Manured plots.

Table 7. Calibrated parameters and results from GLEAMS simulations for soybean

Plot No.	SCS Curve No.	Effective Rooting Depth (mm)	Soybean 1993 (percolation, mm) Observed	Soybean 1993 (percolation, mm) Predicted	Soybean 1995 (percolation, mm) Observed	Soybean 1995 (percolation, mm) Predicted
			1994		1996	
11*	77	1000	73	19	45	132
23*	77	1000	81	25	49	132
27*	91	1000	37	0	19	63
12	77	1000	96	20	70	131
17	94	1000	25	13	16	0
34	77	1000	82	20	50	131

* Manured plots.

Model evaluation criteria were based on both subjective and objective approaches (Zacharias and Heatwole, 1994). Subjective criteria included graphical display of model simulation and measured values; whereas, objective criteria included statistical computation of percentage of relative error between observed and predicted values (Singh and Kanwar, 1995). The subjective criteria were used to locate anomalies in model predictions and to provide an insight on temporal response of the model for the entire simulation period. Objective criteria account for differences in mass of the simulation, ignoring its distribution over time. The overall evaluation of the model was made based on model predictions for all four years from 1993 to 1996 (Shirmohammadi et al., 1998). The combination of both subjective and objective criteria provides validation of model output. Both criteria were used to evaluate the model simulations.

Results and Discussion

Table 8 provides an objective evaluation of GLEAMS simulation based on percentage of relative difference, while a subjective evaluation is presented in figures 2 through 5. Model calibration and evaluation were performed on a monthly basis. Daily simulations were also made to compare with the measured daily tile flows. The model simulated about the same amount of percolation on a monthly basis, but the temporal distribution was not comparable to the measured data. GLEAMS model predicted very high peaks in the daily tile flow simulations with short durations. GLEAMS simulates water movement

Table 8. Summary of simulation results for percolation (mm) from manured and UAN-fertilized plots

Crop	Years	Fertility*	Obs.†	Pred.†	% Diff.
Corn	1993, 1995	Manured	983	1044	6.2
		UAN-fertilized	1052	1006	–4.4
Soybean	1994, 1996	Manured	304	371	22.0
		UAN-fertilized	339	315	–7.1
Corn/Soybean	1993-1996	Manured	1287	1415	9.9
		UAN-fertilized	1391	1321	–5.0
Corn/Soybean	1993-1996	Total (manured/ UAN-fertilized)	2678	2736	2.2
Corn/Soybean	1994-1996	Manured	503	727	44.5
		UAN-fertilized	584	646	10.6
		Total	1087	1373	26.3

* Fertilizer or manure applied for corn phase of production; UAN = urea ammonium nitrate.

† Obs. = observed; Pred. = predicted.

through the root zone based on a maximum of 12 computational layers. Water movement through each layer is calculated using a storage routing technique with travel time for percolation estimated from layer thickness and saturated conductivity (RC). The RC is not a sensitive parameter in most cases, especially when its value is not restricting (soil group D). Daily simulations showed that there was short travel time for each layer, which resulted in sharp percolation peaks for each rainfall event when compared with measured daily subsurface drain flows. The lack of routing the percolation water to drain flow might have resulted in sharp peaks of the daily tile flow simulations. Based on these discrepancies, monthly simulations were deemed more reasonable than daily simulations when comparing simulated percolation with measured drain flows. The simulation of percolation has been used as an estimate for subsurface drain flow, with drains installed at 1.2 m depth. Such an assumption has been reported for drain depth of even 1.0 m (Shirmohammadi et al., 1998).

Simulations of Subsurface Drain Flow

Continuous simulation output for 1993 through 1996 and observed data for all plots are shown in figures 2 through 5. The standard error bars (vertical lines) show the upper and lower limits for 95% confidence interval of the measured data; whereas, the dotted lines show the upper and lower limits for 95% confidence limits for simulated data. These limits show the ranges of the observed and simulated data to assess variability among replicated plots. The model simulation of percolation followed the pattern of measured subsurface flows and showed a relative difference of about 10% between the measured and predicted values for manured plots (table 8). The model responded similarly for all plots except for plots no. 27 and no. 17, which had land slopes of 4% and 3%, respectively. The model was calibrated to give a satisfactory output using measured data from 1993, but it underestimated the subsurface drain flows for 1994 and overestimated those for 1995 and 1996 (fig. 2). The calibration year of 1993 was a very wet year compared with the validation years of 1994, 1995, and 1996. The amount and distribution of rainfall, crop growth characteristics, and interaction of soil

