ESTIMATING NITRATE LEACHING AND SOIL WATER DYNAMICS WITH LEACHM

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INTRODUCTION

The effect of agriculture on the environment has become a major issue over the last 30 years. The intensification of agriculture during that period increased the use of nitrogen (N), phosphorus (P), and potassium (K) fertilizers from just under 6.8 x 10^9 kg in 1960 to over 1.7 x 10^{10} kg in 1987. Nitrogen is currently the dominant nutrient applied with the use of approximately 8.2 x 10^9 kg in 1987 (National Research Council, 1989). Excessive application of N fertilizers can lead to leaching of nitrate out of the soil profile and into groundwater. Thus, a current environmental issue at the forefront is the potential contamination of drinking water with nitrates, which can cause health problems to humans.

In addition to the amount of N fertilizer applied to the soil, there are several other factors that affect the leaching of nitrates, among them cover crops, tillage system, soil type, and irrigation. Although cover crops were initially used for erosion control, they can also be very effective in the reduction of nitrate leaching. Cover crops planted following and between harvests of a multi-crop system can retrieve excess nitrate left in the soil thereby preventing its leaching. The type of cover crop used is important because its rooting pattern and N requirement will determine the amount of nitrate removed from the soil (Mitchell and Teel, 1969).

While we understand the factors that affect nitrate leaching, measuring nitrate leaching under field conditions is difficult because it requires sampling the soil or the water leaving the soil profile. One alternative to measuring nitrate leaching is to estimate it with the use of computer simulation models. However, in order to use these models, it is necessary to validate them for the soils and climatic conditions in which they will be used (Ramos and Carbonell, 1991). The objective of this study was to evaluate LEACHN, the nitrate version of LEACHM (Leaching Estimation and Chemistry Model, Wagenet and Hutson, 1989) for estimating nitrate leaching and soil nitrate and water contents in plots with and without a rye cover crop.

LEACHM SIMULATION MODEL

LEACHM consists of four versions: LEACHW, water flow; LEACHP, pesticide transport and degradation; LEACHC, transient movement of Ca, Mg, Na, K, SO_4^{2-}, Cl^-, CO_3^{2-}, and HCO_3^-; and LEACHN, transport and transformation of N (Wagenet and Hutson, 1989). LEACHN requires three main types of initial data input: soil parameters and hydrologic properties, soil surface and bottom boundary conditions, and crop data.

1) Soil parameters and hydrologic properties. The soil profile is divided into equal depth increments, each requiring the following data:
   - bulk density
   - particle size distribution
   - initial carbon and nitrogen content
   - initial water content
   - water retentivity parameters (Table 1)
   - hydraulic conductivity at saturation (Table 1)
   - nitrification and denitrification constants (Table 2)

2) Surface and bottom conditions:
   - fertilizer applications
   - rain/irrigation (amount/rate)
   - weekly pan evaporation
   - mean weekly temperature and amplitude

3) Crop data:
   - time of planting and emergence
   - date of root and crop maturity
   - date of harvest and relative root distribution
   - crop cover fraction

The output produced by the model includes mass balance in the profile and concentration in each layer for water, inorganic N, and organic N. It also includes information related to plant growth.

MATERIALS AND METHODS

The study was conducted at the Southern Piedmont Conservation Research Center in Watkinsville, Georgia, in an area mapped as Cecil sandy loam (clayey, kaolinitic, thermic, Typic Kanhapludults). Physical properties of the soil for the initial input data were obtained from Bruce et al. (1983). The study area consists of twelve 10 x 30 m plots, each plot underlined with slotted PVC tubes at a 1 % slope, placed 2.5 m

Table 1. Hydraulic Conductivity and Water Retentivity Parameters for each layer.

Layer (cm)	K_s (mm d^{-1})	Theta at Saturation (cm^3 cm^{-3})	Campbell'sparameters *a* (kPa)	*b*
0-15	4596	0.453	-0.364	4.08
15-30	1845	0.411	-0.302	4.68
30-45	1845	0.464	-0.743	10.05
45-60	3552	0.475	-0.305	17.15
60-75	2592	0.472	-1.100	14.82
75-90	621	0.445	-1.100	14.82

Table 2. Some Soil Parameters used in the Simulation.

Parameter	Value
Diff. coeff. in water (mm^2 d^{-1})	120
Dispersivity (mm)	600
$NH4^+$ partition coef. (dm^3/kg)	2
Nitrif. rate const.[a] (day^{-1}) (Cover/No cover)	
0-15	0.05
15-30	0.05
30-45	0.02
45-60	0.02
60-75	0.01
75-90	0.01
Denitrif. rate const.[a] (day^{-1}) (Cover/No cover)	
0-15	0.005
15-30	0.005
30-45	0.002
45-60	0.002
60-75	0.001
75-90	0.001

(a) Assuming first order kinetics

apart to a 1 m depth. To prevent lateral flow, the boundary for each plot is enclosed with polyethylene plastic sheets from the soil surface to the depth of the drain line. All the plots had conventionally tilled corn during the summer of 1991. After the corn residue was chopped, six of the plots were no-till planted to rye on October 18, 1991, and six remained fallow during winter.

