EVALUATION OF LEACHM-N ON NITRATE LEACHING IN SANDY REGOSOLS IN BATTICALOA

Bawatharani.T[1], Mowjood.M.I.M[2], Dayawansa.N.D.K[2] and Kumaragamage.D[3]

ABSTRACT

Agricultural contamination of groundwater with nitrates in Batticaloa is of prime importance, due to the intensive use of inorganic N fertilizers, together with excess irrigation on highly permeable soils. The objective of this study was to evaluate the applicability of LEACHM-N on nitrate leaching in sandy regosols under laboratory conditions. Leaching behaviour of NO_3^- - N was evaluated through laboratory experiments with those predicted by LEACHM-N, a one dimensional, water flow, solute transport and plant uptake model. To perform laboratory column studies, PVC pipes of 20, 30 and 40 cm depths and 8.9 cm internal diameter were used to represent soil profile at three depths. Each column was fertilized with KNO_3, at the rate of 0, 70 and 140 kg N/ha. Three water application rates (7mm, 14mm and 30mm) were combined with each of these fertilization rates in each column. The leachate samples were collected and analyzed for nitrate nitrogen colorimetrically using spectrophotometer. LEACHM-N produced satisfactory predictions for all the treatments in 20cm column. The accuracy of prediction was found to be decreasing when the column depth was increased and the decrease in rate of irrigation. In most treatments the simulated results showed no significant difference between LEACHM-N predicted and measured losses. Comparisons of simulated NO_3^- - N losses in the columns showed reasonable match with the measured values as indicated by their non significant mean difference values. For most of the treatments in 20cm column, the mean difference values were non significant with higher correlation coefficient values and lower Root Mean Square Error values. Therefore it can be concluded that LEACHM-N predictions are successful and could be used as a decision making tool at field conditions to evaluate nitrate leaching.

Key words : LEACHM-N, Nitrate Leaching, Sandy regosols, Soil column, Water flow, Mean difference, Root mean square error

INTRODUCTION

The East coast soils in Batticaloa have been classified as sandy *regosols*, containing 95 - 98% sand with no confining horizons in the soil profile. Since this area usually experiences shallow groundwater, it provides a favourable condition for leaching of surface applied fertilizers. The intensive use of inorganic N fertilizers, together with excess irrigation to meet the evaporative demand and percolation losses on these highly permeable soils has contributed significantly to the groundwater pollution.

Therefore an understanding of the movement and transport of NO_3^- and quantifying the loss of nitrate beyond the root zone are very important to minimize the fertilizer loss and to avoid the ground water contamination. However the behaviour of nitrogen in the soil-plant water system is very complex, dynamic and involves numerous interactions and transformations. Hence, mathematical models are useful tools for integrating these different processes involved in N transport in soil and can be used in forecasting how a system will behave without actually making measurements in a physical system (Tanji and Gupta, 1978).

LEACHM-N (Leaching Estimation And CHemistry Model), (Hutson and Wagenet, 1992) is one of the widely used model to simulate field scale N transformations and movement in the unsaturated zone of the soil profile (Ramos and Carbonell, 1991; Bergstrom and Jarvis, 1991, Addiscott and Whitmore, 1987,). LEACHM-N consists of many subroutines to calculate water flow, NO_3^- leaching, evaporation, heat flow, rate constant adjustments for temperature and water content, N transformation and uptake and plant growth. It uses many equations from Johnson *et al.*, (1987) to simulate N transformations.

[1] Department of Agricultural Engineering, Faculty of Agriculture, Eastern University, Sri Lanka. (bavatharani@yahoo.com.sg)
[2] Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya. (mmowjood@pdn.ac.lk; dammid@pdn.ac.lk)
[3] Environmental Studies Program, University of Winnipeg, Manitoba, Canada. (dkumaragamage@yahoo.co.uk)

As consideration of the environmental impact of agricultural land use in the sandy *regosols* of Batticaloa, had been limited due to lack of information on the effects of fertilizer use on nitrate leaching into groundwater, validation of the nitrate leaching simulation model (LEACHM-N) for the environmental conditions of Batticaloa could be a useful predictive tool. Therefore, the objective of this study was to evaluate the applicability of LEACHM-N on nitrate leaching in *sandy regosols* under laboratory conditions.

