Calibration and Validation of GLEAMS for Predicting Non-Point Source Pollution from Agricultural Lands

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Nonpoint source pollution has been identified as one of the major sources of pollution of surface water bodies in Iowa and the Midwest. GLEAMS (Version 2.1) model was calibrated and validated using three years (1990-92) field data on nitrate-nitrogen (NO3-N) and herbicide concentrations in subsurface drain water. GLEAMS model was calibrated for chisel plow system and was validated for chisel plow, moldboard plow, ridge till and no-till systems based on measured tile flows, nitrate-nitrogen (NO3-N), atrazine, and alachlor losses with tile flows, N-uptake and other biomass parameters. The nutrient component of the GLEAMS model was calibrated using steady state N-pool values obtained after multiple years of model runs. The results of this study has demonstrated that GLEAMS model has the potential to simulate tillage effects on tile flow, leaching losses of NO3-N, atrazine, and alachlor with tile flows, N-uptake and biomass parameters within 10% difference of the measured values.

Keywords

Tillage systems, NO3-N losses, Atrazine, Alachlor, Biomass

Disciplines

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Calibration and Validation of GLEAMS for Predicting Non-Point Source Pollution from Agricultural Lands

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Abstract

Nonpoint source pollution has been identified as one of the major sources of pollution of surface water bodies in Iowa and the Midwest. GLEAMS (Version 2.1) model was calibrated and validated using three years (1990-92) field data on nitrate-nitrogen (NO_3-N) and herbicide concentrations in subsurface drain water. GLEAMS model was calibrated for chisel plow system and was validated for chisel plow, moldboard plow, ridge till and no-till systems based on measured tile flows, nitrate-nitrogen (NO_3-N), atrazine, and alachlor losses with tile flows, N-uptake and other biomass parameters. The nutrient component of the GLEAMS model was calibrated using steady state N-pool values obtained after multiple years of model runs. The results of this study has demonstrated that GLEAMS model has the potential to simulate tillage effects on tile flow, leaching losses of NO_3-N, atrazine, and alachlor with tile flows, N-uptake and biomass parameters within 10% difference of the measured values.
Keywords: Tillage systems, NO_3-N losses, Atrazine, Alachlor, Biomass.

Introduction

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model was developed to simulate edge-of-field and bottom-of-root zone loadings of sediments and chemicals to evaluate the effects of alternate management practices on soil and water quality (Knisel et al., 1993). GLEAMS model has been evaluated for predicting the N-management effects under corn-soybean rotation (Bakhsh et al., 2000a), water balance components and chemical loadings (Knisel et al., 1993; Leonard et al., 1987), leaching losses of N and P with subsurface drain water (Shirmohammadi et al., 1998). However, no such study has been conducted to evaluate GLEAMS for simulating integrated effects of tillage on tile flows, NO_3-N, atrazine, and alachlor losses with tile flows, plant N-uptake, and biomass parameters. GLEAMS represents a complex interaction of soil-climate-plant and management systems to simulate the fate of agrichemicals within and beyond the root zone. The calibration of the nutrient component of the model becomes complicated when field measured data for its various pools such as total N, mineralizable N, and organic N are not available particularly in the beginning of the simulations. Therefore, this study presents a unique approach to calibrate the nutrient component of the model and validate the calibrated model for simulating tillage effects on subsurface drainage water quality. The specific objectives of the study were to: (1) calibrate GLEAMS model for chisel plow system using measured field data in 1991 on tile flows, NO_3-N, atrazine, and alachlor losses with tile flows, N-uptake and aerial biomass parameters for continuous corn production system, and (2) validate the model by making continuous simulation from Jan 1, 1990 through Dec. 31, 1992 for chisel plow (CP), moldboard plow (MB), ridge till (RT) and no-till (NT) systems effects on subsurface drain water quality, N-uptake and aerial biomass parameters.

