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Analysis of Groundwater Contamination with Nitrate Using Gleams: Case Study

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Abstract. A field experiment was conducted during the summer season of 2004 at agricultural research station, University of Tehran, karadj, Iran to study effect of different management system on nitrate leaching in sandy loam soil. In this study, the transport and fate of nitrate within the soil profile and nitrate leaching to out of root zone, were analyzed by comparing historic field data with the simulation result of the GLEAMS model. The model was used to simulate the performance of the nitrogen transport. In the analysis continues cropping with corn was assumed. Comparison between experimental measured and simulated state variable indicate that the nitrate concentration in the soil and nitrate leaching out of root zone are controlled by the field management practices. These practices include nitrate application rate, timing, type of fertilizer and irrigation practices. Comparison between observed data and simulated result conclude that, GLEAMS model after calibration is a useful tool to optimize nitrate application rate, resulting for the environment in an acceptable level. At the end because of GLEAMS's weakness at result presentation, GS+ Software was used.

Keywords. Environment, Fertilizer, Groundwater, GLEAMS,Nitrate leaching

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Introduction

Using fertilizers to improve the crop production especially nitrogen fertilizers is a common practice in most agricultural lands. Excess use of this nitrogen has caused soil and water pollution world (Costa et al., 2002; Lee et al., 2005; Neve et al., 1998; Mansingh, 2002; Hudak, 2000; Assimakapoulos, 2003) and the main reason is the difficulty in matching fertilizer application rates and timing to the needs of a given crop. The challenge facing farmers and farm policy makers is therefore to attain a level of crop productivity high enough to feed a growing world population while reducing the enormous impact of nitrogen pollution (Gurian-Sherman and Gurwick, 2009). Modeling the transport and chemical reactions of major solute species in and below the root zone plays a critical role for proper irrigation, fertilization, and surface and groundwater management in different technical and environmental conditions (Sheffer et al., 1991; Ramos and de Paz, 2004; Gardi, 2001; Wolf et al., 2004; Rimski et al., 2004).

In this study, GLEAMS model has been used to simulate the nitrogen leaching through root zone of a corn farm in Karadj, Iran. Since GLEAMS is designed as one dimensional and single point source pollution, a geostatistics model, GS+, was used to interpolate the results between measured and calculated points and present the output in two dimensions.

Materials and Methods

A one hectare corn field was selected for the field measurements located in the research farm of University of Tehran, Karaj, Iran. Table 1 and 2 show the soil characteristics and nitrogen contents, respectively.

Table 1: Soil characteristics of the study area

Depth (cm)	Porosity (%)	Field Capacity (%)	Wilting Point (%)	K (cm/hr)
0 – 25	40	21	12.3	2.5
25 – 100	40	20	10.0	3.5
100 - 120	40	21	10.8	3.0

Table 2: Chemical properties of the soil regarding Nitrogen

Parameter	Value
Plant Residues (Kg/ha)	500
Nitrate in Irrigation water (ppm)	2.1
Total Nitrogen of Soil (%)	0.1
Nitrogen Concentration in Soil (ppm)	4.5

During the growing season, ammonium-nitrate fertilizer in granular form was used. Corn was irrigated using furrow irrigation method. Eight points along two furrows in the middle of the farm were selected for measuring the nitrate concentration and water content in soil profile.

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) was developed by USDA-ARS in 1980 and after that several new editions were developed. GLEAMS is a model for evaluating different management practices in farm scale by calculating the water content and nutrients movement in soil layers. This work is based on GLEAMS Version 3

(Knisel and Davis, 2000). Version 3 is modified to accommodate annual leaf drop which is added to soil surface residue and incorporates corrections to metric crop height in hydrology parameters. Several researchers have been used this model to study the nitrate movement in fields (Shirmohammadi and Knisel, 1994; Shirmohammadi et al., 1998; Turtola and Knisel, 1999 and Ramoz and de Paz, 2004).

In order to interpolate the measured data, a robust and accurate method has to be selected. A branch of statistics known as geostatistics offers a unique means of analyzing spatial relations between the diverse data. The assumption that makes interpolation a viable option is that spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics. The Kriging method fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. The Kriging method is a multistep process which includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. This function is most appropriate when there is a spatially correlated distance or directional bias in the data. The experimental semivariogram, γ(h), is computed as half the average squared difference between the components of data pairs (Isaaks and Srivastava, 1989):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x) - Z(x+h) \right]^2 \qquad (1)$$

where N(h) is the number of pairs of data locations a vector h apart and Z(x) is the measurement at point x. Before using a semivariogram in estimation, it is necessary to fit a suitable mathematical model. In this study, a Gaussian model performed best; and it is defined as follow:

$$\begin{cases} \gamma(h) = C_0 + C\left(1 - e^{-\frac{h^2}{a^2}}\right) & if \quad h\langle a \\ \gamma(h) = C_0 + C & if \quad h\rangle a \\ \gamma(0) = C_0 & if \quad h = 0 \end{cases} \qquad (2)$$

where C0 is the nugget effect, a is range of effluence, and C is the difference between nugget effect and sill.