MATERIALS AND METHODS

SOIL COLUMN LEACHING EXPERIMENTS

The soil column leaching experiments were conducted in Soil and Water Analysis laboratory at University of Peradeniya. Soil (sandy *regosol*) collected from Kaluthawalai, 25 km from South of Batticaloa, was used for this study. Laboratory experiments were conducted using PVC (polyvinyl chlorides) pipes of 8.9 cm internal diameter and 20, 30 and 40 cm depths. The bottom end of the pipes was tightly covered with muslin cloth. The columns were packed with 2-mm sieved sandy *regosols*, to a bulk density of 1.6 gcm^{-3} and were saturated from the bottom with distilled water. The columns were arranged vertically with plastic funnels at the bottom, to facilitate the collection of leachate.

Each column was fertilized with 0, 314 and 621 mg of KNO_3, which is equivalent to the fertilization rates of 0, 70 and 140 kg N/ha for onions. Three irrigation treatments, 7, 14 and 30 mm, were combined with each of these fertilization rates in each column, resulted in 27 treatment combinations. According to the rate of irrigation, calculated amount of distilled water was sprayed uniformly in defined time period at a constant rate over the surface area of the columns to simulate the irrigation. Each treatment was run in three replications.

The water fluxes and the nitrate concentrations in the leachates, passing through the column were measured at frequent intervals soon after each water application. Water samples were collected continuously, from the drainage flask kept at the bottom of the column. The columns were flushed with one pore volume of distilled water followed by each treatment prior to starting the next experiment to displace any remaining NO_3^-. The moisture contents of columns were maintained at field capacity prior to the commencement of next water application. The evaporation, volatilization, denitrification and any other losses of nitrogen were considered to be negligible during the experimental period.

MEASUREMENT OF NITRATE CONCENTRATION

The volume of the water leached to the drainage flask was measured followed by each water application. The water sample, approximately 30ml, was collected and analysed for nitrate nitrogen using JENWAY Model 6305 UV/Vis Spectrophotometer. The water samples were stored frozen at -4º C for the analysis of nitrate, at times where immediate analysis of samples was not possible.

Determination of soil physical, chemical and hydraulic properties

Important soil physical properties in characterizing nitrate leaching were determined in the laboratory using the following methods for which soil was sampled in 10cm increments up to 50cm depth. Selected soil properties and their method of analysis are given in Table 1.

INPUT DATA FOR THE MODEL

The LEACHM required a variety of input data for soil physical, hydraulic and chemical characteristics, soil nitrogen transformation rate constants, weather, environmental and crop management data for each layer of soil profile. The input parameters required by the model were obtained from laboratory measurements, from literature and from the calibration process.

Table 1: Selected properties of *sandy regosols* (top 50-cm) at the field site

Properties	Method of analysis	Reference
Saturated hydraulic conductivity (Ks)	Constant head	Klute and Dirksen, 1986
Bulk density	Core sampler	Blake and Hartge, 1986a
Particle density	Pycnometer	Blake and Hartge, 1986b
Porosity (f)	Calculated	-
Particle size distribution	Hydrometer method	Sheldrick, and Wang, 1993
Organic matter content	Walkley-Black	Nelson and Sommers, 1982

LEACHM-N Simulations of nitrate leaching in soil columns

The simulated soil profile was equally divided into 20 horizontal segments. NO_3^- leaching was simulated at depths 20, 30 and 40cm of soil profile. The crop cover was assumed to be zero throughout the simulation period on the soil columns. To simplify the NO_3^- leaching modeling, a steady state water flow was assumed through the soil columns. It was also hypothesized that solute transport in these non structured coarse sandy soils could be less affected by soil water status than in well structured soils (Jury and Roth, 1990). Freely draining profile boundary conditions were used in the lower boundary condition of the columns.

RESULTS AND DISCUSSION

LEACHM-N predicted NO_3^- - N losses from all the columns were in good agreement with measured NO_3^--N losses almost in all the treatments (Figure1, 2). However in few simulations, the predicted losses were not in good agreement with the measured losses (Fig 3, 4). In most treatments the simulated results showed no significant differences between LEACHM –N predicted and measured losses.

