Modification of DRAINAGE Model by Using the Nitrogen Component from the GLEAMS Model

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Abstract
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Keywords
GLEAMS, DRAINAGE, Nitrogen, Groundwater pollution

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Water Resource Management

Comments
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A. Verma, R. S. Kanwar, U. S. Tim

ABSTRACT. The NITRO subroutine of the DRAINAGE model (Kanwar et al., 1983) was modified using the nitrogen transformation components of the GLEAMS (Leonard et al., 1987) model to predict more accurately the leaching of NO₃-N to subsurface drainage water. Predicted values of tile flows and nitrate concentrations in tile effluent have shown a good agreement with observed data for the period from 1984 to 1992. There were some discrepancies between the predicted and observed values in the beginning of the simulation period resulting from lack of field data for soil-profile initialization. Despite the assumed steady-state condition within each time increment (one day) and the complexity of the drainage system, the modified DRAINAGE model has shown the capability to reasonably estimate long-term N loss with tile effluent. Average deviation and standard error between the predicted and observed NO₃-N concentrations in the tile water indicated that the modified DRAINAGE model developed in this study resulted in better predictions of NO₃-N concentrations in the drainage water than the original DRAINAGE model. Keywords. GLEAMS, DRAINAGE, Nitrogen, Groundwater pollution.

Contamination of groundwater and surface water by nonpoint source (NPS) pollutants is an environmental issue of increasing concern and a legitimate problem specifically with respect to water quality (Sun, 1986; Kanwar et al., 1983; Bauder et al., 1993). A major component of current agricultural production practices is the use of chemicals (fertilizers, pesticides) to produce higher yields. Nitrogen fertilizers (N) are often considered to be the most important factor contributing to elevated NO₃-N levels in water supplies. The elevation is thought to be primarily due to large surpluses of N applied. The U.S. Environmental Protection Agency's national survey of drinking water wells (U.S. EPA, 1990) indicated that nitrate-nitrogen (NO₃-N) was the most commonly found contaminant in 57 and 52% of the rural wells and community water supplies, respectively, containing detectable concentrations of NO₃-N in these water sources, and 2.4 and 1.2% of these wells exceeded the drinking water standard of 10 mg/L for NO₃-N.

The loss of soil-applied N to groundwater leads to environmental, economic, and energy-conservation concerns. The fate of N in agricultural soils can be assessed through field monitoring (Baker et al., 1975) and/or laboratory testing to determine indices of contamination potential, or through simulation modeling. Field testing is, however, limited to the number of locations and scenarios that can be feasibly examined and also requires several years of observations to collect valid data that reflects climatic variability. Computer simulation modeling, on the other hand, serves as a tool for evaluating field scenarios. It involves the integration of complex chemical, physical, and biological processes that influence soil-applied N. Simulation models also assist in extrapolating management impacts to sites outside the experimental area with a minimum of further experimentation and enables the researcher to study new management systems and estimate their effect on production and environmental conditions. The capability of simulation models to incorporate descriptions of the key processes that modulate system behavior make them valuable tools. The combined use of mathematical models and field experimentation is the most cost-effective way to conduct research on the effects of agricultural chemical use on environmental quality.

Several process-oriented models have been developed and evaluated under diverse climatic and management scenarios to assess groundwater loading impacts of NPS pollution. The NPS models divide into two broad categories depending on intended use—screening or planning models and hydrologic assessment models (Novotny, 1986).

Simulation models vary in complexity, output presentation, and input parameter requirements. They pursue different approaches to predict chemical behavior in the environment. Extensive effort has gone into the development of these models, yet comprehensive evaluation has been limited mainly because of the scarcity of cognizant personnel and of field data for testing and validation. Spatial and temporal variations involved with the data result in a high degree of uncertainty associated with the results obtained. The DRAINAGE model was developed by Kanwar et al. (1983) to simulate the transport of NO₃-N to the drainage water. This model utilized...
empirical functions for denitrification and mineralization of soil nitrogen which resulted in weaker comparisons between the predicted and observed NO$_3$-N concentrations in the drainage water. Therefore, the overall objectives of this study were to modify the NITRO subroutine of the DRAINAGE model (Kanwar et al., 1983) by utilizing the nitrogen transformation components of the GLEAMS model (Knisel et al., 1987) to simulate more accurately the behavior of nitrogen transport in a tile-drained area. The predicted values of tile flow and NO$_3$-N concentrations in tile effluent were compared with the observed data collected by Kanwar and Baker (1993).