Geostatistical interpolation for estimating the variable at unsampled location x_p, $Z^*(x_p)$, as a linear combination of neighboring observation, $Z(x_i)$, is:

$$Z^*(x_p) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad \text{with} \sum_{i=1}^{n} \lambda_i = 1 \qquad (3)$$

where λ_i are the Kriging weights for observation points.

GS^+ is a geostatistics software program that provides geostatistics components, from semivariance analysis through Kriging and mapping (Anonymous, 2002).

Results and Discussion

GLEAMS is a one-dimensional model, therefore, it could evaluate the results only in a single point. It was needed to interpolate the simulated data to extend the results through the entire filed. Figure 1 shows the cross validation graph with $R^2 = 0.79$ for nitrate concentration in subsurface water.

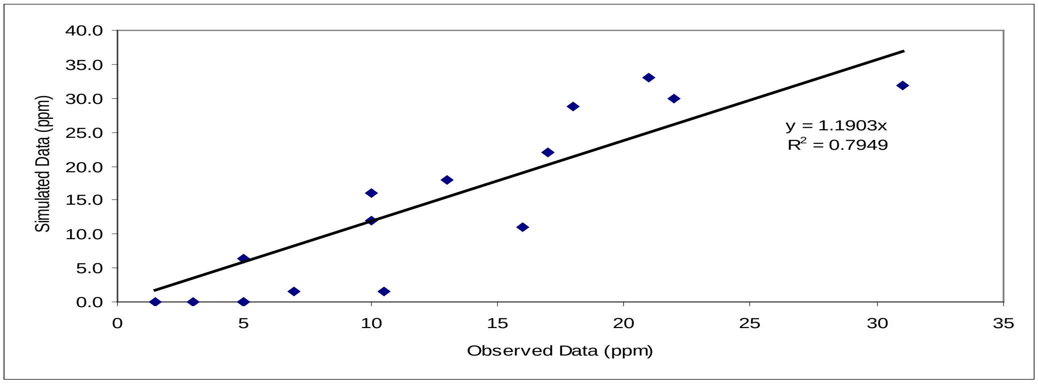

Figure 1 Cross validation of nitrate concentration in drainage water

Using GS+ software and selected Kriging parameters, spatial changes in nitrate concentration were estimated and presented in Figures 2 and 3 for 190th and 240th Julian day, respectively. Based on the observed and simulated results, after each irrigation, nitrate concentration was decreased in drainage water. The reasons for this can be contributed to the plant consumption. On the other hand, corn in early stages of growth has short root length, therefore, it cannot uptake much nutrient from soil and most of the nitrate fertilizer will be washed away from soil profile. Since the application water depth at the beginning of furrow was higher than that at the end of furrow, nitrate concentration in drainage water was higher at the beginning and it was decreased along the furrow length.

The calibrated model was used to test three different alternatives of agricultural practices to reduce the nitrate leachate. In the first scenario, 50% of fertilizer was applied in early stages of corn growth and the other 50% was applied after 25 days. Nitrate leaching from root zone after each irrigation has been shown in Table 3.

In the second scenario, nitrate was dissolved in irrigation water. This method is mostly suitable in sprinkler irrigation. A high increase in NO3-N in drainage water was encountered. The main reason for that was the fast leaching of dissolved nitrate with water. Table 3 shows the nitrate concentration in drainage water in scenario 2.

Third scenario is changing the irrigation management. Instead of applying the usual irrigation frequency which it was 10 days, 75% of the irrigation depth is delivered in a 10-day frequency and 25% of that in a 5-day frequency. In this situation, it is expected that the water seepage will be reduced and it causes the decrease in nitrate leaching. In Table 4 the nitrate leaching from root zone has been shown.