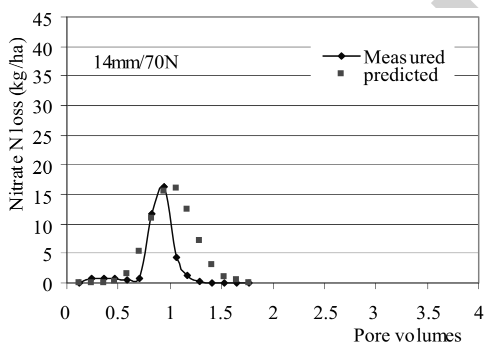

Figure 1: LEACHM-N predicted vs measured nitrate N losses in 30cm column at 70 kg N/ha at 14mm irrigation

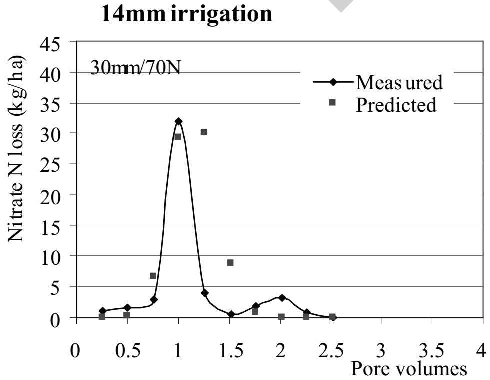

Figure 2: LEACHM-N predicted vs measured nitrate N losses in 30cm column at 70kg N/ha at 30mm irrigation

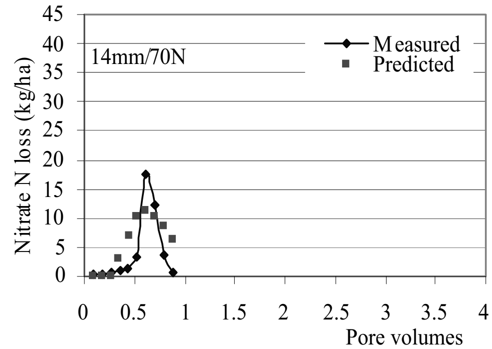

Figure 3: LEACHM-N predicted vs measured nitrate N losses in 40cm column at 70kg N/ha at 14mm irrigation

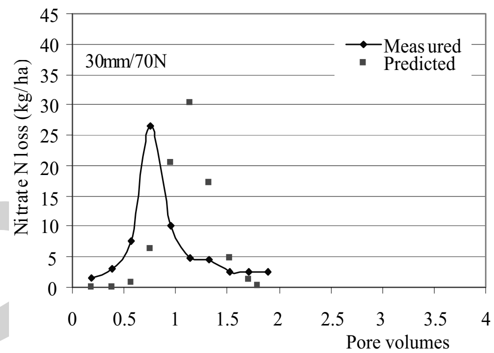

Figure 4: LEACHM-N predicted vs measured nitrate N losses in 40cm column at 70kg N/ha at 30mm irrigation

It has also been observed that the degree of association between the simulated and measured losses had highest agreement in 20cm column for all the treatments (Figure 5,6). The simulation accuracy decreased in 30cm column and it further decreased in 40cm column (Figure 1,3). At the same time, the simulated losses were comparatively in good agreement with the measured losses at higher irrigation rates in all the columns (Figure 2, 4).

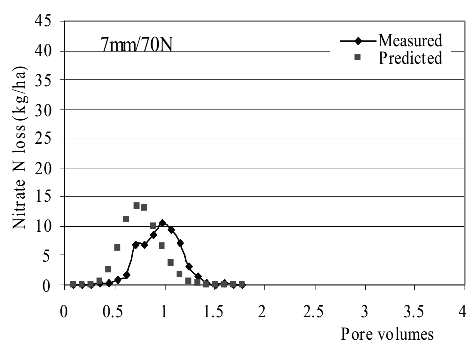

Figure 5: LEACHM-N predicted vs measured nitrate N losses in 20cm column at 70kg N/ha at 7mm irrigation

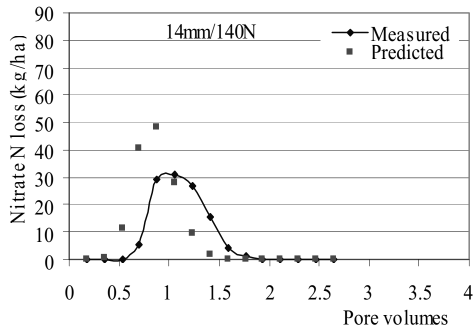

Figure 6: Figure 6 LEACHM-N predicted vs measured nitrate N losses in 20cm column at 140kg N/ha at 14mm

Comparisons of simulated NO_3^- - N losses in the columns showed reasonable match with the measured values as indicated by their non significant *Md* (mean difference) values (Table 2).

