AGRIEAST 2010 (9) P.17-27

Seasonal variation of leaching of nitrate under onion cultivation in sandy regosols and its predictions by LEACHM-N

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

[1]*Department of Agricultural Engineering, Faculty of Agriculture, Eastern University, Sri Lanka*
[2]*Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Sri Lanka*
[3]*Environmental Studies Program, University of Winnipeg, Manitoba, Canada*

ABSTRACT

An investigation was carried out with an objective to find out the seasonal variation of nitrate concentration due to different fertilizer and irrigation application rates for onion cultivation in sandy regosol. Field experiments were conducted in Batticaloa, during Maha 2004 and Yala 2005, using the 3 nitrogen rates (0, 70 and 140 kg N/ha) together with 3 irrigation rates (7, 14 and 30 mm). Twenty seven (27) cylindrical lysimeters were built in at the experimental site and red onion (Allium cepa; var. Vethalan) was planted in the lysimeters and irrigated using a micro sprinkler system with a delivery rate of 30 mmhr^{-1}. Nitrate-N concentration in the leachate were determined colorimetrically by the Cadmium reduction method. A field scale mathematical model, LEACHM-N, was used to simulate the concentration of Nitrate-N in the leachate in both seasons. The Nitrate-N concentration during Yala 2005 showed a clear trend and exceeded the maximum permissible limit of 10 mg/l which were found to be higher than the concentrations observed during Maha 2004. Peak Nitrate-N concentration occurred 8-14 days following a fertilizer application in the fertilized treatments in Yala 2005, which could be comparable with the time of peak concentration during Maha 2004 where the peak was observed 9-13 days after 1st top dressing. Statistical analysis indicated that LEACHM-N simulated the Nitrate-N concentrations reasonably well in Maha than in Yala.

Keywords: LEACHM-N, leachate, lysimeter, leaching, sandy regosols

Introduction

Nitrogen loss from the field and the threat of groundwater contamination increase under irrigation on sandy soils because the nitrate as a mobile contaminant is more easily leached through sandy soils, compounded with excess water applications. In addition to this, nitrate leaching typically occurs when fertilizer application rates exceed crop nitrogen requirements (Roth and fox, 1990; Jokela, 1992; Guillard *et al*., 1995). Thus, minimizing the nitrogen fertilizer losses from the crop fields is a great concern in view of increasing fertilizer use efficiency and reducing groundwater contamination.

Higher level of NO_3^- in water is unsafe for drinking as the Nitrate-Nitrogen concentration in drinking water above Maximum Contaminant Level (MCL) of 10 mg/l causes serious health threat to infants and adults (Salley, 1992). The most familiar problem associated with elevated levels of nitrate is methemoglobinemia, or "blue baby syndrome". Many studies in Sri Lanka have reported high nitrate concentrations in water, which had been attributed to intensive use of fertilizers on highly permeable soils (Kuruppuarachchi *et al*., 1995). Therefore an understanding of the movement and transport of NO_3^- and quantifying the concentration of nitrate beyond the root zone is very important to avoid the ground water contamination.

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). In recent years, development and application of models to simulate field scale N transformations and movement in the unsaturated zone of the soil profile (Dodds *et al.*, 1998; Ramos and Carbonell, 1991; Bergstrom and Jarvis, 1991, Addiscott and Whitmore, 1987).

As the coastal regions of Batticaloa consists of *sandy regosols* where intensive cultivation is being carried out with the application of excessive inorganic fertilizer and irrigation, the application of LEACHM-N would be useful for predicting the nitrate contamination in groundwater to represent the natural system, and to use it in an objective manner to guide both the future research efforts and current management practices. Therefore the objective of this study was to determine the nitrate nitrogen concentrations in groundwater at selected levels of fertilizer and water application rates.

Materials and Methods

The field experiments were conducted in *Maha* 2004 and *Yala* 2005, at Ramakrishna mission, in Batticaloa. The experimental site is located around 2.5 km on the South of Batticaloa town (latitude 71 43’ N, longitude 81'1 42’ E). The area is flat and low lying with an elevation of 7.8m from mean sea level.

1. 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, 14 mm and 30 mm). The irrigation treatments were assigned as main plot factor, whereas the fertilizer treatments were assigned as sub plot factor.

2. Preparation of lysimeters

Twenty seven (27) lysimeters were prepared using plastic (50 cm diameter and 100cm 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 1mm 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 base 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.

3. 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 gcm^{-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 points. Water was applied to the lysimeter and the smooth drainage at the outlet was confirmed. All the outlets pipes were labeled to identify the respective lysimeter.