**MODEL DEVELOPMENT**

**BRIEF OVERVIEW OF DRAINAGE MODEL**

The DRAINAGE model (Kanwar et al., 1983) was developed to simulate the movement of the water and nitrate-nitrogen (NO$_3$-N) transport processes occurring in a typical artificially drained agricultural field during the crop growth period. The soil profile is divided vertically into 11 layers. Each of the first 10 layers, starting from soil surface is 150 mm thick, and the final layer extends from 1.5 to 3.9 m below the surface. Within each layer, the soil properties, water content, and nitrate concentration are considered uniform. The simulation can be divided into two basic components: 1) a daily hydrologic component that predicts runoff using the SCS curve number technique, evapotranspiration, tile drainage, and soil moisture distribution in each layer; and (2) a nitrogen component (fig. 1) that estimates concentration of nitrate in tile flow and in soil layers, nitrogen uptake by plants, mineralization, and denitrification. The hydrology component of this model is presented in detail by Kanwar et al. (1983). Some of the details on the nitrogen component of the DRAINAGE model are discussed in the following paragraphs.

**DRAINAGE Nitrogen Component.** Nitrate-Nitrogen Transport. Bartholomew and Clark (1965) mentioned that nitrogen moves in the soil only when it is in the form of nitrate because nitrate is soluble and negatively charged. Other forms of nitrogen movement are not considered in this model. Beek and Frissel (1973) considered that the nitrate flow is caused by mass flow of water, diffusion, and/or dispersion.

**Diffusion.** Diffusion is a function of the concentration gradient of nitrate between layers and is assumed to be governed by the following relationship (Beek and Frissel, 1973):

\[
FLRTD = DIF \times TORT \times \left[ (\theta_i + \theta_s)/2 \right] \times \left[ (NO_3-N)_{i-1} - (NO_3-N)_i \right]/L
\]

where

- $FLRTD$ = flow rate of nitrate due to diffusion [mg (N)d$^{-1}$ m$^{-2}$]
- $DIF$ = diffusion coefficient for nitrate of water (m$^2$d$^{-1}$)
- $TORT$ = labyrinth factor (Bartholomew and Clark, 1965)
- $(NO_3-N)_i$ = nitrate concentration in layer $i$ [mg (N)m$^{-3}$]
- $L$ = thickness of each (m)
- $\theta$ = soil water content (m$^3$/m$^3$)

**Dispersion.** Dispersion is mainly caused by the movement of water through the soil pores. The flow rates of nitrates due to dispersion are proportional to the absolute flow rate of water and the concentration gradient according to the following equation (Beek and Frissel, 1973):

\[
(1)
\]

Figure 1—Inputs, outputs, processes, and variables in the hydrologic model.
where

\[ \text{FLRTS} = v_i \times \text{DISP} \times [(\text{NO}_3^-\text{N})_{i-1} - (\text{NO}_3^-\text{N})_i/L] \] (2)

\[ \text{MFL} = v_i \times (\text{NO}_3^-\text{N})_{i+1} \times \text{WF} \] (3)

**Nitrogen Transformation.** The microbiological nitrogen transformations considered in this model are the nitrification of \( \text{NH}_4^- \) to \( \text{NO}_3^- \), the mineralization of organic-N, to \( \text{NH}_4^- \), the immobilization of \( \text{NH}_4^- \) and \( \text{NO}_3^- \) to organic-N, and the denitrification of \( \text{NO}_3^- \) to gaseous forms. These reactions are complex and depend upon a large number of factors such as temperature, pH, oxygen supply, moisture content, and microorganism population (Bartholomew and Clark, 1965). Duffy et al. (1975) pointed out that the nitrate concentrations in the tile effluent are more sensitive to errors in the hydrological part of the model than in the biochemical transformation part. The various nitrogen transformation processes used in the model are taken from Duffy et al. (1975) and are explained briefly as follows.

