USE OF A NITROGEN LEACHING MODEL AS A DESIGN CRITERION FOR LAND APPLICATION OF WASTE WATER

L.T. West and M.L. Cabrera

AUTHORS: L.T. West and M.L. Cabrera, Department of Agronomy, University of Georgia, Athens, GA 30602.

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INTRODUCTION

Land application is a viable alternative to conventional waste treatment plants for environmentally safe disposal of liquid wastes. To ensure protection of the state's water resources, guidelines have been established specifying variables that should be considered in design of land application systems. These guidelines also specify maximum levels of hydraulic loading, heavy metals in the soil, and N concentration in water percolating through the soil (Georgia EPD, 1986). Any of these three factors may limit the annual amount of waste applied to a site. For hydrologic loading, the design criteria are based on monthly net precipitation (precipitation - potential evapotranspiration) and soil properties that influence the hydrology of the soil. The maximum monthly rate of waste application is determined by the month in which net precipitation plus monthly waste addition is maximal. Total net precipitation plus waste additions during this month cannot exceed the soil's capacity to transmit the liquid without ponding and runoff. If nitrogen content of the waste is such that limits on soil percolate N concentration will be exceeded with application rates which meet hydrologic loading criteria, size of spray field area is determined based on an annual rather than monthly N balance.

The major sink for N considered in design of land application systems is plant uptake. Rather than being uniform throughout the year as suggested by the current practice of using annual values in the system design, crop growth and associated N uptake is cyclic, and depending on the crop or crops growing, periods of plant dormancy or reduced growth may occur when little or none of applied N is being removed from the soil. Thus, during these periods N applied may move quickly through the soil profile and potentially to shallow ground water. This may be especially true in Georgia where warm temperatures promote rapid nitrification and the retentive capacity of the soils for ammonium is low.

Models to predict nitrate leaching through soils under different climatic and management regimes are currently available and improved versions are steadily being released. These models simulate N uptake by crops, N transformations such as nitrification, denitrification, and volatilization, and water and nitrate movement through the soil, and offer the opportunity to evaluate the effectiveness of N removal by land treatment under various management, climatic, and soil conditions.

The objective of this study was to use a N leaching model to evaluate the soil N balance under different soil and management conditions for a hypothetical land application system sized by current design criteria.

METHODS

A 378,500 l/d waste stream containing 100 mg N/l, all in the ammonium form, was used for system design and model simulations. For system design as outlined by the Georgia EPD, 20% of the total N produced was assumed lost by volatilization and denitrification. Other parameters used for system design are given in Table 1. The size of the spray field area needed to produce N levels in the percolate below the allowable limit was determined for two cropping systems, corn as a summer crop (planted May 1, harvested October 31) and double crop corn and winter wheat (planted November 1, harvested April 30). Because water uptake by the winter wheat crop was greater than that from a fallow field, less water was available under the double crop system than was available under corn alone to dilute added N. Thus, the spray area needed with the double crop system was actually larger than that needed for corn alone. Because the area needed under the two cropping systems was similar, a constant area of 36 ha was used for model simulations of both cropping systems. For the annual volume to be applied over the 36 ha area, 7 mm of waste containing 3 kg N/ha was applied weekly during the simulation.

Table 1. Characteristics of Waste Stream and N Sinks Used for Determination of Spray Field Area.

	Corn	Corn + Wheat
Net precipitation, mm/yr	287	69
Crop N uptake, kg/ha/yr	178	268
Spray area, ha	34	36

The application of the waste stream to this spray field area was evaluated for nitrate leaching with the NLEAP (Nitrogen Leaching and Economic Analysis Program) simulation model (Shaffer and Brodahl, 1990). In combination with the two cropping systems, N concentration in percolating water was evaluated in three soils, Tifton, Lakeland, and Orangeburg. Climatic data used as model inputs were long term averages taken from the Agricultural Experiment Station in Tifton (NOAA, 1988). Soil properties needed as model inputs were taken from Perkins (1988). Properties of the three soils pertinent to the model runs are given in Table 2.