Field Experiments and Input Data

The field experiments were conducted at Iowa State University's Northeastern Research Center, Nashua, Iowa. The soils at the site are located on Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed mesic Typic Hapludolls) and Readlyn loam (fine-loamy, mixed mesic, Aquic Hapludolls) (Kanwar et al., 1997). These soils have seasonally high water table and benefit from subsurface drainage system. Subsurface drains were installed in 1979 at 1.2 m depth and with 28.5 m spacing. The site has thirty six, 0.4-ha plots with fully documented tillage and cropping records for the past 21 years. Each plot has an independent drainage sump with flow meter for measuring subsurface drain flows and collecting water samples for chemical analysis. Drainage water sampling frequency averaged three times a week if subsurface drains were flowing. Subsurface drain water samples were collected and refrigerated until chemical analyses were made at National Soil Tilth Laboratory in Ames, Iowa. Four tillage treatments, each replicated three

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times, were applied in a randomized complete block design (Bjorneberg et al., 1996). Both CP and MB plow system received fall plowing and spring cultivation before planting corn. Fall plowing was not done in 1991 because of wet weather. All four tillage systems were given field cultivation, during growing season for weed control. Anhydrous ammonia was knifed into the soil before secondary tillage (Table 1). Six to ten corn plants were chosen randomly from each 0.4-ha plot at maturity stage, dried at 65^{o}C, weighed, ground to pass a 0.5 mm stainless screen, and analyzed for total N using a Carlo-Erba Model NCS 1500 dry combustion analyzer. Aerial biomass and total N accumulation were calculated by multiplying the measured plant population each year, averaged (65,455 plt ha^{-1}). Corn grain yield for each plot was measured with a combine (Kanwar et al., 1997).

Table 1. Schedule of management activities

Activities	1990	1991	1992
*Spring fertilizer application @202 kg-N ha^{-1}	April 18	May 14	May 1
Field cultivation	May 1	May 26	May 5
Corn planting with starter fertilizer application @ 4 kg-N ha^{-1}	May 2	May 27	May 6
Surface broadcast of atrazine@2.8 kg ha^{-1}; alachlor@2.2 kg ha^{-1}	May 2	May 27	May 6
Field cultivation, row (weed control)	May 21	June 20	June 4
Field cultivation, row (weed control)	Jul. 2	-	-
Corn harvesting	Oct.2	Oct. 10	Oct. 16
Fall chiseling	Nov. 10	-	Nov. 17

No fall plowing was given under ridge till and no-till system; *anhydrous ammonia knifed into soil

Model Input Data

GLEAMS requires mean daily precipitation and daily air temperature data 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. On site available temperature data, updated for every simulation year, were used and mean monthly data for solar radiation, dew point and wind speed were taken from model database for a station near Osage, Iowa, about 40 km from the experimental site. Average measured soil physical properties data on clay, sand, silt fractions, porosity, field capacity for a single soil profile (Table 2) for all tillage systems were used because block effects were not significant (P=0.05). Tillage date, implement, and depth were used as input to the model for four tillage systems (Table 1). Crop characteristics data such as leaf area index, crop height, dry matter ratio, C:N ratio and N:P ratio were taken from model data base and average measured corn grain yield data for each tillage system was used as input to the model. The characteristics of two herbicides (Atrazine and Alachlor) were taken from the model data base.

Table 2. Average soil physical properties used as input to the model (from Bakhsh et al., 2000a)

	Physical properties				Hydraulic properties			
Soil depth	Clay (%)	Silt (%)	Sand (%)	Organic Matter (%)	Porosity	Field Capacity	Wilting point	Hydraulic conductivity (mm/h)
0-200	24	43	33	4.0	0.48	0.28	0.14	100
200-690	25	35	40	2.0	0.46	0.26	0.14	100
690-890	23	25	52	1.0	0.38	0.24	0.14	100
890-1200	25	29	46	0.1	0.35	0.24	0.14	100