Nitrification. Feigin et al. (1974) found experimentally that 80% of the nitrogen fertilizer applied as \( \text{NH}_4^- \) is nitrified within two weeks. Therefore, in the model 80% of the fertilizer nitrogen is assumed to nitrify within 15 days though Duffy et al. (1974) used a 20-day period for this purpose. Feigin et al. (1974) found a good correspondence between measured and predicted nitrate concentrations at various depths for several weeks after fertilization. All the nitrate produced from nitrification of fertilizer ammonia is added into the second layer of the model. Then 20% of the remaining fertilizer is assumed to nitrify at the very low rate of 50 mg (N)d\(^{-1}\) m\(^{-2}\) (0.5 kg/d day/ha) until all is used.

Mineralization. Mineralization is a function of microorganism activity, temperature, water content, and mineralizable nitrogen present in the soil. Bartholomew and Clark (1965) have mentioned mineralization rates of about 70 kg(N) ha\(^{-1}\) year\(^{-1}\). A high rate of mineralization in springtime in the top layers of the soil was assumed. The following functional relationship was used in the model:

\[ \text{NETMIN} = 30 \text{ mg (N)d}^{-1} \text{ m}^{-2} \text{ from 15 April to 3 June} \]
\[ = 11.5 \text{ mg (N)d}^{-1} \text{ m}^{-2} \text{ from 1 March to 14 April and 3 June to 31 October} \]
\[ = 0.0 \text{ other days where NETMIN is the net mineralization} \] (6)

Denitrification. Denitrification is very difficult to model and a number of factors affect denitrification. In the model, denitrification is assumed to take place in the top two layers when enough available carbon and microorganisms are present. Two conditions are imposed in the model for denitrification to take place—sufficient nitrate present in the soil and a high water content (at field capacity). When these two conditions are present, the denitrification rate is assumed to be equal to 30 mg (N)m\(^{-2}\) d\(^{-1}\) [0.3 kg (N) ha\(^{-1}\) d\(^{-1}\)].

**BRIEF OVERVIEW OF THE NITROGEN COMPONENT OF GLEAMS**

Mineralization. In GLEAMS, nitrogen mineralization is considered a two-stage process (fig. 2). The first is a first-order ammonification process and the second is a zero-order nitrification process. Ammonification occurs from the active soil N, fresh organic N from root and surface residue, and organic N in animal waste. Parton et al. (1978) designated two soil-organic-carbon pools based upon carbon:nitrogen ratios. The active mineralization pool had a half-life of few years and a C:N...
nitrification is not a function of the amount of ammonia in the soil layer. Nitrification, \( NIT \), kg (N) ha\(^{-1}\) d\(^{-1}\), is represented as a zero-order process, i.e., the rate of nitrification occurring in layer \( i \) from the active N pool, is estimated as:

\[
NIT_i = \frac{SN03_i \left(1 - \exp\left[-(DK_i)(TFDN_i) - (SWFD_i)\right]\right)}{SOILMS_i} \tag{9}
\]

where

- \( SN03_i \) = \( N03-N \) in soil (kg/ha)
- \( DK_i \) = active soil carbon daily decay rate (mg kg\(^{-1}\) d\(^{-1}\))
- \( TFDN_i \) = temperature factor for denitrification
- \( SWFD_i \) = soil water factor for denitrification

The second stage of mineralization, nitrification, is represented as a zero-order process, i.e., the rate of nitrification is not a function of the amount of ammonia in the soil layer. Nitrification, \( NIT \), kg (N) ha\(^{-1}\) d\(^{-1}\), is expressed as:

\[
NIT = \frac{(TFN_i)(SWFN_i)/SOILMS_i}{SOILMS_i} \tag{8}
\]

where

- \( TFN \) = temperature function for nitrification
- \( SWFN \) = soil water factor for nitrification
- \( SOILMS \) = soil mass (Mg/ha)

The maximum rate of nitrification given by Bhat et al. (1981) is 14.3 mg (NO\(_3\)-N) kg\(^{-1}\) (dry soil) d\(^{-1}\).