Simulations were made for each soil-cropping system combination for a five year period with a daily time step. Monthly averages for precipitation were equally divided among the average number of rainfall events occurring each month for purposes of these simulations. The waste water was applied weekly and was applied at least two days after any precipitation event. Nitrogen in the waste water was all in the ammonium form at the time of application. The equal spacing of precipitation events may have altered the results of the simulations because no wet or dry periods occurred during the year. These data should, however, represent results expected of long term application of the waste.

Table 2. Soil properties used in model simulations

	Tifton	Lakeland	Orangeburg
Hydrologic group	B	A	B
Drainage class	Well	Excessive	Well
Slope, %	3	3	3
Landscape position	sideslope	sideslope	sideslope
Water/Root restriction	yes-90 cm	no	no
Organic matter, %	0.7	0.7	1.0
Surface pH	5.9	6.1	6.6
Cation Exchange			
Capacity, meq/100 g	2.5	2.5	2.8
Bulk density, g/cm^3			
surface horizon	1.73	1.60	1.47
subsoil	1.77	1.60	1.47
Coarse fragments, %			
surface	16	0	0
subsoil	20	0	0
Available water, cm/cm			
surface	0.08	0.05	0.09
subsoil	0.11	0.05	0.16
15-bar water, cm/cm			
surface	0.06	0.06	0.07
subsoil	0.11	0.06	0.21

RESULTS AND DISCUSSION

Figure 1 shows the solution N concentration in the subsoil of the Orangeburg soil over the five years of simulation. The N concentration is low at the beginning of the run and increases to an "equilibrium" level after four to five years. Subsoil N concentrations increase over time because N additions exceed losses. Under conditions of the simulations, the annual volume of water that leaches below the root zone (125 cm) is constant. Thus, as N concentration increases, total annual amount of N lost from the soil by leaching increases. Eventually, the subsoil N concentration will be great enough that annual losses by leaching will be equal to excess N, and mean annual N concentration will become constant.

Imposed on the general increase in subsoil N concentration over time is a cyclic variation due to seasonal changes in plant uptake and net precipitation (Figs 1 and 2). During the early growth stage of corn, N concentrations generally increase because of low N uptake relative to amount of N being added (Fig. 2). During the period of rapid corn growth and corresponding high N uptake, subsoil N concentrations decrease substantially. As the corn nears maturity N concentrations begin to increase again. This increase continues during early growth of the winter wheat, and a second decrease in N concentration occurs in the spring during active wheat growth and high amounts of net precipitation. As the wheat matures, N concentrations begin to increase again, and the increase continues into the corn crop. A similar type of cycle is observed under corn alone, but the decrease in N concentrations during the spring months is due to excess precipitation alone and is less than that observed when a wheat crop is present.

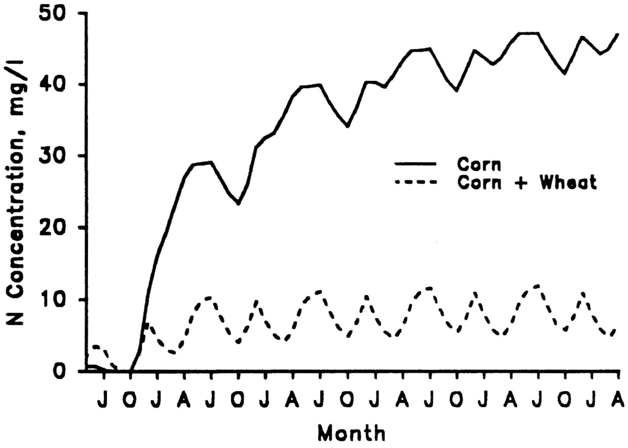

Figure 1. Subsoil N concentrations for 5 years of simulation for the Orangeburg soil.