An initial soil sampling was conducted on November 6, 1991, to measure inorganic N, total N, total C and water contents. The samples were taken in 15-cm increments to a depth of 90 cm. Additional samplings were conducted on February 2 and April 14, 1992, for measuring inorganic N and soil water contents. The volume of water percolating through the plots and drained through the tiles was automatically recorded with tipping buckets connected to a datalogger. Samples of the drained water were also automatically collected using a 3700FR ISCO (ISCO Inc., Lincoln, NE.) refrigerated sampler. These samples were analyzed for inorganic N concentrations. Weekly pan evaporation, rainfall, and mean temperature (and amplitude) were obtained from an onsite weather station.

Table 3. Measured (mean ± 95 % C.I.) and Predicted Values for Soil Nitrate, Soil Water, and Drainage for Plots with and without a Rye Cover Crop.

Date	No cover Meas.	No cover Pred.	Cover Meas.	Cover Pred.
	------------- Soil Nitrate, kg N ha^{-1} -------------			
Nov. 6, 1991	80 ± 17	--	80 ± 27	--
Feb. 2, 1992	60 ± 13	69	40 ± 15	41
Apr. 14, 1992	51 ± 12	41	14 ± 6	1
	---------- Cumulative Drainage Nitrate -------- kg N ha^{-1}			
Feb. 2, 1992	4 ± 2	16	1 ± 1	9
Apr. 14, 1992	12 ± 4	52	4 ± 2	23
	---------------- Soil Water, mm ----------------			
Nov. 6, 1991	163 ± 15	--	147 ± 9	--
Feb. 2, 1992	263 ± 12	272	251 ± 19	272
Apr. 14, 1992	248 ± 34	252	272 ± 12	243
	------------ Cumulative drainage, mm -----------			
Feb. 2, 1992	17 ± 7	53	10 ± 5	34
Apr. 14, 1992	60 ± 15	225	41 ± 15	195

RESULTS AND DISCUSSION

The ability of a model to accurately predict nitrate leaching depends in part on how well the model simulates soil water dynamics. For plots with a rye cover, LEACHN simulated water content adequately for the lower 60 cm of soil and tended to underpredict it for the upper 30 cm (Fig. 1). For fallow plots, the model overpredicted water content between 45 and 75 cm and underpredicted it for the upper 30 cm (Fig. 2). In spite of some of the discrepancies observed, LEACHN produced good estimates of total water content in the profile (Table 3). However, predicted values of cumulative drainage were three to four times larger than measured values. Part of this discrepancy can be explained by the fact that the tiles do not capture all the water drained through the plots. Following a rain event in February and within a day after drainage had ended from a previous rainfall, the drain tiles captured approximately 74.2 % of the measured rain. Thus, the difference between measured and predicted drainage could be due to a combination of overestimation by the model and the incomplete capture of water by the tiles. To better estimate the true water balance in the plots, they are currently being instrumented for measuring surface runoff. These measurements should allow us to obtain a better estimation of the proportion of percolating water that is captured by the tile drains.

Predicted nitrate concentrations under a cover crop followed

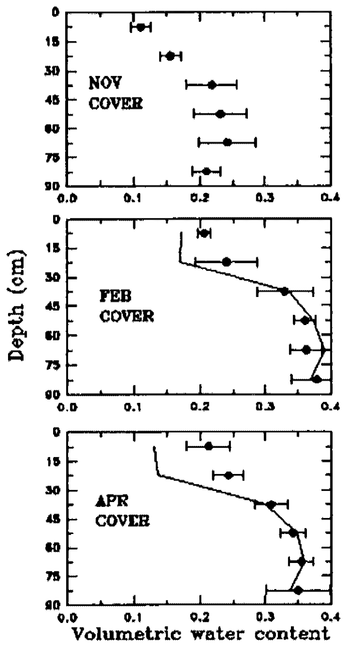

Fig. 1. Measured (mean ± 95 % C.I.) and predicted (line) soil water content in plots with a rye cover crop.

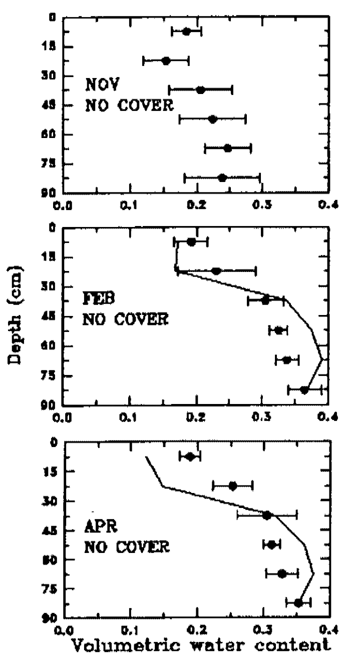

Fig. 2. Measured (mean ± 95 % C.I.) and predicted (line) water content in plots without a rye cover crop.