4. 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 mmhr-1 delivery rate. Three levels of irrigation treatments such as 7, 14 and 30 mm were applied. According to the irrigation treatments, the duration of irrigation was manipulated to apply the required amount of water. Irrigation was not prescribed when there was heavy rain.

5.Planting

Red onion (*Allium cepa*; var. Vethalan) was planted on 12th October, 2004 in *Maha* and12th April, 2005 in yala. The bulbs were soaked in a fungicide (Homai) before planiting.-

6.Fertilization

The fertilization treatments were 3 nitrogen rates, referred to as 0, 70 and 140 kg N/ha. 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.

7.Experimental design

The treatments were arranged in 3x3 split plot design in which the irrigation treatments were assigned as the main plot whereas the nitorgen application rates were assigned as the sub plots.

8.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 Nitrate-N analysis by pooling sub-samples of 100ml 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.

NitrateE-N in the leachate as well as in the well water were determined colorimetrically by the Cadmium Reduction Method (Keeny and Nelson, 1982) using DR/HACH 2010 spectrophotometer, at the Eastern University, Batticaloa.

9.Input Data to LEACHM-N

Soil data

The LEACHM-N required a variety of input data for 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 in 10cm increments up to 50 cm depth (Table 1).

Table 1. Measured soil properties of sandy *regosols*

Soil depth (cm)	Sand %	Silt %	Clay%	Buld density (g/cm3)	Ks (cm/hr)	Porosity	Organic carbon %
0-10	97.6	1.1	1.3	1.5	89.3	0.43	0.08
10-20	98.3	0.4	1.2	1.6	90.4	0.40	0.12
20-30	98.8	0.1	1.1	1.6	96.7	0.40	0.001
30-40	99.3	0.1	0.6	1.6	89.8	0.38	0.0
40-50	99.4	0.1	0.5	1.6	92.4	0.38	0.0

Crop factor

Onion root distribution in each soil layer was obtained from direct observation of the roots in the field. It was observed that about 90% of the roots were found in the top 5cm and the remaining 10% of the roots were distributed within 10 cm. A growing onion crop was assumed to be present throughout the simulation period and with a crop cover fraction of 0.8 (fraction of land covered by the crop).

Weather Data

Daily potential evapo-transpiration was recorded using the evaporation pan at the study site. Daily maximum and minimum air temperatures and rainfall data were obtained at the nearby Meteoro logical station in Batticaloa. Daily potential evapo-transpiration data were summed to calculate a weekly total potential evapo-transpiration as required by LEACHM-N.

Other input data

Other input values were obtained from published sources (Table 2).

Table 2: LEACHM-N input parameter values used to simulate leaching during the field experiments

Model parameters	Values	Reference
Partition coefficient, L kg^{-1}:		Clothier *et al.* (1988)
NH_4^+-N	2.6	
Nitrate-N	0.0	
Molecular diffusion coefficient in water, mm^2 d^{-1}	120.0	Hutson and Wagenet (1992)
Synthesis efficiency factor	0.5	Johnson *et al.* (1987)
Humification fraction	0.2	Johnson *et al.* (1987)
C to N ratio	10.0	Stevenson (1982)
Minimum metric potential for transformation	-1500.0	Hutson and Wagenet (1992)
Mineralization rate constants, d-^{1}:		Clark (1994)
Litter N	0.01	
Manure N	0.02	
Humus N	0.00007	
Other constants d-^{1}:		
Denitrification	0.001	Clark (1994)
Nitrification	0.02	
Amonia volatilization	0.6	Hutson and Wagenet (1992)
Denitrification half saturation constant, mgL^{-1}	10.0	Hutson and Wagenet (1992)
Limiting NO_3^- to NH_4^+ ratio in solution for nitrification	8.0	Hutson and Wagenet (1992)

10. Simulation of nitrate leaching for the field experiments

LEACHM-N was executed for the cropping season with the simulation period beginning from October 12th 2004 to November 10th 2004 and from April 12th 2005 to June 30th 2005. The simulated concentration of Nitrate-N from LEACHM-N was compared with the mean of the 3 replications of measured Nitrate-N for each treatment throughout the cropping season. The simulated soil profile was equally divided into 20 horizontal segments and nitrate 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.

11. Calibration of LEACHM-N

Column leaching experiments had been 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.

