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SIMULATION OF NITRATE LEACHING IN *YALA* SEASON IN BATTICALOA - A MODELING APPROACH

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ABSTRACT

The leaching behaviour of NO_3^--N was evaluated through field experiments with those predicted by LEACHM-N, a uni-dimensional, water flow, solute transport and plant uptake model. Therefore, the objective of this study was to evaluate the application of LEACHM-N for predicting nitrate leaching in Batticaloa during *Yala* 2005. Field experiments were carried out from April 12th 2005 to June 30th 2005. The experimental treatments were 3 nitrogen rates (0, 70 and 140 kg N/ha) together with 3 irrigation rates (7, 14 and 30 *mm*) which resulted in 9 treatment combinations. The treatments were arranged in a split plot design in 3 replicates. Twenty seven cylindrical lysimeters with 1 m height and 50 cm diameter were built in at the experimental site. Outlets from each lysimeters were fixed with outflow pipes, directed to an underground sampling point, from where the water samples were collected. Red onion (*Allium cepa*; var. Vethalan) was planted in the lysimeters. Nitrogen fertilizer was applied 3 times during the cropping season. Irrigation water was delivered using a micro sprinkler system. Leachates from individual outlets were collected separately and NO_3^--N was determined spectrophotometrically by the Cadmium reduction method. A moderately good agreement has been found out in between the measured and the predicted NO_3^--N losses, but the model overestimated the losses. The treatment combination 140 kg N/ha with 30 mm of irrigation showed better simulation accuracy. It was also found out that the model was unable to predict preferential flow.

Keywords: LEACHM-N, leaching, *sandy regosols*,*Yala*, lysimeter, preferential flow

INTRODUCTION

Nitrogen (N) is one of the essential inputs for crop production in agriculture. However, nitrogen application rates on agricultural fields often exceed actual crop use (Mohanty & Kanwar, 1994), and the unused N in the soil profile is either lost through leaching, denitrification, or volatilization. Nitrogen loss from the field and the threat of ground water contamination increase under irrigation on sandy soils because the nitrate, as a mobile contaminant is more easily leached through sandy soils, compounded with possible excess water applications.

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.

Due to the environmental concern about the presence of nitrates in the groundwater in Batticaloa (Vaheesar *et al*., 2001), the demand for understanding the movement and transport of nitrates beyond the root zone has increased considerably over the last decade. Later, computer simulation models have become useful tools in understanding the transport of nitrates through soil into groundwater. There has been a large growth in the number of computer simulation models and their use to predict nitrate leaching losses through the root zone and in the underlying unsaturated soil zone (Molina & Richards, 1984; Addiscott *et al*., 1986; Barraclough, 1989 a,b; Hutson & Wagenet, 1992; Bergstrom *et al*., 1991; & Jarvis *et al*., 1991).

LEACHM-N (**L**eaching **E**stimation **A**nd **CH**emistry **M**odel), (Hutson & Wagenet, 1992) is one of the widely used models to simulate field scale N transformations and movement in the unsaturated zone of the soil profile (Addiscott & Whitmore, 1987).

Consideration of the environmental impact of agriculture in sandy regosols of Batticaloa has been limited due to lack of information on the effects of nitrate leaching into groundwater. Hence, 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 investigate the performance of LEACHM-N in simulating nitrate leaching under different fertilizer and irrigation combinations. The outputs of the model were evaluated against observed data from field experiments carried out in Batticaloa during the *Yala* season.

METHODOLOGY

The field experiments were conducted in Yala 2005, at Ramakrishna mission, in Batticaloa. The experimental site was located around 2.5 km on the south of Batticaloa town (latitude 7° 43' N, longitude 81° 42'E). The area is flat and low lying with an elevation of 7.8 m from mean sea level.

Experimental design and layout

The treatments were arranged in a split plot design with nine treatments in 3 replicates. The experimental treatments were 3 nitrogen rates (referred to as 0, 70 and 140 kg N/ha) together with 3 irrigation rates (referred to as 7 mm/day, 14 mm/day and 30 mm/day). The recommended total water requirement and fertilizer application rate for onion is 70 kg N/ha and 7 mm/day respectively (Techno Guide, Department of Agriculture, 1998), Hence, to study the effect of fertilization on nitrate leaching, a controlled fertilizer application (0 kg N /ha) and a doubled recommended rate (140 kg N/ha) of fertilizer application were considered together with the recommended fertilizer application rate (70 kg N/ha). Similarly, to study the effect of depth of irrigation on nitrate leaching, a doubled recommended rate (14 mm/day) of irrigation as well as an increased depth of irrigation (30 mm/day) was considered together with the recommended crop water requirement (7 mm/day). The irrigation treatments were assigned as main plot factor, whereas the fertilizer treatments were assigned as sub plot factor.