LEACHM-N produced satisfactory predictions for NO_3^- - N losses from all the columns for most of the treatments (Table 2). This is because LEACHM-N accurately predicted the drainage losses of water so that the multiplication of the NO_3^- - N concentration by drainage volume in the model output tends to reduce the error. However, the treatments with non significant *Md* and regression coefficients produced poor *r* values. Therefore at this context non significant mean difference was considered as a selection criteria to determine the modeling accuracy.

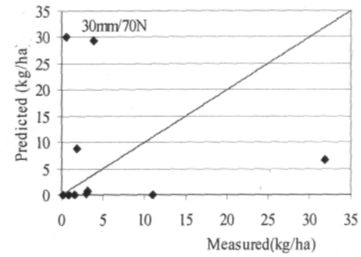

Figure 7: Measurement of NO_3^--N losses vs LEACHM-N simulations in 30cm column

Table 2: Statistical evaluation of simulated NO_3^- - N losses by LEACHM-N in different columns and at different Treatments.

Treatments			r	*Md*	RMSE	Slope	Intercept
Column depth (cm)	Irrigation (mm)	Fertilizer (Kg N/ha)					
20	7	70	0.61	-0.5^{ns}	3.79	0.78^{*}	1.2^{ns}
20	14	70	0.62	-2.02^{ns}	6.81	1.03^{*}	1.93^{ns}
20	30	70	0.89	-2.38^{ns}	8.0	1.7^{*}	0.97^{ns}
20	7	140	0.69	-1.97^{ns}	6.5	0.82^{*}	2.89^{ns}
20	14	140	0.64	-1.63^{ns}	12.18	0.87^{*}	2.63^{ns}
20	30	140	0.98	-1.23^{ns}	8.0	1.31^{*}	2.94^{ns}
30	7	70	0.62	-2.1^{*}	3.07	0.79^{*}	2.35^{*}
30	14	70	0.7	-2.41^{*}	4.78	0.86^{*}	2.75^{*}
30	30	70	0.07	-2.82^{ns}	8.9	0.86^{*}	3.46^{ns}
30	7	140	0.85	-0.62^{ns}	2.52	0.55^{*}	0.95^{*}
30	14	140	0.65	-3.29	6.17	0.62^{*}	5.38^{*}
30	30	140	0.44	-4.97^{ns}	13.33	0.66^{ns}	7.86^{ns}
40	7	70	0.26	-1.8^{ns}	4.02	0.44^{ns}	2.94^{*}
40	14	70	0.7	-1.52^{ns}	4.29	0.54^{*}	3.42^{*}
40	30	70	0.11	-1.55^{ns}	11.83	0.16^{ns}	7.05^{ns}
40	7	140	0.02	-3.27^{*}	5.98	0.04^{ns}	5.2^{*}
40	14	140	0.67	-3.85^{ns}	5.79	0.5^{*}	5.71^{*}
40	30	140	0.89	-5.76^{ns}	11.9	1.61^{*}	2.67^{ns}

* Significant ($P<0.05$) differences between predicted and observed data, or slope estimates or intercepts significantly different from 1.0 and 0.0 respectively.
ns- The differences in between the predicted and the observed data are not significant at P=0.05

For most of the treatments in 20cm column, *Md* values were non significant, with higher *r* values and lower RMSE (Root Mean Square Error) values, despite the regression analysis did not reflect a 1:1 relationship between simulated and measured values for NO_3^- - N losses. However, all the simulations had error term which is < 15%.