**Denitrification.** Soil nitrate can be reduced to nitrogen gases, through denitrification by anaerobic bacteria when soil water content exceeds field capacity. This process is important in humid climates where percolation occurs frequently or a high water table occurs within the root zone. Denitrification is the first order process with a constant rate a function of organic carbon and modified by soil water content and temperature. Denitrification, kg/ha, is:

\[
DN_i = SNO3_i \left(1 - \exp\left[-(DK_i)(TFDN_i) - (SWFD_i)\right]\right) \tag{9}
\]

where

- \( SNO3_i \) = \( N03-N \) in soil (kg/ha)
- \( DK_i \) = active soil carbon daily decay rate (mg kg\(^{-1}\) d\(^{-1}\))
- \( TFDN_i \) = temperature factor for denitrification
- \( SWFD_i \) = soil water factor for denitrification

The model structure allows 1) denitrification in the upper soil layers on days of rainfall and irrigation that may not produce percolation out of the root zone; and b) denitrification in the lower soil layers when percolation may occur over an extended period due to a perched water table.

**Modification of DRAINAGE Chemical Component**

The NITRO subroutine was modified to simulate more accurately the fate of NO\(_3\)-N in the subsurface soil environment. Modifications involve incorporating mineralization and denitrification processes from the GLEAMS model. In DRAINAGE, two conditions are imposed for denitrification to take place—sufficient nitrate present in the soil, and high soil water content (at field capacity). When these two conditions are met, the denitrification rate is assumed to be equal to 30 mg (N)d\(^{-1}\) m\(^{-2}\). In GLEAMS, denitrification is based on the daily decay rate, the soil-profile temperature, and soil moisture. Denitrification takes place when soil moisture reaches 10% above field capacity and increases to a maximum of unity at the saturation point.

**Model Testing and Evaluation**

**Experimental Site**

For model calibration and evaluation, experimental data on daily tile-flows and NO\(_3\)-N concentrations in tile effluent were available for nine years (1984 to 1992); however, for 1985, 1988, and 1989 no data were available on tile flow because of dry conditions. The experimental site for the study was located at the Iowa State University Agronomy and Agricultural Engineering Research Center, Ames. The experimental site is on a Clarion-Webster soil with a maximum slope of 2%. The drainage system consists of 102-mm-diameter subsurface drains spaced 36.6 m apart. The observations made from one 0.42-ha plot were used to test and evaluate the modified DRAINAGE model. There were some shallow depressions near the tile line otherwise, surface drainage was fair.

To provide access to the tile line, a sump 1.5 m deep was placed to intercept the drain tile, which was at a depth of 1.2 m. A float-activated stage recorder was installed in

Figure 2—Schematic representation of the GLEAMS nitrogen cycle (adopted from Leonard et al., 1987). AM = ammonification, NI = nitrification, DN = denitrification, VL = volatilization, IM = immobilization, UP = uptake, FX = fixation.

- **Defined by:**
  - CMN = mineralization constant [0.0003 kg (N) ha\(^{-1}\) d\(^{-1}\)]
  - TFA = temperature factor for ammonification
  - SWFA = soil water factor for ammonification
  - POTMN = active N (potentially mineralizable) (kg/ha)
  - AM = ammonification
  - RO = mineralization
  - IM = immobilization
  - NIT = nitrification
  - DN = denitrification
  - VL = volatilization
  - RO = mineralization
  - IM = immobilization
  - NIT = nitrification
  - DN = denitrification
  - VL = volatilization

- **Data Sources:**
  - Seligman and van Keulen (1981) defined an active mineralization pool with a C:N ratio less than 12. Sharpley and Williams (1990), following the work of Seligman and van Keulen (1981), defined an active mineralization pool with a C:N ratio less than 25, and a stable pool from which mineralization did not take place, had a C:N ratio less then 12. Sharpley and Williams (1990) further indicated a nitrogen flux between the two pools governed by the relative pool sizes. The detailed discussion is presented in Knisel et al. (1993). The following sections only provide a brief summary on some of the key modeling processes:

- **Mineralization of nitrogen, MN, kg (N) ha\(^{-1}\) d\(^{-1}\), occurring in layer \( i \) from the active N pool, is estimated as:**

\[
MN_i = (CMN) (POTMN_i) [(SWFA_i) (TFA)]^{0.5} \tag{7}
\]

- **Model Testing and Evaluation**

The experimental site is a Clarion-Webster soil with a maximum slope of 2%. The drainage system consists of 102-mm-diameter subsurface drains spaced 36.6 m apart. The observations made from one 0.42-ha plot were used to test and evaluate the modified DRAINAGE model. There were some shallow depressions near the tile line otherwise, surface drainage was fair.