Preparation of lysimeters

Twenty seven lysimeters were prepared using plastic (50 cm diameter and 100 cm height) barrels. A sloped concrete base was laid at the bottom of each lysimeters to facilitate the percolating water to move towards the exit hole of outlet pipe. A 1 mm wire mesh was fixed at the inner opening of the pipe, which was again covered with nylon net to prevent the soil particles from moving with the leachate and draining into the collection vessel. The bases of the lysimeters were covered with a 3 cm layer of crushed granite rock (coarser particles), followed by which a 2 cm layer of chips (finer particles) before the soil was filled, which reduced the effective depth of the lysimeters to 95 cm.

Lysimeter installations

The soil was excavated for 1.1 m depth and the plastic barrels were placed. The soil was packed into the barrel to original bulk density of 1.6 g cm^{-3}. The soil surface of each lysimeter was kept levelled. The outlets of each lysimeter barrels were extended by buried PVC pipes (1.25 cm diameter) to the sampling point to collect the leachate. The pipes were laid at a slope of approximately 8-10% to ensure rapid water flow into sampling chambers. Water was added to the lysimeter and the smooth drainage at the outlet was confirmed. All the outlets pipes were labelled to identify the respective lysimeter.

Irrigation

Water was delivered using a micro sprinkler system, pumped from a well adjacent to the experimental site throughout the cropping season with a 30 mm h^{-1} delivery rate. According to the irrigation treatments, the duration of irrigation was manipulated to apply the required amount of water.

Planting

Red onion (*Allium cepa*; var. Vethalan) was planted on 12th April 2005 in Yala. The bulbs were soaked in a fungicide (Homai) before planting.

Fertilization

Nitrogen was applied according to the treatments in the form of $(NH_4)_2SO_4$ (21% N) and urea (46% N). Nitrogen was applied 3 times during the cropping season. Control plots received no N fertilizer.

Collection and analysis of leachate and irrigation water

Leachate samples from individual outlets were collected continuously using plastic buckets and the total volume was measured. Leachate samples were obtained from 3-4 days intervals for NO_3^--N analysis by pooling sub-samples of 100 ml collected every day, which represented composite samples of the leachate that had drained during 3-4 days. Irrigation water was sampled weekly from the well during the cropping season. NO_3^--N in the leachate as well as in the well water were determined spectrophotometrically by the Cadmium Reduction Method (Keeny & Nelson, 1982) using DR/HACH 2010 spectrophotometer, at the Eastern University, Batticaloa.

Input Data to LEACHM-N

The LEACHM-N required a variety of input data on soil physical, hydraulic and chemical characteristics, soil N transformation constants, weather, environmental and crop management data of the simulation site. Important soil properties in characterizing nitrate leaching were determined in the laboratory, for which soil was sampled at 10 cm increments up to a 50 cm depth. Important soil properties in characterizing nitrate leaching were determined in the laboratory using the methods given in Table 1.

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

Soil properties	**Method of analysis**	**Reference**
1. Saturated hydraulic conductivity	Constant head	Klute & Dirksen, 1986
2. Bulk density	Core sampler	Blake & Hartge, 1986a
3. Particle density	Pycnometer	Blake & Hartge, 1986b
4. Porosity	Calculated from 2&3	-
5. Particle size distribution	Hydrometer	Sheldrick & Wang, 1993
6. Organic matter content	Walky –Black	Nelson & Sommers, 1982

All model input values except those measured in the laboratory were obtained from published sources. Daily pan evaporation was recorded using the evaporation pan at the study site. Daily maximum and minimum air temperature data were obtained at the nearby meteorological station in Batticaloa. The LEACHM-N data files require weekly totals of potential evapotranspiration. The stand-alone weather data utility processes daily rain, temperature and pan evaporation data and has options for predicting potential evapotranspiration.

Simulations of nitrate leaching for the field experiments

LEACHM-N was executed for the cropping season with the simulation period beginning from 12th April 2005 to 30th June 2005. Irrigation was stopped two weeks before harvesting. The simulated mass of NO_3^--N leached from LEACHM-N was compared with the mean of the 3 replications of measured NO_3^--N for each treatment throughout the cropping season. The simulated soil profile was equally divided into 20 horizontal segments and NO_3^--N leaching was simulated at a depth of 1.0 m having 5 cm segment thickness. The upper boundary condition of the simulated system was considered as a flux controlled surface boundary during the period of evaporation and non-ponded infiltration. The pressure potential of the first node was set to zero. A lysimeter condition was used in the lower boundary condition of the simulated profile given the absence of water table at the simulated depth. The profile was assumed to have moisture content close to field capacity. A growing onion crop was assumed to be present throughout the simulation period and with a crop cover fraction of 0.8.