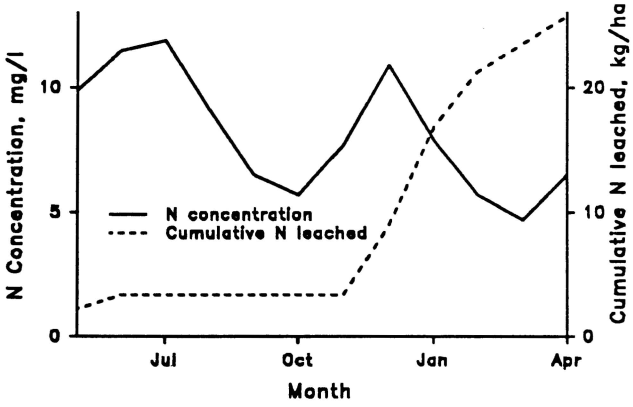

Figure 2. Subsoil N concentration and cumulative N leached during year 5 of model simulation for Orangeburg soil with corn + wheat cropping system.

It should be noted that the low N concentrations during summer and early fall occur during the period of the year when no leaching occurs (Fig. 2). Most leaching occurs during the late fall to mid spring period and overlaps all of the fall N concentration peak and a portion of the spring peak.

Waste application with corn as the only crop in the management scheme resulted in predicted mean subsoil N concentrations that ranged from 45 to 55 mg/l (Table 3); well over the maximum concentration of 10 mg/l allowed under EPD regulations. Additional N uptake from the winter wheat crop in the management scheme resulted in subsoil N concentrations that were 18 to 39% of those with corn alone. In addition to higher mean subsoil N concentrations when a winter crop was not present, peak concentrations occurred during the winter and early spring months when greatest amounts of water movement below the root zone were occurring.

Of the soil/cropping system combinations evaluated with these simulations, Orangeburg with double-cropped corn and wheat was the only one that had mean annual percolate N concentrations below the regulatory limit of 10 mg/l (Table 3). Even though the mean was below 10 mg/l, subsoil N concentrations above 10 mg/l were observed during three months of the year, and two of these three months were during periods that solutes were moving below the root zone. Under a corn crop alone, subsoil N concentrations were well above regulatory limits for all soils. Generally, however, the Orangeburg soil would be considered to be an acceptable soil for N removal from land applied wastes under proper crop management.

Table 3. Mean annual N concentrations in percolate leaching from the three soils.

	Corn		Corn + Wheat	
	Mean	Range	Mean	Range
Orangeburg	45	43-47	8	5-12
Lakeland	55	41-73	20	3-36
Tifton	44	37-51	17	9-24

Mean annual percolate N concentration in the Lakeland soil under the double crop system was 20 mg/l. During January, February, and March N concentrations in the percolate dropped below the 10 mg/l level, but levels during the rest of the year were great enough to increase the mean to unacceptable levels. Under corn alone, mean percolate N concentration was 55 mg/l. This soil had a much lower available water holding capacity and 15-bar water content than Orangeburg (Table 2). Thus, less water was retained in the soil to dilute N not taken up by plants. Additionally, sandy textures and excessive drainage in this soil allow more rapid water and solute movement from surface and upper subsoil horizons to lower horizons where N uptake is reduced because of low root density. Because of low available and 15-bar water and rapid solute movement through this soil, a larger spray field area, as compared to soils such as Orangeburg, would be required to adequately treat high N waste to ensure protection of ground water from nitrate contamination.

For the Tifton soil, mean annual percolate N concentration was 17 mg/l under the double crop system and 44 mg/l with corn as the only crop. Though the upper part of the Tifton soil has a similar texture to Orangeburg, the available water holding capacity in the subsoil is less, as is the 15 bar water content (Table 2). Additionally, Tifton has horizons containing plinthite beginning at 90 cm which are considered to be root and water restrictive (Daniels et al., 1978; Carlan et al., 1985; Blume et al., 1987). The NLEAP model stops the rooting depth at this restrictive layer, and thus, the total volume of soil considered for Tifton is less than that considered for Orangeburg. Reduced soil volume and reduced volume of water retained per unit volume of soil combine to substantially reduce the amount of water present to dilute N from the waste that is not taken up by the crops. Thus, the model indicates a larger area of Tifton soils, as compared to Orangeburg, would be needed to adequately treat the same volume of applied waste water.