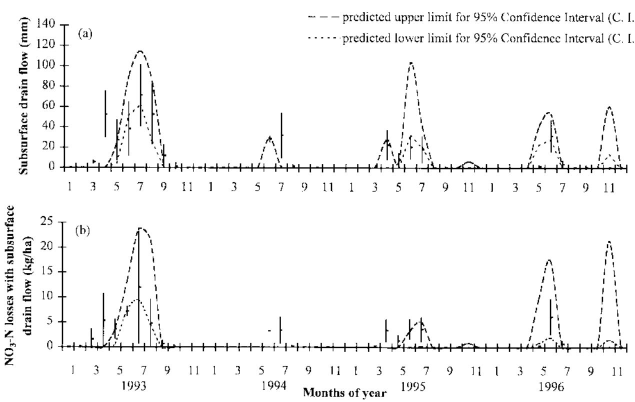


Figure 2–Comparison of observed and predicted subsurface drain flow (a), and NO_3-N losses (b) for swine manure-applied plots [95% confidence limits (vertical line), average (horizontal line) for observed, and dotted lines for 95% confidence interval (C.I.) for predicted data].

with crop residue affect the subsurface drain flow processes and may have affected the overall performance of the model.

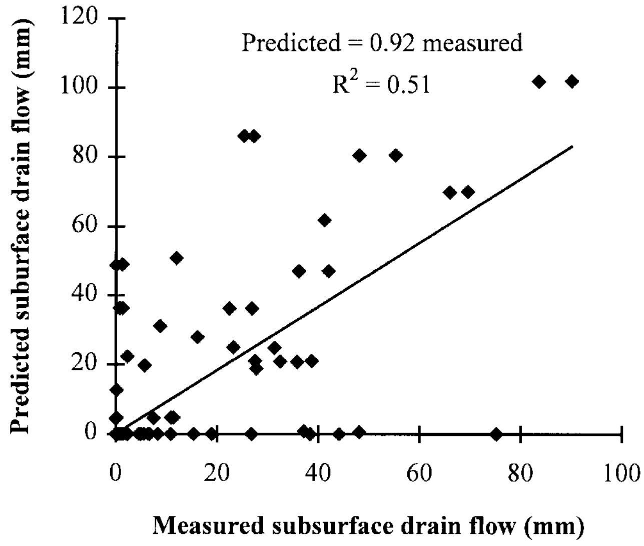
The crop-wise analysis of subsurface drain flow simulation shows that the model did an acceptable job in predicting subsurface flows for the corn years 1993 and 1995 with a relative error of 6.2% and –4.4% for manured and UAN-fertilized plots (table 8). The model overpredicted subsurface flow beneath soybean with a relative error of 22% for manured plots. There could be several factors responsible for these fluctuations, the most apparent being rainfall variation from year to year, crop characteristics, calibration of model for a corn year and not for soybean, and possibly macropore flow. Macropore flow is an important factor to be considered during water flow to subsurface soil layers (Singh and Kanwar, 1991). GLEAMS (V.2.1) does not have a macropore flow function. The addition of crack flow component to GLEAMS improved its water distribution and solute movement out of the root zone (Morari and Knisel, 1997). Overall, the relative difference between observed and predicted subsurface drain flow was about 2% for all six plots (table 8).

Figure 3(a) shows the model performance in simulating subsurface drain flow against a 1:1 best fit line for measured and predicted subsurface drain flows for manured plots. All measured and predicted data were pooled for the entire four-year simulation period and for both crops. The correlation coefficient (r) of 0.71 was found between monthly predicted and measured subsurface flows for manured plots. The slope of the zero intercept line shows that overall the model underpredicted observed values by 8%. The continuous model simulation takes into account the effect of crop residue incorporated from the previous year as GLEAMS calculates the impact of decay and addition of crop residue on a daily basis. This analysis shows that the model was able to incorporate the effects of corn-soybean rotation and crop residue during the continuous simulation period. Figure 4a compares the subjective evaluation of model simulation of percolation with measured subsurface drain flows for UAN-fertilized plots. Despite yearly differences of simulations the relative difference between four-year total percolation losses and measured subsurface drain flow was –5% (table 8).