Calibration of LEACHM-N

Column leaching experiments were conducted to calibrate LEACHM-N. Calibration is the process of adjusting the model parameters within an accepted range to minimize the difference between predicted and observed values. This method assumes that some of the input parameters would apply for the field validation of the model. In applying LEACHM-N to simulate the NO_3^--N loss in column leaching experiments, mainly the soil dispersivity was adjusted to match the NO_3^--N losses from the columns with measured losses.

RESULTS AND DISCUSSION

The test of statistical approaches such as correlation coefficient *(r)*, mean difference (M_d), root mean square error (RMSE) and error % (Er%) were considered in determining the simulation accuracy. There was a lower degree of association between simulated and measured NO_3^--N losses obtained in *Yala* 2005. However, Bawatharani *et al.* (2009a) observed a good agreement in between the measured and the simulated NO_3^--N losses across the fertilizer irrigation treatments in *Maha* 2004. Even though LEACHM- N model did not meet the statistical criteria in most cases, statistically significant *r* values were obtained. The *r* values ranged from 0.73-0.99 (Table 2) indicating a good agreement between simulated and observed data. Nevertheless, the *r* values solely are not sufficient to determine the accuracy of simulations. Non-significant slope and intercept error terms were also observed.

The slope and intercept of regression lines were used to fit the simulated values to the measured values. However, the regression analysis reflected lower degrees of association between simulated and measured values for most of the treatments as indicated by their slope and intercept values which are significantly different from 1 and 0 respectively (Table 2).

Table 2 : Statistical e valuation of simulated NO_3-N losses by LEACHM-N from different treatments

Treatment combination		*r*	*Er%*	$*M_d$	*RMSE*	*Slope*	*Intercept*
Irrigation (mm)	Fertilizer (kg N/ha)						
7	0	0.73	-4.54	-0.06^{ns}	0.2	1.4^{*}	-0.6^{*}
7	70	0.86^{*}	-9.62	-0.51	1.03	2.4^{*}	-3.0^{*}
7	140	0.74^{*}	-10.96	-0.96	2.04	2.2^{*}	-5.0^{*}
14	0	0.95^{**}	-1.79	-0.2^{ns}	0.63	1.4^{*}	-3.5^{*}
14	70	0.94^{**}	-0.1	-0.05^{ns}	2.4	1.04^{*}	-11.2^{*}
14	140	0.95^{**}	-2.88	-1.55^{ns}	3.78	1.6^{*}	-17.7^{*}
30	0	0.98^{**}	-7.04	-1.31	1.74	2.8^{*}	-3.3^{*}
30	70	0.98^{**}	-0.6	0.51^{ns}	3.68	1.2^{*}	-15.7^{*}
30	140	0.99^{**}	-0.91	1.13^{ns}	4.77	1.2^{*}	-19.2^{*}

* Significant (P<0.05) differences between predicted and observed data, or significant correlation coefficient or slope estimates or intercepts significantly different from 1.0 and 0.0 respectively.

^{ns} M_d was not significantly different from zero ($P \leq 0.05$).

Non significant mean differences were found in between the simulated and the observed values for treatment combinations such as 14 mm/70 N, 14 mm/140 N, 30 mm/70 N, 30 mm/140 N, 7 mm/0 N and 14 mm/0 N treatments, indicating better simulation accuracy. These treatments were significantly correlated with each other. LEACHM-N did not simulate the measured NO_3^--N leached from 7 mm/70 N, 7 mm/140 N and 30 mm/0 N treatments in *Yala* as indicated by their M_d values that are significantly different from zero.