Results and Discussion

1. Measured Temporal Changes in NO_3^- - N Concentrations

Nitrate-N concentrations in leachate exhibited a strong seasonal pattern. The earlier peak of Nitrate-N in leachate occurred at 30mm of irrigation in the N fertilized treatments in both seasons. As expected, Nitrate-N concentrations in leachates were consistently low (10 mgl^{-1}) from all the treatments in *Maha*. But the concentrations were slightly higher than the control during this period. During the first two weeks of the study, Nitrate-N in leachates rose for all treatments and had 2 distinct peaks. The Nitrate-N concentration from 7mm/140N treatment reached a maximum of 11.67 mg Nitrate-N/l, while other treatment concentrations reached values below the MCL of 10 mg Nitrate-N/l during *Maha*.

The nitrate N concentrations during *Yala* showed clear trend and exceeded the maximum permissible limit of 10mg Nitrate-N/l in the fertilized treatments. All the treatments resulted in 3 peaks, which varied with respect to the rate of fertilizer application and the rate of irrigation. At each N fertilizer treatment, the peak concentration reduced with the increase in irrigation rate. These concentrations during this period were found to be higher than the concentrations observed during *Maha*. The highest concentration of 42.5 mg/l was observed at 140 kg N/ha of fertilizer application at 7 mm of irrigation. Nitrate-N concentrations at 0 kg N/ha at all irrigation rates were below 10 mg Nitrate -N/l.

The trend in Nitrate-N concentrations clearly showed the effect of rainfall during *Maha*. In the N fertilized treatments maximum peak concentrations occurred 8-16 days after planting. The N fertilized treatments resulted in an unclear peak flux of Nitrate-N during the latter part of the growing season in *Yala*. This could be due to the induced volatilization loss of the applied fertilizer as a result of the increased temperatures (»31°C) prevailed during May 2005. The control treatments at all the 3 irrigation levels did not show any clear peak fluxes and the effect of irrigation on Nitrate-N concentration was non-significant (P = 0.079).

The plots received about 368.6mm rainfall and about 91, 182 and 273mm of irrigation according to the irrigation treatments (7 mm, 14 mm and 30 mm) during the first 21 days following basal application in *Maha* 2004. The Nitrate-N concentrations increased up to first 10 days and had a mild peak at the 14th day after planting in both of the N fertilized treatments, which were substantially lower when compared to the peak concentrations observed during *Yala* for the same treatments. This was due to the period of relatively high intensity rainfall during 3-20 days after basal fertilizer application, which moved Nitrate-N rapidly through the lysimeters and diluted the Nitrate-N concentrations as well. Comparatively little amount of precipitation received during the first 3 days after 1st top dressing (1st top dressing was done 3 weeks after planting) was accounted for 83mm and with the absence of irrigation, a slight increase in the Nitrate-N concentrations of leachates in all the treatments were observed. Thus the Nitrate-N concentrations increased in a decreasing trend in the subsequent days and did not result in any prominent peaks. This trend in Nitrate-N concentrations followed by the 1st top dressing were unlikely to be measured continuously, due to the interruption in sample collection as a result of high precipitation.

The Nitrate- N concentrations were higher and became concentrated during *Yala*. This clearly reflected the effect of fertilizer application during this period. Both N fertilized treatments exceeded the MCL limit of 10 mg/l several times during this period. The 140 kg N/ha treatment resulted in maximum leachate concentrations which were greater than those observed for the 70 kg N/ha treatment at all the 3 irrigation levels. The 140 kg N/ha treatment Nitrate-N leachate concentrations reached 42.5mg/l while 70 N only reached a maximum of 20.4 mg/l at 7mm of irrigation. However no significant differences (P=0.05) existed among the N concentrations of leachates from 0N treatment at all the 3 irrigation rates.

Following basal application, the concentrations showed an increasing trend up to 13 days and decreasing during the next 14-21 days after planting, during which period the concentrations were in the range of 4.7-9.7 mg Nitrate-N /l across all the 3 irrigation levels when the fertilizer application was 70 kg N/ha in *Maha*. The same trend was observed when the fertilizer application was doubled but the concentrations were in the range of 8.6-13.9 mg Nitrate-N /l. The same trend in concentration pattern was observed following 1st and 2nd topdressings in *Yala*. From these observations it is clearly shown that the maximum peak concentrations occur in between 9-13 days after a fertilizer application in the N fertilized treatments in *sandy regosols*, which is comparable with the time of peak during *Maha*, where the peak was observed almost at the 14th day of planting.

Increased Nitrate-N concentrations *Yala*, may be due to very little precipitation received, which delayed the Nitrate-N movement though the soil profile. As a result of crop growth in lysimeters with fertilizers, the leaching loss of water further reduced. Therefore water percolation as a fraction of total supply was lower in *Yala* due to high rates of evaporation and transpiration (Kendaragama and Jayakody, 1989). All these factors contributed to the increased concentrations for Nitrate-N in the leachates.