Model Calibration

The hydrology component of the model was calibrated first, then model components on nutrient, plant, and pesticide were calibrated. The hydrologic parameters on effective rooting depth for corn (1200 mm), SCS curve number (77), were adopted from Bakhsh et al. (2000a) study for the same site, and the drainable porosity (difference between porosity and field capacity) was slightly adjusted to fit model percolation to the measured tile flow data (Shirmohammadi et al., 1998). The measured data for various soil nitrogen pools of total N, potentially mineralizable N, organic N, and NO_3-N concentrations in the beginning of model simulations were not available and, therefore approach of Bakhsh et al. (2000b) and Ma et al. (1998) was used to obtain steady state N-pool values. Model runs were repeated seven times, each run for three years (1990-92), until steady state conditions reached (Table 3) because it is hypothesized that nitrogen pools reach equilibrium over 20 years of cultivation. These values were used as initial conditions for N-pools. The adjustment of plant N-uptake coefficient (0.8) improved simulations of NO_3-N losses with tile flow. The soil half life (75 days for atrazine and 37 days for alachlor) and partitioning coefficients based on soil organic carbon (43 for atrazine and 60 for alachlor) were adjusted to minimize the difference between measured and simulated annual pesticide losses with tile flow for 1991. Model was calibrated using 1991 field measured data and was evaluated using 1990 and 1992 data. The 1991 year was selected for calibration because it has rainfall of 975 mm, which was close to the normal rainfall of 840 mm for this site compared to wet year 1990 with rainfall of 1049mm and dry year 1992 with rainfall of 748 mm. After calibrating the model for CP, model was run continuously from Jan. 1, 1990 through Dec. 31, 1992 for CP, MB, RT, and NT systems and no calibration parameter was changed during evaluation period except management systems.

Table 3. Model runs approaching steady state N-pool values after 20 years of simulations

Nitrogen pools	Model runs and N pool values, for four soil horizon, approaching steady state conditions			
	Default	1st	2nd	3rd
TKN (%)	0.12, 0.16, 0.06, 0.01	0.13, 0.16, 0.06, 0.01	0.07, 0.18, 0.06, 0.01	0.04, 0.19, 0.06, 0.01
PMN (kg ha^{-1})	285, 380, 162, 18	295, 381, 163, 18	91, 109, 82, 6	37, 34, 42, 2
INC (ug g^{-1})	5, 5, 5, 5	8.3, 5.2, .04, 0	8.3, 6.6, .03, 1.2	8.3, 7, 0.29, 2.5
ON (kg ha^{-1})	0	0.01	0.01	0.01
	4th	5th	6th	7th
TKN (%)	0.03, 0.19, 0.06, 0.01	0.02, 0.19, 0.06, 0.01	0.02, 0.19, 0.06, 0.01	0.02, 0.19, 0.06, 0.01
PMN (kg ha^{-1})	22, 13, 22, 0.88	18, 7, 12, 0.31	17, 6, 6, 0.10	17, 5, 3, 0.03
INC (ug g^{-1})	6.8, 7.6, 0.14, 1.6	6.8, 7.6, 0.14, 1.6	6.8, 7.6, 0.14, 1.6	6.8, 7.6, 0.14, 1.6
ON (kg ha^{-1})	0.01	0.01	0.01	0.01

TKN=total N; PMN=potentially mineralizable N; INC=initial NO_3-N concentrations; ON=organic N

Results and Discussion

Tillage system effects on NO_3-N losses with tile flow were not significant (P=0.05) but tillage and year effects on tile flow were found to be significant (P=0.05), which can be associated with rainfall variability from year to year. The drainable porosity was found to be the key parameter in adjusting simulated tile flow and varied from 0.11 for the bottom soil horizon to 0.20 for the upper two horizons (Table 2), which could be due to tillage effects and the corresponding changes in the bulk density values. The steady state N-pool values (Table 3) are site specific and management dependent (Knisel, 1993) and, therefore were determined using multiple year runs of the model. TKN and INC values reached equilibrium after 10 years of simulations whereas PMN reached steady state after 20 years of simulations. Using these steady state values improved the simulations of NO_3-N leaching losses with tile flow and the average predicted values were 96% of the observed values (Table 4) under chisel plow system. However, there was compromise between simulations of N-uptake and NO_3-N losses with tile flow. The adjustment in N-uptake values affected NO_3-N losses. This shows that simulations including plant component and NO_3-N losses are important for better predictions of real field conditions. Moreover, simulation of either one of these may introduce error in the model calibration processes. Model predictions of tile flow under CP were adequate and the difference was <10% between measured and predicted values. Similarly model predicted adequately the atrazine and alachlor losses with tile flow in the order of 94% and 92% of the observed values, respectively. The calibrated values of soil half life and partitioning coefficient based on soil organic carbon varied by a factor of 2 because these parameters can vary with soil properties (such as soil temperature, soil moisture, and pH) (Knisel, 1993). The model predictions of plant N-uptake and aerial biomass for CP were adequate and the difference was within 10% from the measured data (Table 4).