The negative sign of M_d, and large negative Er% values show that LEACHM-N over estimated the leaching losses of NO_3^--N in all the treatments. The model however, under-estimated the losses of NO_3^--N except the losses in the control treatments in *Maha* 2004 (Bawatharani *et al*., 2009a). The problem of over-estimation of losses in between the observed and the predicted losses in *Yala* 2005 is mainly due to the over-estimation of the drainage losses of water by LEACHM-N. LEACHM-N over-estimated the leachate volume in *Yala* 2005, as 46.0 mm vs 388.2 mm for 7 mm irrigation, 522.8 mm vs

808.7 mm for 14 mm irrigation and 1286.4 mm vs 1784 mm for 30 mm irrigation treatments which in turn over-estimated the NO_3^--N losses. Therefore LEACHM-N did not respond well in *Yala* 2005 on NO_3^--N leaching losses in leachate. However, this simulation trend resulted in a reasonably good agreement of NO_3^--N losses for only in 14 *mm* and 30 *mm* irrigation treatments due to a reasonable agreement in the simulation of drainage volume of water.

Further, the most obvious reported cause of the simulation error in the validation process is that the LEACHM- N model did not adequately simulate macro pore influenced water flow in the well structured soil. This inability to simulate macro pore flow resulted in an over estimation of the amount of NO_3^--N leached from the soil profile (Jabro *et al*., 1995; Dodds *et al*., 1998) as shown in Figure 1 and treatment combinations where M_d is negative and significantly different from zero (Table 2). Preferential flow would be an important phenomenon, under which soil has layering, cracks and fissures as a result of the presence of shrinking and swelling clay, natural soil pipes and dead plant roots and residues (Hillel, 1998). In case of sandy regosols preferential flow provides a mechanism to bypass most of the porous media and it causes enhanced solute transport and fast travel.

In these cases, it is speculated that NO_3^--N was stored in the micro pore system and that percolating water bypassed this NO_3^--N. However, Paramasivam *et al*. (2002) reported that preferential flow factors are unlikely to be present under a structureless homogeneous sandy soil (>96% sand) and not expected that it could play a dominant role in water and solute movement in extremely sandy soils. Selker *et al.* (1992a) reported that preferential flow had been observed in uniform soils with uniform rainfall and low water application rates.

Jemison (1991) observed similar modelling inaccuracies. The total NO_3^--N loss in leachate in model simulation agreed well with the measured value although the time taken to travel the NO_3^--N to the bottom of the lysimeter was greater (7 days) in LEACHM- N simulation. The inability of LEACHM-N to detect immediate loss of NO_3^--N after the fertilizer application is expected to be due to the inability to account for preferential flow due to macropores (Dodds *et al.*, 1998).

Bawatharani *et al.* (2009b) found that the model (LEACHM-N) accurately predicted the NO_3^--N losses at lower depths and at increased depth of irrigation during the column leaching studies.

LEACHM-N has simulated considerably higher NO_3^--N losses at the end of the cropping season in *Yala* 2005 (Fig. 1). However, by the end the growing period, as the N uptake completes, the model is expected to predict lower NO_3^--N losses. The problem of this over-estimation of leaching losses is intensified under-estimated N uptake (zero throughout the cropping season) (Jemison, 1991). This is because the plant growth module in LEACHM-N was not adequately calibrated with the data obtained from the column studies as there was no plant growth in the columns. This effect might have also created the discrepancies between measured and simulated mass of NO_3^--N in both seasons, but this effect is apparent in *Yala* 2005. Therefore, simulation of LEACHM-N can be considered as moderately successful in *Yala* 2005. Hence, uses of several statistical approaches are needed to determine the modelling accuracy further.

Validation of LEACHM-N

Validating LEACHM-N using data obtained during *Maha* 2004 with the same treatment combinations as used in *Yala* 2005 indicated that the overall agreements between measured and LEACHM-N simulations during *Maha* 2004 were acceptable (Bawatharani *et al.,* 2009a). A good agreement was observed in between the measured and the simulated NO_3^--N losses across the fertilizer irrigation treatments. Non-significant mean differences were found in between the simulated and the observed values for all the treatment combinations indicating better simulation accuracy. The model however, under-estimated the losses of NO_3^--N except the losses in the control treatments where it overestimated the losses.