2. Mass of nitrate N in the leachate

Nitrate N leaching losses from the lysimeters amended with different rates of fertilizer and irrigation were significantly higher ($P<0.05$) than from the control treatments. Comparatively higher amount of nitrate N was leached from the 140 kg N/ha treatment than the 70 kg N/ha treatment. The Table 3 shows the amount of nitrate N lost at different treatment combinations during *Maha* 2004 and *Yala* 2005.

Paramasivam *et al.* (2002) reported that mineralized N could affect the distribution patternof nitrate N in the soil profile and leaching, althoughthe contribution may vary with time since the mineralization process is affected by various factors in the soil environment. Therefore, the higher leaching losses in *Yala* 2005 could be attributed to the addition from the mineralization process where the conditions were favourable for the nitrification process. Lower percentage of losses in *Maha* 2004 indicates the effect of denitrification as the water table was closer to the surface during this period as reported by Astakie *et al.*, 2001.

Simulation of Nitrate-N leaching using LEACHM-N

LEACHM-N was executed for *Maha* 2004 from October-November and for *Yala* 2005, from April-June.

Simulated concentrations of Nitrate-N from each treatment were compared with the mean of the 3 replications of measured Nitrate-N concentrations in both seasons. Comparison of Measured and Predicted Nitrate-N concentrations are presented in Figures 7 and 8. LEACHM-N did not accurately predict Nitrate-N concentrations in *Yala*, while it produced satisfactory predictions in *Maha*, as indicated by their significant correlation coefficient values (Table 4) for most of the treatment combinations. The test of other statistical approaches such as slope and intercept of the 1:1 line, and mean differences did not provide non-significant values, so that the correlation coefficient (r) and Error percent (Er %) were only considered in determining the simulation accuracy. The *r* values were highly significant except the *r* values obtained in 30mm/70N, 7mm/0N and 30mm/0N treatment combinations (Table 3). Further the Er% and Root Mean Square Error (RMSE) values were also found to be lower for all the treatments, which indicate better simulation accuracy.

Table 3. Measured leaching losses of nitrate N from different treatments

Treatment combination	Percentage losses	
	Maha 2004	*Yala* 2005
7mm/0 kg N/ha	-	-
14mm/0 kg N/ha	-	-
30mm/0 kg N/ha	-	-
7mm/70 kg N/ha	43.8	5.7
14mm/70 kg N/ha	44.7	53.8
30mm/70 kg N/ha	43.8	95.1
7mm/140 kg N/ha	40.7	5.3
14mm/140 kg N/ha	40.9	30.3
30mm/140 kg N/ha	41.3	74.8

The RMSE values were found to be higher when compared to the values obtained in *Maha*. Even though there were poor simulation results for Nitrate-N concentrations in *Yala*, it produced Er%< [25]. However, large deviations occurred in between measured and simulated Nitrate-N concentrations for some of the treatments (Figures8g and 8i) and LEACHM-N failed to meet more of the evaluation criteria for these treatments (Table 3).

Jemison and Fox (1994) found that LEACHM-N predicted the Nitrate-N concentrations fairly well when the rate constants were calibrated for each year. Therefore calibration of the model for *Maha* and *Yala* separately could have resulted in better simulations.

Table 4. Statistical evaluation of simulated NITRATE-N concentrations by LEACHM-N from different treatments

Treatment combination		r	Er%	*M_d	RMSE	Slope	Intercept
Irrigation (mm)	Fertilizer (Kg N/ha)						
				Maha 2004			
7	0	0.64	-5.90	-0.34	0.83	7.24	-4.01
7	70	0.82*	7.80	2.28*	2.51	0.52*	-0.54
7	140	0.92**	9.20	4.60*	4.9	0.48*	-1.41*
14	0	0.90*	-5.80	-0.30	0.79	12.4*	-7.50*
14	70	0.91**	6.58	1.70*	1.77	0.89*	-1.36*
14	140	0.81*	7.80	3.30*	3.74*	0.47*	-0.58*
30	0	0.67	-15.10	-0.66*	0.87	4.60	-1.30
30	70	0.44	3.60	0.78	1.18	0.58	0.32
30	140	0.87**	6.20	2.06*	2.2	0.67*	-0.71
				Yala 2005			
7	0	0.08	1.50	0.90*	1.7	0.20	1.40
7	70	0.54*	0.74	1.70	5.09	0.54	3.60
7	140	0.09	-0.007	-0.02	12.9	0.08	16.30*
14	0	0.26	-0.50	-0.24	1.1	0.40	1.50
14	70	0.20	1.20	2.10*	3.8	0.20	4.70*
14	140	-0.20	-0.50	-1.02	6.5	-0.20	12.90*
30	0	0.72*	2.80	0.92*	1.1	0.98	-0.89*
30	70	-0.31	1.54	1.90*	4.11	-0.20	6.00*
30	140	-0.05	1.71	3.20*	5.1	-0.06	6.90*

* 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. ** Highly significant ($P<0.01$).