Because the Tifton soil is considered to have a water restrictive layer, the argument could be made that the perching of water above this layer would protect ground water and make the soil more acceptable for high N waste treatment than predicted by the model. The restrictive layer, however, slows water movement rather than completely stopping it (Carlan et al., 1985). Thus, over the long term, considerable amounts of water and nitrate could leach through these horizons and eventually reach shallow ground water. Additionally, the plinthite horizons promote lateral water movement above the plinthite to lower landscape positions (Hubbard and Sheridan, 1983). The fate of nitrate moving to these lower landscape positions depends on a combination of factors including soils, vegetation, and hydrologic conditions present at these positions.

Use of model simulations of nitrate leaching under land application waste disposal systems indicates several important factors that should be considered in design and regulation of these systems. Even on the Orangeburg soil, which produced the lowest percolate N concentrations under a double crop management system, mean annual N concentration of the leachate was just under the allowable limit. This was observed even though total uptake of N predicted by the model was 20% greater than N sinks used in sizing of the spray field area (363 vs. 300 kg/ha/yr). Nitrogen uptake under corn alone was also greater than the level used for system sizing, and N concentrations in the leachate far exceeded allowable limits.

Two major factors contributed to the greater than expected N concentrations observed. First, in calculation of spray field area, 15% of the total N applied to the area was assumed to be lost by denitrification and 5% was assumed to be lost by volatilization of ammonia. The model predicted no N losses by volatilization and no denitrification on either the Tifton or Lakeland soils. Minor denitrification was predicted for the Orangeburg soil, but these losses totaled only 13 kg/ha/yr. Second, the N balance currently used to size spray field areas does not assume any N contribution from mineralization of soil organic matter. Depending on initial soil organic matter contents, the model predicted from 19 to 48 kg/ha/yr of N mineralized from organic matter.

Often it is assumed that a portion of N applied in the ammonium form will be retained in the soil by its exchange sites. Such adsorption during periods of reduced plant uptake and subsequent release, nitrification, and uptake during periods of rapid plant growth would tend to buffer the system. Under temperatures and rainfall found in Georgia, however, the model predicted essentially immediate nitrification of all the N applied in the ammonium form. Thus, little, if any, retention of N in these soils would be expected. The low cation exchange capacity found in most soils in Georgia would also reduce N retention in the soil, even if nitrification was slowed by using a nitrification inhibitor.

SUMMARY

Disposal of high N wastes by land application is a viable alternative to traditional methods. However, use of a nitrogen leaching model, NLEAP, to evaluate nitrogen leaching from a hypothetical land application system indicated that more N may be moving below the soil root zone than predicted from estimates based on annual N input and uptake as currently used for spray field area determination. Much of the N leaching occurs during the late fall to mid spring period of the year when net precipitation is highest and plant uptake rates are reduced. Results of model simulations also indicated that percolate N concentrations were substantially reduced when a winter crop was incorporated in the management system because of extra N uptake during the critical leaching period. Amounts of N leaving the root zone varied among soils evaluated and was primarily related to the soil's capacity to retain water and the presence of root restrictive layers within the profile. Model simulations for sandy soils with low water retention capacity and soils with root restrictive horizons predicted percolate N concentrations above the allowable limit.

The model predicted high percolate N concentrations even though the simulations predicted greater N uptake by plants than were assumed for calculation of spray field area. A part of this discrepancy is due to assumptions concerning amounts of N volatilization and denitrification used in determining size of the spray field area. Model simulations indicated that N losses from these two processes were negligible and substantially lower than assumed amounts.

These results illustrate the applicability of simulation models to evaluation of land application waste disposal systems. Soil and management factors that impact the performance of the system can be better evaluated with model simulations than with the evaluation system currently being used. Additionally, individual components of the overall process can be evaluated through simulation models and critical periods of the year when the chance of ground water contamination is the greatest can be identified. Numerous simulations can be easily run over various time periods with variations in inputs and management schemes to find the combination of inputs and management that provides maximum removal of N in the waste water. With the current availability of computers and ongoing development and improvement of models to simulate various processes, use of such models to evaluate systems for land application of wastes appears to be viable alternative to methods currently used.

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