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**Published in:**

Transactions of the ASAE
conjunction with a calibrated flume to provide the time and depth records. The data on daily-tile-flow rate and the concentration of nitrate in the tile flow (sampled once every three days) were collected for nine years (1984 to 1992). Because of the frozen conditions, little tile flow occurred during December, January, February, and most of the March. Therefore, evaluations were based on data collected between the period 1 April to 30 November for each year.

**Model Input Data**

Initial soil moisture profile, soil temperature profile, water table depth, organic matter, bulk density, and chemical concentration were input to the model. Table 1 shows the list of calibrated parameters and input data used for the final simulation run.

**Weather Data.** The required weather data for the entire growth period were available. Daily rainfall data and other data, such as Class A pan evaporation, wind velocity, air temperature, and soil temperature, were collected at a location about 1/2 km from the experimental site and were used for model calibration and testing. Daily rainfall, daily pan evaporation, and soil temperature were used as inputs into the model. The model calculates evapotranspiration by the method developed by Shaw (1963). For some years, the pan evaporation data were not available for the months of January, February, March, November, and December. Therefore, a fixed amount of evapotranspiration (0.35 mm/day for January through April, and 0.75 mm/day for November and December) was used for part of these months.

**Soil Properties Data.** The data on initial soil water content (table 2), field capacity, wilting point, diffusivity, unsaturated and saturated hydraulic conductivities, and initial water table depth are required as input in the model. Data on wilting point were taken from Shaw et al. (1972). The saturated hydraulic conductivity was taken from Kanwar et al. (1989). The soil profile temperature data for 0 to 150, 150 to 300, 450 to 600, and 900 to 1050 mm depth were available from Iowa State University Agronomy and Agricultural Engineering Research Center, Ames. For other depths (300 to 450, 600 to 750, 750 to 900, 1050 to 1200, 1200 to 1350, and 1350 to 1500 mm), soil profile temperature data were estimated by the linear interpolation method. The soil profile temperature data are required by the modified NITRO subroutine to calculate mineralization and denitrification.

**Nitrogen Input.** Fertilizer application time and rate data (tables 1 and 3) are needed as inputs to the model. 1 April of each year is set as the starting day for the model simulation; therefore the beginning nitrate concentrations for all layers considered in the model are needed on this date. Total nitrogen (TN) was calculated by converting organic matter (%) to organic carbon by dividing by 1.724 g(OM)g⁻¹ (OC), then dividing by the average carbon:nitrogen (C:N) ratio (10:1) for all layers. It certainly is not site specific, but it gives a good estimate of TN.

**Plant-growth Variables and Parameters.** The planting and harvesting days for the crops, distribution of the root system as a function of time, the crop development ratios, and crop stress factors as a function of soil moisture are system as a function of time, the crop development ratios, and crop stress factors as a function of time, the crop development ratios, and crop stress factors as a function of time, the crop development ratios, and crop stress factors as a function of time, the crop development ratios, and crop stress factors as a function of time, the crop development ratios, and crop stress factors as a function of time, the crop development ratios, and crop stress factors as a function of time...

**RESULTS AND DISCUSSION**

**Simulated Tile Flow and NO₃-N Concentrations in Tile Effluent**

Simulations were conducted by using the original and the modified DRAINAGE model to predict NO₃-N concentrations in subsurface tile effluent for 1984 to 1992. The daily observed and predicted data from 1 April to 30 November for the normal and wet years 1984, 1986, 1987, 1990, 1991, and 1992 (excluding the dry years of 1985, 1988, 1989 because tiles did not flow in these years) were compared. Figures 3 and 4 show that predicted values of tile flows and nitrate concentrations in the tile water for 1984 and 1986, respectively, which compare reasonably well to daily measured values although some discrepancies exist. Table 5 gives the calculated values of average deviation and standard error between observed and predicted tile flows. The average deviation varies from