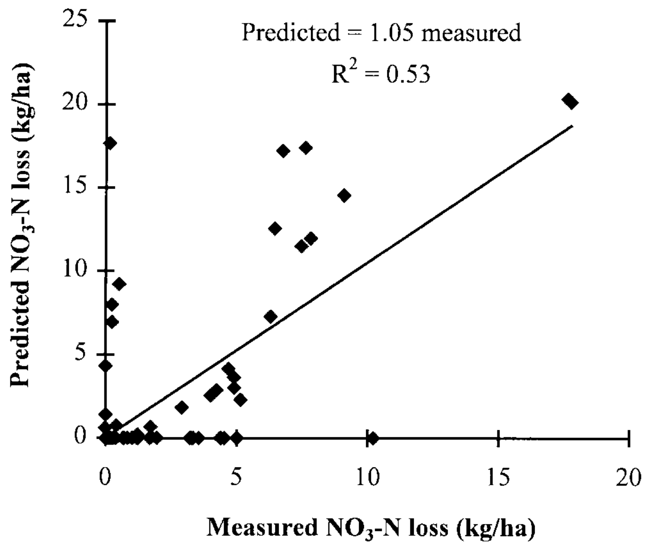
Figure 5a compares the overall model simulations of subsurface drain flow against 1:1 best fit line for the UAN plots. A correlation coefficient of 0.75 was found between observed and predicted values for these plots. The slope of the zero intercept line shows that overall the model underpredicted the observed values by 15%.

Simulation of NO_3-N Concentration in Subsurface Drain Flow

Table 9 compares the measured and predicted NO_3-N concentrations for the four years of simulation for manured plots. Annual average of predicted NO_3-N concentrations for 1993 were significantly higher than measured values. Zero NO_3-N concentrations were predicted for 1994 when measured values averaged 10.6 mg/L. GLEAMS predicted a large amount of NO_3-N leached in 1993 at higher concentrations, which might have caused the lower NO_3-N concentrations predicted in 1994. It underpredicted NO_3-N concentration for 1995 (corn) and overpredicted for 1996



(a)



(b)

Figure 3–Model evaluation for subsurface drain flow (a), and for NO_3-N losses (b) for manured plots.

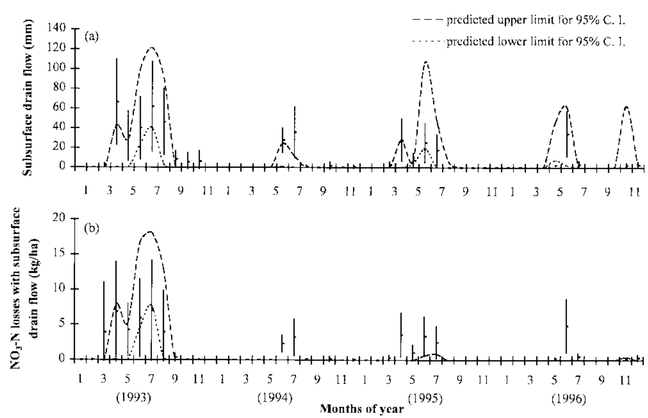
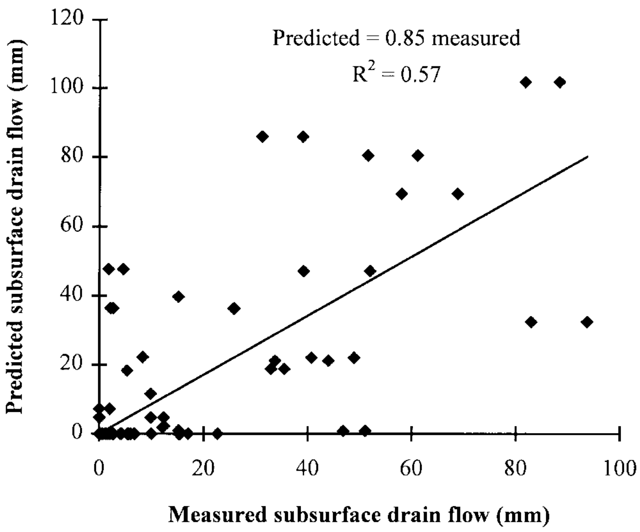
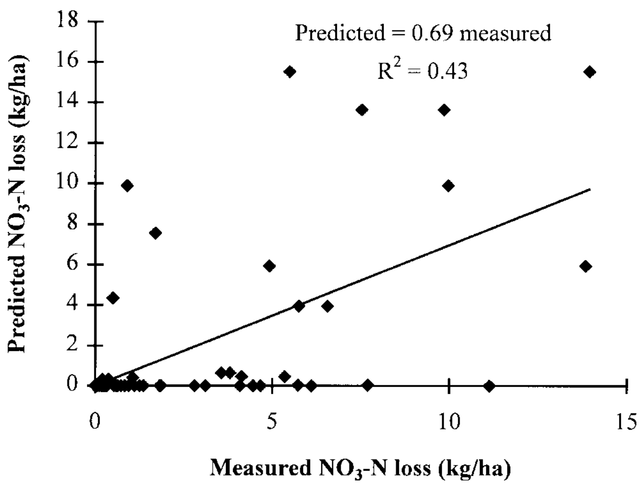