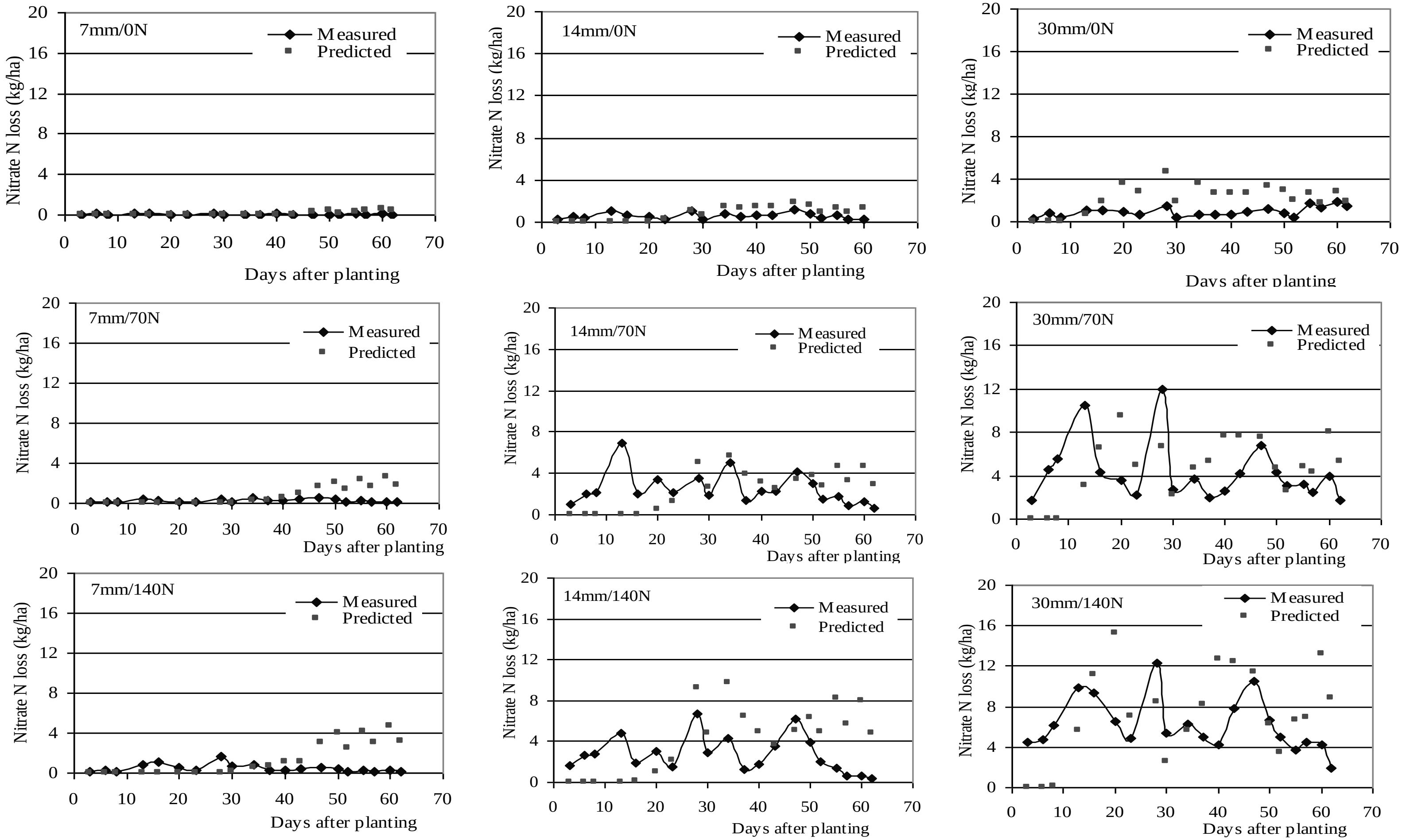

Figure 1. LEACHM-N simulated vs measured NO_3^--N losses from the lysimeters at different treatment combinations in *Yala* 200F5.

Evaluation of LEACHM-N

The model was calibrated to a certain extent using the data obtained from the column leaching experiments, where the real environmental conditions and variations were in a controlled condition. Further, apart from dispersivity and water retention parameters, LEACHM-N was used in an uncalibrated manner. i.e., other parameters were not selected by determining which parameter values gave the good agreement between the observed and the predicted data. This has incorporated more environmental variation and possibly less accuracy. When the input parameters which were used in the calibration process were used in the field experiments, it will result poor modelling accuracies. This is a most possible reason for modelling inaccuracies found during the field experiments. Therefore, it is suggested to calibrate the model with field data obtained for a certain year and to validate it independently.

CONCLUSIONS AND RECOMMENDATIONS

LEACHM-N tended to over-estimate leaching in *Yala* 2005. Based on the simulation results obtained in *Yala* 2005, LEACHM-N was found to be unable to predict preferential flow of water. The simulation results of the treatment 30 mm/140 kg N/ha showed best simulation accuracy in *Yala* 2005. Based on the statistical criteria, the overall performance of LEACHM-N was effective in simulating NO_3^--N leaching losses in sandy regosol in *Yala*. It is recommended to calibrate the model with field data obtained for a particular year and to use input data, which are site specific, so that the modelling accuracies could be improved further.

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