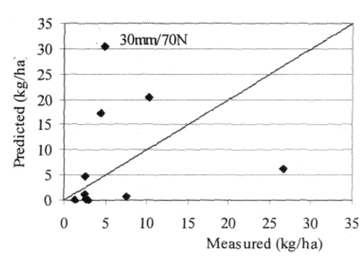

Figure 8: Measurement of NO_3^--N losses vs LEACHM- N simulations in 40cm column

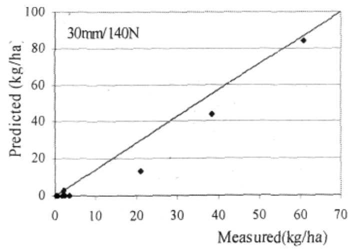

Figure 9: Measurement of NO_3^--N losses vs LEACHM-N simulationsin 20cm column

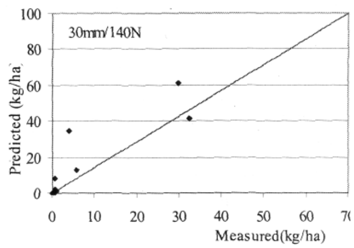

Figure 10: Measurement of NO_3^--N losses vs LEACHM-N simulationsin 40cm column

Some of the simulations in 30cm and 40cm columns contain data points that are far from the 1:1 line. This trend is moreapparent in 40cmcolumn (Figure7,8) which reveals the decreasing modeling accuracy with the increase in column depth. However the data points are verycloser to the 1:1 linein all the treatment combinations at fertilizer application 140 kgN/ha(Figure 9, 10).Despite some discrepancies, LEACHM-N adequately predicted NO_3^- - N losses for all the treatments in 20cm column. However, for all the treatments the model overestimated NO_3^--N losses as indicated by their negative sign of Md values.

CONCLUSION

LEACHM-N reasonably simulated NO_3^- - N losses in all the columns with the measured values. LEACHM-N adequately predictedNO_3^- - N lossesforall thetreatments in 20cm column. However, for all the treatments the model overestimated NO_3^- - N losses. The prediction accuracy decreased at lower irrigation rates and as the depth of the columnwas increased. Better simulation results were obtained at fertilizer application rate of 140 kgN/ha even when the column depthwas increasedto 40cm. Therefore it can be concluded that LEACHM-N can be used as a decision making tool in real field conditions to minimize the leaching losses of NO_3^- N fromextremely sandysoils.

REFERENCES

Addiscott, T.M., and Whitmore, A.P. (1987). Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. J.Agric.Sci.Camb.**109:**141-157.

Bergstorm, L.,and Jarvis,N.J. (1991).Predictionof nitrate leaching losses from arable land under different fertilization intensities using the SOIL-SOILN models. Soil Use Manage. **7:** 79-84.

Blake, G.R., and Hartge, K.H. (1986a). Bulk density. In Methods of Soil Analysis, Part1, Physical and Mineralogical Methods - Agronomy Monograph no. **9** (II ed.): 363-376, ed. A. Klute. Madison, WI: ASA - SSSA.

Blake, G.R., and Hartge, K.H. (1986b). Particle density. In Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods - Agronomy Monograph no. 9 (II ed.): 377- 382, ed. A. Klute. Madison, WI: ASA - SSSA.

Hutson, J.L., and Wagenet, R.J.(1992). LEACHM: Leaching Estimation and Chemistry Model: A process based model of water and solute movement,transformation, plant uptake and chemical reactions in the unsaturated zone. Water Resour. Ist., Cornell Univ., Ithaca, NY.

Johnson, H., Bergstrom, L., Jansson P.E., and Paustian, K. 1987. Simulated nitrogen dynamics and classes in a layered agricultural soil. Agric. Ecosyst. Environ. **18:**333-356.

Klute, A. (1986). Water retention: laboratory methods. In Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods - Agronomy Monograph no. **9** (II ed.): 635- 662, ed. A. Klute. Madison, WI: ASA - SSSA.

Klute,A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity: laboratory methods. In Methods of SoilAnalysis, Part 1, Physical and Mineralogical Methods (II ed.). Agronomy 9:687-703, ed. A. Klute. Madison, WI: ASA - SSSA.

Nelson, D.W. and Sommers, L.E. (1982). Total carbon, organic carbon, and organic matter. In Methods of SoilAnalysis,Part 2, Chemicaland Microbiological Properties (II ed.). Agronomy **9:**539-577, ed. A.L. Page. Madison, Wisc.: ASA – SSSA.

Ramos, C., and Carbonell, E.A (1991). Nitrate leaching and soil moisture prediction withLEACH-M model. Fertilizer Research **27:**171-180.

Sheldrick, B. H., and Wang, C. (1993). Particle-size Distribution. pp. 499-511. In: Carter, M.R.(ed), Soil Sampling and Methods of Analysis, Canadian Society of Soil Science, Lewis Publishers, Ann Arbor, MI.

Tanji, K.K. and Gupta, S.K. (1978). Computer simulation modelling for nitrogen in irrigated croplands. In: D.R.Neilson and J.G. Macdonald. ed. Nitrogen and Environment: Vol 1. Nitrogen Behaviour in Field Soil. Academic Press, NewYork, 79-130.