Figure 4–Comparison of observed and predicted subsurface drain flow (a), and NO_3-N losses (b) for UAN-applied plots [95% confidence limits (vertical line), average (horizontal line) for observed, and dotted lines for 95% confidence interval (C.I.) for predicted data].



(a)



(b)

Figure 5–Model evaluation for subsurface drain flow (a), and for NO_3-N losses (b) for UAN plots.

Table 9. Monthly average measured and predicted NO_3-N concentration (mg/L) from manured plots during the simulation period (1993-1996)

	1993		1994		1995		1996	
Month	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Jan.	-	-	-	-	-	-	-	-
Feb.	-	-	-	-	-	-	-	-
Mar.	7.6	-	-	-	13.2	-	-	-
Apr.	13.6	-	-	-	16.5	-	-	-
May	13.7	14.5	-	-	18.0	-	18.1	19.1
June	16.3	14.9	11.9	0.0	19.0	2.7	17.9	26.7
July	21.3	19.8	11.9	0.0	21.9	10.1	14.0	-
Aug.	10.2	24.6	9.7	-	10.0	-	-	-
Sept.	5.5	-	-	-	-	-	-	-
Oct.	8.7	-	2.9	-	-	-	-	-
Nov.	3.6	-	16.7	-	-	12.7	-	31.2
Dec.	-	-	-	-	-	-	-	-
Avg	11.1	18.4	10.6	0.0	16.4	8.5	16.7	25.7
SD	5.6	4.7	5.0	-	4.3	5.2	2.3	6.1

- No drain flow; SD = standard deviation; Obs. = observed; Pred. = predicted.

Table 10. Monthly average measured and predicted NO_3-N concentration (mg/L) from UAN-fertilized plots during the simulation period (1993-1996)

	1993		1994		1995		1996	
Month	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Jan.	-	-	-	-	-	-	-	-
Feb.	-	-	-	-	-	-	-	-
Mar.	5.5	-	-	-	9.0	-	-	-
Apr.	13.4	18.3	-	-	12.1	-	-	-
May	12.1	18.0	-	-	13.7	-	12.7	0.0
June	11.1	16.9	9.4	0.0	13.2	0.6	14.6	0.0
July	12.0	15.3	9.9	0.0	14.7	1.8	14.4	-
Aug.	9.4	14.3	8.2	-	-	-	-	-
Sept.	5.8	-	-	-	-	-	-	-
Oct.	0.3	-	-	-	-	-	-	-
Nov.	-	-	-	-	-	-	-	-
Dec.	-	-	-	-	-	-	-	-
Avg	8.7	16.6	9.2	0.0	12.5	1.2	13.9	0.0
SD	4.5	1.7	0.9	-	2.2	0.8	1.0	-

- No drain flow; SD = standard deviation; Obs. = observed; Pred. = predicted.

(soybean). These inconsistent patterns of NO_3-N concentrations were probably affected by very wet and dry years and also were due to poor simulation of the N-transformation processes between crops and during the soybean years. Lower leaching losses in 1995 and simulated higher mineralization rates during 1995 and 1996 presumably became more dominating and increased the NO_3-N concentrations drastically to the predicted level of 25.7 mg/L compared with an average measured value of 16.7 mg/L in 1996. Despite yearly differences in simulated and measured NO_3-N concentrations, the overall annual averages of simulated NO_3-N concentrations for the four-year simulation and for both crops were found to be closer to the observed concentrations by showing the relative difference of –4.0% between measured and predicted values for manured plots.