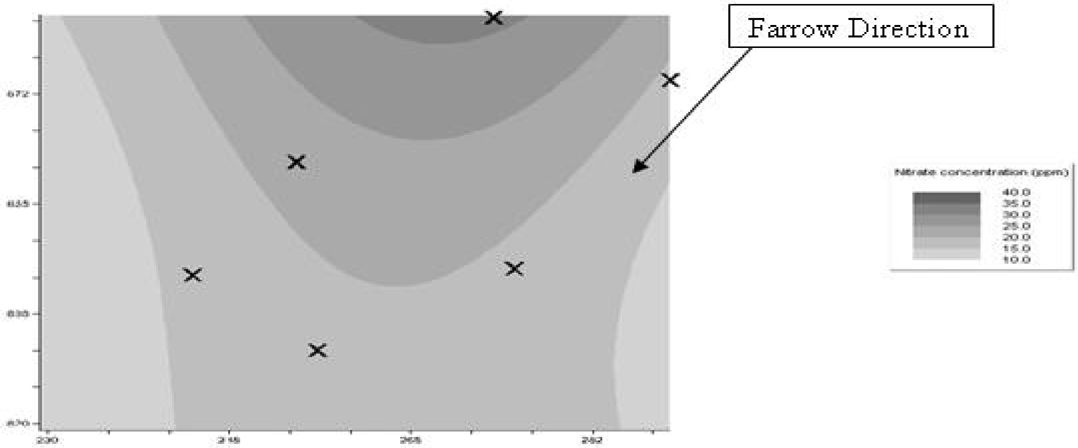

Figure 2. Nitrate concentration in drainage water after 190th Julian day

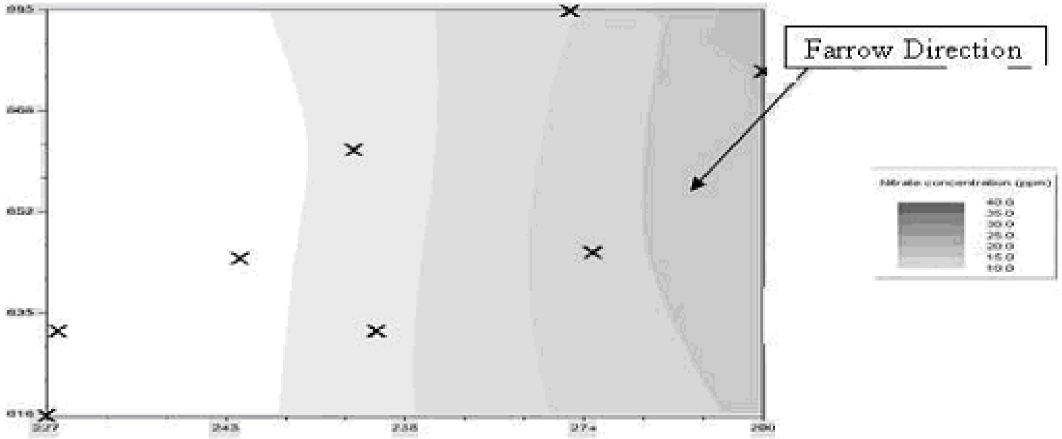

Figure 3. Nitrate concentration in drainage water after 240th Julian day

Conclusion

Comprehensive data sets collected in a corn filed during the growing season and they were used to evaluate and calibrate the GLEAMS model. GS+ software with Kriging method was employed to predict the value of nitrate concentration in unmeasured points. In order to evaluate different management practices to prevent nitrate leaching, different scenarios were simulated. The comparisons between scenarios show that the first two practices are not successful in reducing the nitrate leaching. But the scenario 3 had better performance in this regard. On the other hand, by closing the end of furrow, it is possible to prevent the nitrate wash out in runoff. But it will increase the leaching through the soil profile and contamination of groundwater.

Table 4. Nitrate mass leaching from root zone in scenario 1 and 2

NO3-N Leaching (kg/ha)									
Senario no.	peresent condition			Senario 1			Senario 2		
Position Julian day	top	middle	end	top	middle	end	top	middle	end
190	7	6.5	3.5	5.4	6	3.5	7.1	8.7	8.7
200	7.3	4	2.1	3.2	3.4	1.7	11	13.2	12.1
210	6.5	3.5	1.7	2.1	0.5	0.7	15.5	9.6	9.2
220	2.5	0.3	0.3	5.2	4.3	1.9	0	0	0
230	0.5	0.3	0	2.9	1.2	0.7	0	0	0

Table 4. Nitrate mass leaching from root zone in scenario 3

NO3-N Leaching (kg/ha)			
Senario no.	Senario 3		
Position in depth Julian day	top	middle	end
190	7	8	3.5
195	1.7	0.7	0.7
200	3.1	2.1	1.4
205	0.4	0.4	0
210	1.3	0.4	0.4
215	0	0	0
220	0.7	0	0
225	0	0	0

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