---

**Table 1. Summary of input parameters for the DRAINAGE model**

(Kanwar et al., 1983)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Calibrated or Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain depth</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Drain diameter</td>
<td>102 mm</td>
</tr>
<tr>
<td>Drain spacing</td>
<td>36.58 m</td>
</tr>
<tr>
<td>Depth from drain to impermeable layer</td>
<td>2.7 m</td>
</tr>
<tr>
<td>Thickness of nearly impermeable layer</td>
<td>20.0 m</td>
</tr>
<tr>
<td>Vertical hydraulic conductivity of impermeable layer</td>
<td>1 mm/d</td>
</tr>
<tr>
<td>Hydraulic head in ground water aquifer</td>
<td>19.5 m</td>
</tr>
<tr>
<td>Drainable porosity</td>
<td>0.05</td>
</tr>
<tr>
<td>Effective lateral Ksat</td>
<td>150 m/d</td>
</tr>
<tr>
<td>Percentage of depressional area near the tile</td>
<td>0.03</td>
</tr>
<tr>
<td>Maximum root depth</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Labyrinth factor used to compute nitrate flow by diffusion</td>
<td>0.80</td>
</tr>
<tr>
<td>Diffusion coefficient of nitrate in water</td>
<td>0.0000 m/d</td>
</tr>
<tr>
<td>Dispersion coefficient of nitrate in water</td>
<td>0.01 m</td>
</tr>
<tr>
<td>Rate of nitrification of fertilizer</td>
<td>80% within 20 d of fertilizer application</td>
</tr>
<tr>
<td>Rate of denitrification</td>
<td>40 mg(N) m⁻² d⁻¹</td>
</tr>
<tr>
<td>Rate of mineralization 4/15 to 6/3, 4/1 to 4/14 and 6/4 to 10/31</td>
<td>30mg(N) m⁻³ d⁻¹</td>
</tr>
<tr>
<td>11.5 mg(N) m⁻³ d⁻¹</td>
<td>26.17</td>
</tr>
<tr>
<td>Weighting factor for nitrate flow 0-750 mm depth =~ 0.4</td>
<td>750-1500 mm depth =~ 0.6</td>
</tr>
<tr>
<td>Weighting factor for nitrogen uptake</td>
<td>0.30 mm depth =~ 0.5</td>
</tr>
<tr>
<td>Fertilizer application day</td>
<td>April 1</td>
</tr>
</tbody>
</table>

**Table 2. Initial soil moisture content in soil profile**

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Moisture Content in Different Layers (1-10) m⁻³</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>0.12</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.29</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.36</td>
</tr>
<tr>
<td>1986</td>
<td>0.45</td>
<td>0.32</td>
<td>0.35</td>
<td>0.32</td>
<td>0.31</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>1987</td>
<td>0.90</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.30</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>1990</td>
<td>1.35</td>
<td>0.31</td>
<td>0.29</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>1991</td>
<td>0.60</td>
<td>0.31</td>
<td>0.31</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>1992</td>
<td>0.60</td>
<td>0.32</td>
<td>0.34</td>
<td>0.32</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.33</td>
<td>0.36</td>
</tr>
</tbody>
</table>

* Each soil profile is 150 mm thick.
† Initial water table depth (m).

**Table 3. Initial NO₃-N concentration in soil profiles**

<table>
<thead>
<tr>
<th>Year</th>
<th>FAR*</th>
<th>NO₃-N Concentrations in Soil Layers (1-10) mg/L</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
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<td>42.93</td>
<td>23.61</td>
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<td>18.89</td>
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<td>36.67</td>
<td>23.28</td>
<td>17.18</td>
<td>17.79</td>
<td>22.84</td>
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<td>26.91</td>
<td>26.78</td>
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<td>46.00</td>
<td>39.64</td>
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<td>23.35</td>
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<td>25.27</td>
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<td>38.49</td>
<td>47.58</td>
<td>30.18</td>
<td>17.44</td>
<td>11.89</td>
<td>11.32</td>
<td>10.50</td>
<td>9.36</td>
<td>8.34</td>
<td>7.79</td>
<td></td>
</tr>
</tbody>
</table>