Table 10 compares the measured and predicted NO_3-N concentrations for the UAN-fertilized plots. GLEAMS greatly underpredicted NO_3-N concentrations for the validation years except 1993, when rainfall was excessive. The comparison of model predictions of NO_3-N concentration from manured and UAN-fertilized plots shows that the model overpredicted NO_3-N concentrations in 1996 for manured plots and highly underpredicted for UAN-fertilized plots. The N-transformation processes are affected by soil temperature and soil moisture contents. The GLEAMS model derives its soil temperature values from mean daily air temperature data. The soil temperature component of GLEAMS also has not been tested extensively and it may not simulate the actual soil temperature for different soil layers adequately (Shirmohammadi et al., 1998). The GLEAMS model has been reported as quite weak in handling cold temperature as an inherent weakness (Rekolainen and Posch, 1994). The denitrification process in GLEAMS begins at a soil moisture content of 10% above field capacity, which also may not represent the actual field conditions.

Simulating NO_3-N Losses with Subsurface Drain Flow

Manured Plots. Figure 2b and tables 11 and 12 show the measured and simulated NO_3-N losses with subsurface

Table 11. GLEAMS simulations for NO_3-N (kg-N/ha) leaching from manured plots

Year	Crop	Rainfall (mm)	Plot No. 11 Obs.	Plot No. 11 Pred.	Plot No. 23 Obs.	Plot No. 23 Pred.	Plot No. 27 Obs.	Plot No. 27 Pred.
1993	Corn	1027	49.2	52.3	49.9	52.1	13.4	21.5
1994	Soybean	733	6.4	0.0	7.2	0.0	2.0	0.0
1995	Corn	802	13.5	6.5	14.9	7.3	4.3	0.3
1996	Soybean	683	7.3	34.8	11.1	40.2	3.1	3.9
Avg		811	19.1	23.4	20.8	24.9	5.7	6.4
SD		152	20.3	24.5	19.7	25.2	5.2	10.2

SD = standard deviation; Obs. = observed; Pred. = predicted.

Table 12. GLEAMS simulations for NO_3-N(kg/ha) leaching from UAN-fertilized

Year	Crop	Rainfall (mm)	Plot No. 12 Obs.	Plot No. 12 Pred.	Plot No. 173 Obs.	Plot No. 173 Pred.	Plot No. 34 Obs.	Plot No. 34 Pred.
1993	Corn	1027	53.5	49.0	5.6	12.3	38.1	48.9
1994	Soybean	733	8.0	0.0	1.7	0.0	7.9	0.0
1995	Corn	802	17.5	1.1	1.5	0.0	13.6	1.1
1996	Soybean	683	9.9	0.0	1.6	0.0	7.2	0.4
Avg	811		22.2	12.5	2.6	3.1	16.7	12.6
SD	152		21.2	24.3	2.0	6.1	14.6	24.2

SD = standard deviation; Obs. = observed; Pred. = predicted.

drain flow over the period of four years of simulations for manured and UAN-fertilized plots. Like subsurface drain flow simulations, GLEAMS predicted NO_3-N losses adequately for corn years (1993 and 1995), showing an average difference of about –3.6% (table 13). However, greatly overpredicted NO_3-N losses beneath soybean showed an average difference of 113% between measured and predicted NO_3-N losses. The four-year total NO_3-N losses for both crops were comparable and showed a relative difference of 20% with the total measured values for manured plots.

Figure 3b shows the 1:1 best fit line between monthly measured and predicted NO_3-N losses for all pooled data during the four years of simulations for manured plots. The slope of the line of 1.05 shows that overall the model slightly overpredicted the NO_3-N losses. The correlation coefficient of 0.73 between measured and predicted NO_3-N losses shows that the model was able to simulate the impact of swine manure application and the effect of corn-soybean rotation on NO_3 losses.

The overall analysis shows that model predictions were within 20% of measured NO_3-N losses for both of the crops during the four-year simulations for manured plots (table 13). This overprediction might be attributed to model simulation of higher N-fixation rate by soybean in addition to simulated higher mineralization rate for 1995 and 1996. The model underpredicted NO_3 losses for 1994. Extensive rainfall in 1993 presumably flushed large amounts of NO_3-N from the root zone, leaving less for 1994. But the model overpredicted NO_3 losses for 1996. The model simulations of low mineralization rate during 1993 and 1994 and higher percolation losses during 1993 reduced the NO_3 losses during 1994. The simulated denitrification during 1996 was also found to be less than that of 1995, which may also have affected the overall leaching losses. The denitrification rate (DNR) is affected by soil water content at field capacity and/or saturation. GLEAMS has