The calibrated model for chisel plow was used to simulate tillage effects on NO_3-N losses with tile flow, plant N-uptake and aerial biomass as a part of the evaluation process of the model. No parameter was changed during evaluation except the corn grain yield because GLEAMS does not predict grain yield other than the fixed in-built potential yield margins. The use of measured grain yield data also improved the predictions of N-uptake and NO_3-N losses with tile flow. The change in tillage management options did not affect the tile flow simulations but affected the prediction of NO_3-N losses with tile flow. These prediction effects were not significant. Model overestimated tile flow and NO_3-N losses with tile flow for MB but N-uptake and biomass predictions were satisfactory. Similarly model predicted tile flow, N-uptake and biomass adequately for RT but overestimated NO_3-N losses with tile flow. Model predictions were in close agreement with the observed data for the NT system. These results suggest that use of steady state N-pool values were useful and the model predictions were adequate for various tillage systems. Moreover, on the average model showed potential to predict the relative management effects on nonpoint source pollution from agricultural fields. The calibration

Table 4. GLEAMS simulations for different tillage systems

Variables	1990 obs.	1990 pred.	1991 obs.	1991 pred.	1992 obs.	1992 pred.	Average obs.	Average pred.	Average %diff.
Chisel plow (CP)									
Rainfall (mm)	1050	-	970	-	750	-	923	-	-
Tile flow (mm)	183.3	257.6	271.8	273.3	128.0	96.1	194.4	209.0	7.5
NO_3-N loss (kg-N/ha)	100.0	89.4	76.0	82.9	19.0	14.5	65.0	62.3	-4.1
Atrazine loss (g/ha)	7.67	7.70	7.35	7.16	0.78	0.07	5.3	5.0	-5.6
Alachlor loss (g/ha)	0.295	0.254	0.004	0.021	0.002	0.001	0.10	0.092	-8.0
Aerial Biomass (kg/ha)	21031	19958	17696	16432	NA	15938	19364*	18195*	-6.0
N-uptake (kg/ha)	234	203	188	175	NA	170	211*	189*	-10.4
Moldboard Plow (MB)									
Tile flow (mm)	89.8	257.6	185.0	273.3	111.0	96.1	128.6	209.0	62.5
NO_3-N loss (kg-N/ha)	58.1	89.2	62.7	80.0	19.0	17.1	46.6	62.1	33.3
Aerial Biomass (kg/ha)	19940	20613	16965	17318	NA	16500	18453*	18966*	2.8
N-uptake (kg/ha)	222	210	183	185	NA	176	203*	198*	-2.5
Ridge Tillage (RT)									
Tile flow (mm)	191.2	257.6	326.0	273.3	104.0	96.1	207.1	209.0	0.9
NO_3-N loss (kg-N/ha)	83.4	89.6	68.2	89.5	11.0	15.4	54.2	64.8	19.6
Aerial Biomass (kg/ha)	19285	19092	17390	14914	NA	16313	18338*	17003*	-7.3
N-uptake (kg/ha)	214	194	190	159	NA	172	202*	177*	-12.4
No-tillage (NT)									
Tile flow (mm)	274.5	258.0	336.0	271.5	178.0	96.1	262.8	208.5	-20.6
NO_3-N loss (kg-N/ha)	107.2	90.3	63.0	99.2	20.0	17.6	63.4	69.0	8.8
Aerial Biomass (kg/ha)	18886	17535	14280	13744	NA	15750	16583*	15640*	5.7
N-uptake (kg/ha)	210	179	125	147	NA	166	168.0*	163*	-2.7

*average is from 1990 and 1991; obs.=observed; pred.=predicted; %diff.=% difference; NA=not available
Cumulative predicted sediment yield for 1990-92 was <2000 kg/ha for all tillage systems.

approach developed for nutrient component of the model using steady state N-pool values obtained after multiple years of model runs was effective in predicting system response effects on water quality and needs to be tested for long-term simulations under different cropping systems.

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