* Fertilizer application rate (kg/ha) for continuous corn production.
† In 1992 soybean crop was planted.
0.05 to 1.1 mm/day and the standard error varies from 0.8 to 2.3 mm/day. These results along with figures 3 and 4, show that hydrology component of the model has a good capability of simulating tile flow satisfactorily. Results of this study show that the model simulated the daily subsurface drain flows and nitrate concentrations in the tile water for 1987 fairly well. But there are major discrepancies between observed and predicted values of drainage volume and nitrate concentration for 1984, 1986, 1990, 1991, and 1992. This model does not make accurate simulations once the water table reaches below 1.5 m. This behavior could be due to changes in DRAINAGE model water table depths which are in increments of 150 mm (Kanwar et al., 1983). These changes may have resulted in some discrepancies between predicted and measured values. Finer depth increments might avoid this problem. Moreover, once the water table falls below 1.5 m, the soil profile system needs greater quantities of water to raise the water table and give tile discharge. This shortfall caused the missing peaks in the predicted tile flow during the simulation period. For 1986, on day 189 (water table depth = 1.2 m) tile stopped flowing; again on day 289 the water table started building up and tile flow started. When tile stopped flowing in mid-June 1986, the model also stopped predicting tile flow; when tile started again flowing in late September 1986, the model predicted tile flow during the same time. For 1987 and 1992, a similar phenomena was observed. Tile flow for 1990, unlike that for the other years, was overpredicted to a small extent for most flow periods, the model NO3-N concentrations in tile flow. As NO3-N concentrations in the tile effluent are proportional to the NO3-N concentration of the saturated profile, a decrease in the NO3-N concentration in tile flow is due to increased tile flow. For 1992, observed and measured values of tile flow and nitrate concentrations were quite close. Nitrate concentrations, however, were again underpredicted for 1984, 1986, 1990, and 1991. Most of the representations of processes used in the nitrogen simulations were empirical; errors in these representations

### Table 4. Predicted and observed tile flows for different years

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Precipitation (mm)</th>
<th><em>PD</em></th>
<th><em>OD</em></th>
<th><em>PD</em>+</th>
<th><em>OD</em>+</th>
<th><em>PD</em>+</th>
<th><em>OD</em>+</th>
<th><em>PD</em>+</th>
<th><em>OD</em>+</th>
<th><em>PD</em>+</th>
<th><em>OD</em>+</th>
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</thead>
<tbody>
<tr>
<td>1984</td>
<td>April</td>
<td>173.0</td>
<td>68.0</td>
<td>63.0</td>
<td>132.0</td>
<td>53.0</td>
<td>47.0</td>
<td>35.0</td>
<td>31.0</td>
<td>51.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>128.0</td>
<td>92.0</td>
<td>64.0</td>
<td>138.0</td>
<td>79.0</td>
<td>77.0</td>
<td>92.0</td>
<td>23.0</td>
<td>19.0</td>
<td>217.0</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>167.0</td>
<td>94.0</td>
<td>56.0</td>
<td>165.0</td>
<td>24.0</td>
<td>22.0</td>
<td>77.0</td>
<td>1.0</td>
<td>40.0</td>
<td>210.0</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>86.0</td>
<td>15.0</td>
<td>6.0</td>
<td>139.0</td>
<td>21.0</td>
<td>19.0</td>
<td>147.0</td>
<td>-</td>
<td>5.0</td>
<td>196.0</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>Aug</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Sept</td>
<td>101.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Oct</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>52.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>807.0</td>
<td>269</td>
<td>189</td>
<td>987</td>
<td>282</td>
<td>273</td>
<td>917</td>
<td>104</td>
<td>154</td>
<td>921</td>
<td>52</td>
</tr>
</tbody>
</table>

*PD* - Predicted (mm).
*OD* - Observed (mm).
*PRE* - Precipitation (mm).
could be responsible for some discrepancies in the predicted values.