Table 13. Summary of simulation results for NO_3-N (kg/ha) leaching from manured and UAN-fertilized plots

Crop	Years	Fertility*	Obs.	Pred.	% Diff.
Corn	1993 & 95	Manured	145.2	140.0	–3.6
		UAN-fertilized	129.8	112.4	–13.4
Soybean	1994 & 96	Manured	37.1	78.9	112.7
		UAN-fertilized	36.3	0.4	–99.0
Corn/Soybean	1993-96	Manured	182.3	218.9	20.0
		UAN-fertilized	166.1	112.8	–32.1
Corn/Soybean	1993-96	Total (manured/ UAN-fertilized)	348.4	331.7	–4.8
Corn/Soybean	1994-96	Manured	69.8	93.0	33.2
		UAN-fertilized	68.9	2.6	–96.2
		Total	138.7	95.6	–31.1

* Fertilizer or manure applied for corn phase of production; UAN = urea ammonium nitrate.

been reported to underestimate DNR by up to 100%, because it simulates the denitrification process only when soil water values are higher than soil water at field capacity. In actual systems, denitrification occurs at lower soil water values (Marchetti et al., 1997).

UAN Fertilized Plots. Figure 4b compares the measured and predicted NO_3-N losses with subsurface drainage water from UAN-fertilized plots. The model predicted NO_3-N losses reliably for 1993 but predicted very low losses for 1994, 1995, and 1996. The predicted losses of NO_3-N from UAN-fertilized plots were not consistent with the measured values. The model greatly underpredicted NO_3-N losses, particularly for soybean crops in 1994 and 1996, but greatly overpredicted losses for the same crop under swine manure application. The model's N-transformation processes for soybean crops in conjunction with UAN applications resulted in underprediction of NO_3-N losses compared with measured NO_3-N losses with subsurface drainage water.

Figure 5b compares the overall model predictions for NO_3-N losses with the measured values for the UAN-fertilized plots. The overall slope of the predicted NO_3-N losses from the UAN-fertilized plots was found to be 0.69, which shows that the model underpredicted NO_3-N losses for UAN-applied plots by 31%. The correlation coefficient between measured and predicted NO_3-N losses was found to be 0.65 for UAN-fertilized plots. This analysis shows that the model's predictions for NO_3-N losses were not consistent with the measured values, and its N-transformation process, particularly between crops and during soybean growth period, resulted in disagreement between predicted and measured values for UAN-fertilized plots.

Summary and Conclusions

The GLEAMS model was calibrated using the observed data for the year 1993 on subsurface drain flows from the experimental plots. The SCS curve number of 77 for hydrologic soil group A and root zone depths of 1200 mm for corn and 1000 mm for soybeans were used to calibrate predicted subsurface drain flows to the experimentally measured values of 1993. These calibrated parameters then were used for continuous simulations for four years from 1993 to 1996. The model evaluation was also performed using measured data from UAN-fertilized plots. Other management input parameters included characteristics of swine manure, corn and soybean crop growth parameters, and tillage variables.

The GLEAMS model does not have a subsurface flow component, but the percolation below the root zone was compared with the measured subsurface drain flow. The model slightly overpredicted subsurface drain flow for manured plots but predicted adequately for UAN-fertilized plots. The overall analysis shows that the model adequately predicted subsurface drain flow, and the relative difference between predicted and measured subsurface drain flow was about 2% for all the plots for four years of simulations. The model predicted subsurface drain flows better for the corn years than those for the soybean years, because it was calibrated using data from corn years. The percentage of difference between predicted and measured subsurface flow in 1994-1996 was found to be 44% and 11% for manured and UAN-fertilized plots, respectively.

The model overpredicted NO_3-N losses with subsurface drain flows for manured plots and underpredicted NO_3-N losses for UAN-fertilized plots. The model predictions of NO_3-N losses from manured plots for corn years are comparable to the measured values; whereas, the model did not predict NO_3-N losses consistently for UAN-fertilized plots for both corn and soybean. Despite yearly differences in simulated NO_3-N concentration with subsurface drainage with measured values, the four-year average NO_3-N concentrations were in close agreement with the measured data for manured plots. However, the predicted NO_3-N concentrations for UAN-fertilized plots were not consistent with the measured values. The results of the study suggest that the N-transformation processes and the associated rate factors based on soil temperature and soil water levels may need to be refined for consistent simulation of NO_3-N losses with subsurface drainage water when fertilized with either swine manure or UAN for corn production.

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