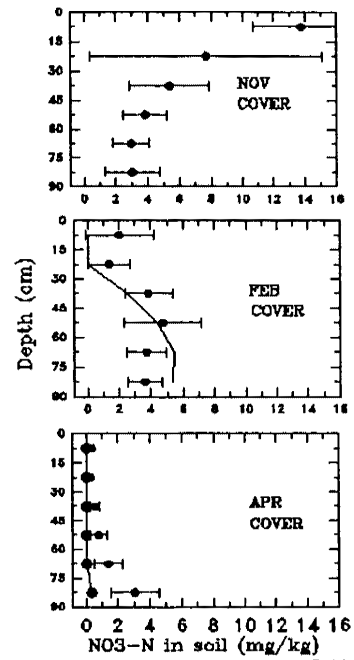

Fig. 3. Measured (mean ± 95 % C.I.) and predicted (line) nitrate concentration in plots with a rye cover crop.

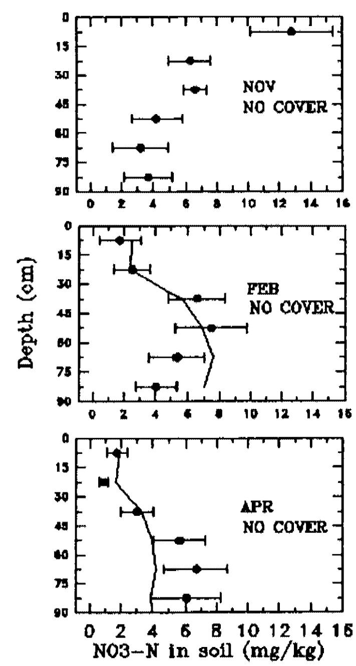

Fig. 4. Measured (mean ± 95 % C.I.) and predicted (line) nitrate concentrations in plots without a rye cover crop.

the same trend as measured values (Fig. 3), but the predicted nitrate content in the profile was lower than the measured amount in April (Table 3). Predicted N uptake by the rye crop was lower (61 kg N ha^{-1}) than the amount measured (94 ± 15 kg N ha^{-1}), which may have left more nitrate available for leaching in the profile during the computer simulation. In fact, the predicted amount of nitrate leached was larger than that observed (Table 3). In addition to crop uptake, part of this difference could be due to the incomplete capture of drainage by the tiles.

In plots without a cover crop, LEACHN predicted total nitrate content and nitrate concentrations for February that were similar to measured values (Table 3, Fig. 4). Predicted nitrate concentrations for April were lower than those observed, possibly due in part to overprediction of drainage. The predicted amount of nitrate leached by April was larger than the observed value (Table 3), again possibly due to a combination of overprediction of drainage and incomplete capture of drainage water by the tiles.

The cover crop reduced the amount of nitrate in the profile by 33 % and 72 % in April and February, respectively. The model predicted corresponding reductions of 41 % and 98 %, respectively. The average nitrate concentration measured in the drainage during the measurement period was 8.8 mg N L^{-1}in plots with rye and 21.6 mg N L^{-1} in plots without a cover crop. LEACHN predicted average concentrations of 11.7 and 23.0 mg N L^{-1} for plots with and without a cover plot, respectively. Thus, in spite of possible overestimation of drainage, the model provided reasonable estimates of the concentration of nitrate in the water leaving the soil profile.

The results obtained in these simulations could probably be improved if water retentivity functions were to be obtained for each layer in the profile. The water retentivity data used in this study came from samples taken in the same area, but using different depth increments (Bruce et al., 1983). In addition, the water retentivity function used in the model did not describe the data adequately; it tended to predict higher pressure potentials than observed at high water contents. In a similar validation study with LEACHN, Ramos and Carbonell (1991) also found a poor fitting of the water retentivity function to their experimental data. In addition, they observed that measured soil hydraulic conductivity varied with water content in a different manner than predicted by the model. As a result, the model grossly overpredicted soil water content in their study. Thus, improvements in the water retentivity and hydraulic conductivity functions may improve model performance.

In spite of the problems observed, LEACHN provided approximate estimates of soil nitrate and water contents under our conditions. Validating LEACHN's ability to predict nitrate leaching and soil water dynamics will be improved once measurements of surface runoff are available from the plots.

LITERATURE CITED

Bruce, R. R., J. H. Dane, V. L. Quisenberry, N. L. Powell, and A. W. Thomas. 1983. Physical characteristics of soils in the Southern region: Cecil. South. Coop. Series Bull. 267.

Mitchell, W. H., and M. R. Teel. 1977. Winter annual cover crops for no-tillage corn production. Agron. J. 69:569-573.

National Research Council. 1989. Alternative agriculture. National Academy Press, Washington DC.

Ramos, C. and E.A. Carbonell. 1991. Nitrate leaching and soil moisture prediction with the LEACHM model. Fert. Research 27:171-180.

Wagenet, R. J., and J. L. Hutson. 1989. Leaching estimation and chemistry model: LEACHM. Water Resource Institute, Ithaca, NY.