There were discrepancies each year in the beginning of the simulation process resulting from lack of field data for soil profile initialization. True steady-state conditions seldom exist under field situations. Despite the assumed steady-state conditions within each time increment (one day) and the complexity of the drainage problem, the model can reasonably estimate long-term nitrogen loss with tile drainage water. Moreover, the nitrate concentration results did improve with this modified model, indicating that nitrate transformation is better presented by taking into account the soil profile temperature and soil moisture. Tables 6 and 7 give the average monthly observed NO₃-N concentrations in tile effluent and those predicted by the DRAINAGE model and the modified DRAINAGE model. The predicted NO₃-N concentrations for 1984 through 1992 have shown better agreement with the observed values. However, some discrepancies still exist. Observations of measured versus simulated nitrate concentrations in 1984 and 1987 compared with those in 1986 and 1990 explain the system behavior of nitrate retention, transformation, and transportation for these wet years followed by either a dry or wet year. Data indicate that when a wet year (i.e., 1986, 1990) is followed by a dry year, the observed nitrate concentrations were much higher than the simulated concentration in the tile effluent. This shows that initial nitrate concentrations in the beginning of the simulation year become very important and better representation of the processes involved in the retention, transformation, and transportation of NO₃-N during winter months of each year are needed for better simulation predictions.

Table 6. Average monthly observed and predicted NO₃-N concentration (mg/L) in tile effluent without modification of the DRAINAGE model

<table>
<thead>
<tr>
<th>Year</th>
<th>No. Observations</th>
<th>Average Deviation (mg/L)</th>
<th>Standard Error (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>OD* 11.77</td>
<td>10.85 12.38 12.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PD† 14.21</td>
<td>12.81 13.56 13.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% DF $\Delta$ 20.7</td>
<td>18.06 10.2 7.6</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>OD 17.53</td>
<td>16.67 17.37 16.04 0.21 17.37 14.99 13.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PD 12.06</td>
<td>12.67 13.31 6.01 11.74 10.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% DF 31.2</td>
<td>23.99 23.37 62.53 21.68 25.79</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>OD 12.09</td>
<td>12.34 13.52 11.66 11.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PD 12.36</td>
<td>13.41 12.43 10.31 10.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% DF 2.2</td>
<td>6.86 0.06 11.57 2.3</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>OD 28.45</td>
<td>29.68 30.1 25.7</td>
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</tr>
<tr>
<td></td>
<td>PD 12.33</td>
<td>13.05 12.41 11.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% DF 56.67</td>
<td>56.03 58.17 54.03</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>OD 21.86</td>
<td>20.31 19.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PD 10.94</td>
<td>10.73 11.43</td>
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</tr>
<tr>
<td></td>
<td>% DF 49.95</td>
<td>47.17 41.38</td>
<td></td>
</tr>
<tr>
<td>1992</td>
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<td>16.26 16.8 17.66</td>
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</tr>
<tr>
<td></td>
<td>PD 11.48</td>
<td>12.35 13.11 13.47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% DF 25.74</td>
<td>24.05 21.96 23.73</td>
<td></td>
</tr>
</tbody>
</table>

* OD = observed. † PD = predicted. $\Delta$ DF = difference.
CONCLUSIONS

Predicted tile flows for 1984, 1986, 1987, 1991, and 1992 compare reasonably well with measured tile flows. The summary of observed and predicted tile flow is presented in table 4. The peaks of the measured and predicted tile flows do not match exactly all the time (figs. 3 and 4); this shows that the hydrologic component of the model could be further improvement. Discrepancies can be minimized by reducing the soil layer thickness to less than 150 mm. To further improve the prediction of the tile flows, spatial variability in soil properties should be considered in the model. For example, the SCS curve number method of estimating runoff does not consider rainfall intensity. Accurate measurement of initial soil moisture content and initial NO3-N concentrations in the soil will certainly improve model predictions.

Simulated NO3-N concentrations in the tile effluent were compared with the field-measured concentrations to evaluate the model’s performance. The modified DRAINAGE model, in general, showed a good prediction of NO3-N concentrations in the tile effluent. Results from statistical analysis (table 7) show that the modified model has better agreement with measured NO3-N concentrations than the original DRAINAGE model, in which mineralization and denitrification processes are based on empirical functions. These two processes in the GLEAMS model take soil profile temperature and soil moisture content into account. However, discrepancies between simulated and measured NO3-N concentration indicated a need for better estimation of input data as well as a need for further improvements in the model. Overall, the model provides long-term, satisfactory simulation results and is suitable for simulating soils with varying soil characteristics. Nitrate-nitrogen concentrations in tile flow show a close match between observed and predicted values for the wet years preceded by one or more dry years. Discrepancies between measured and predicted nitrate concentration values for the years preceded by the dry years indicate lack of representation for nitrate retention, transformation, and transportation processes in these years.

REFERENCES