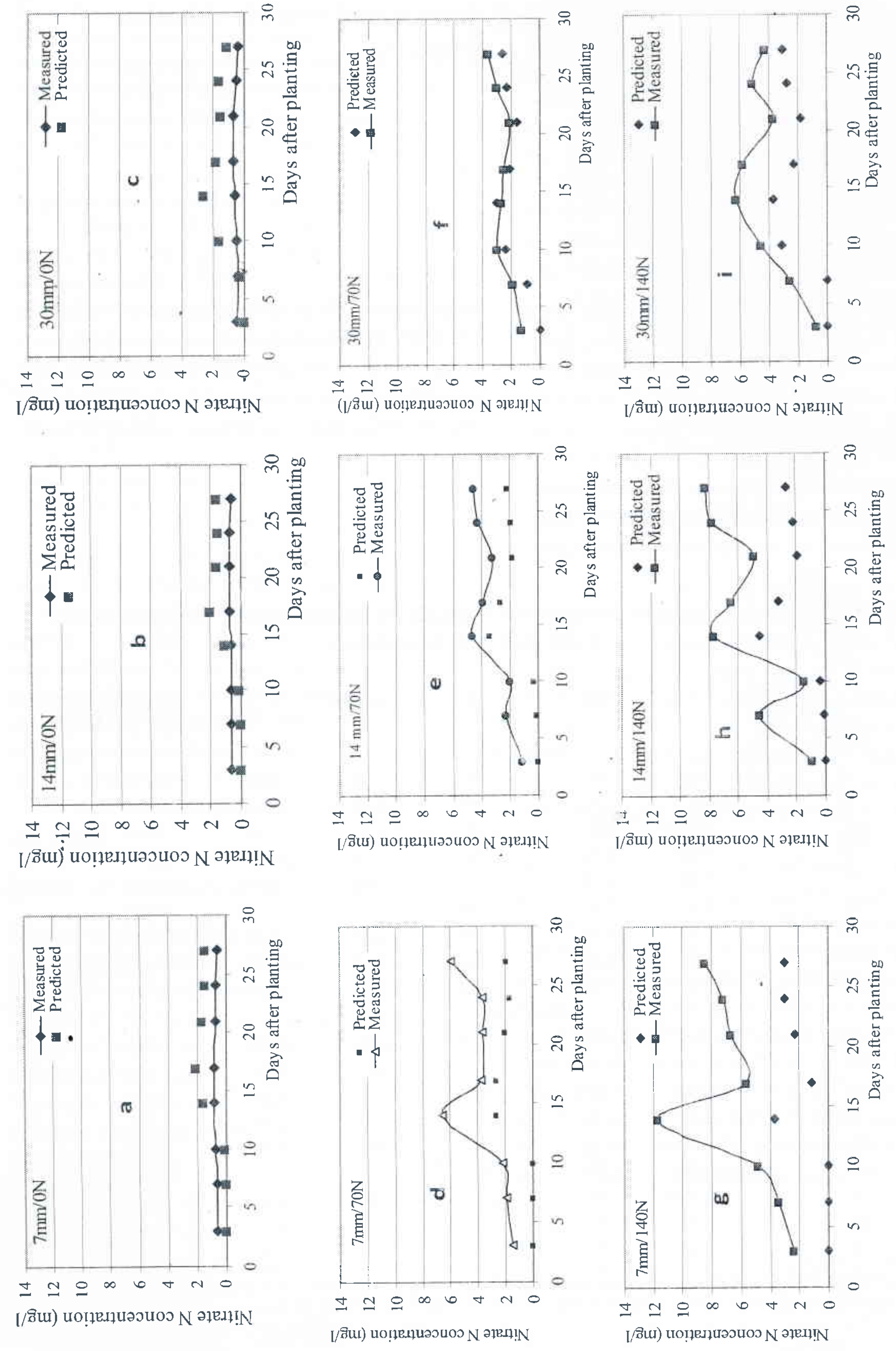

Fig 7. LEACHM-N predicted vs measured NO_3^- - N concentrations from the lysimeters at different treatment combinations in *Maha* 2004

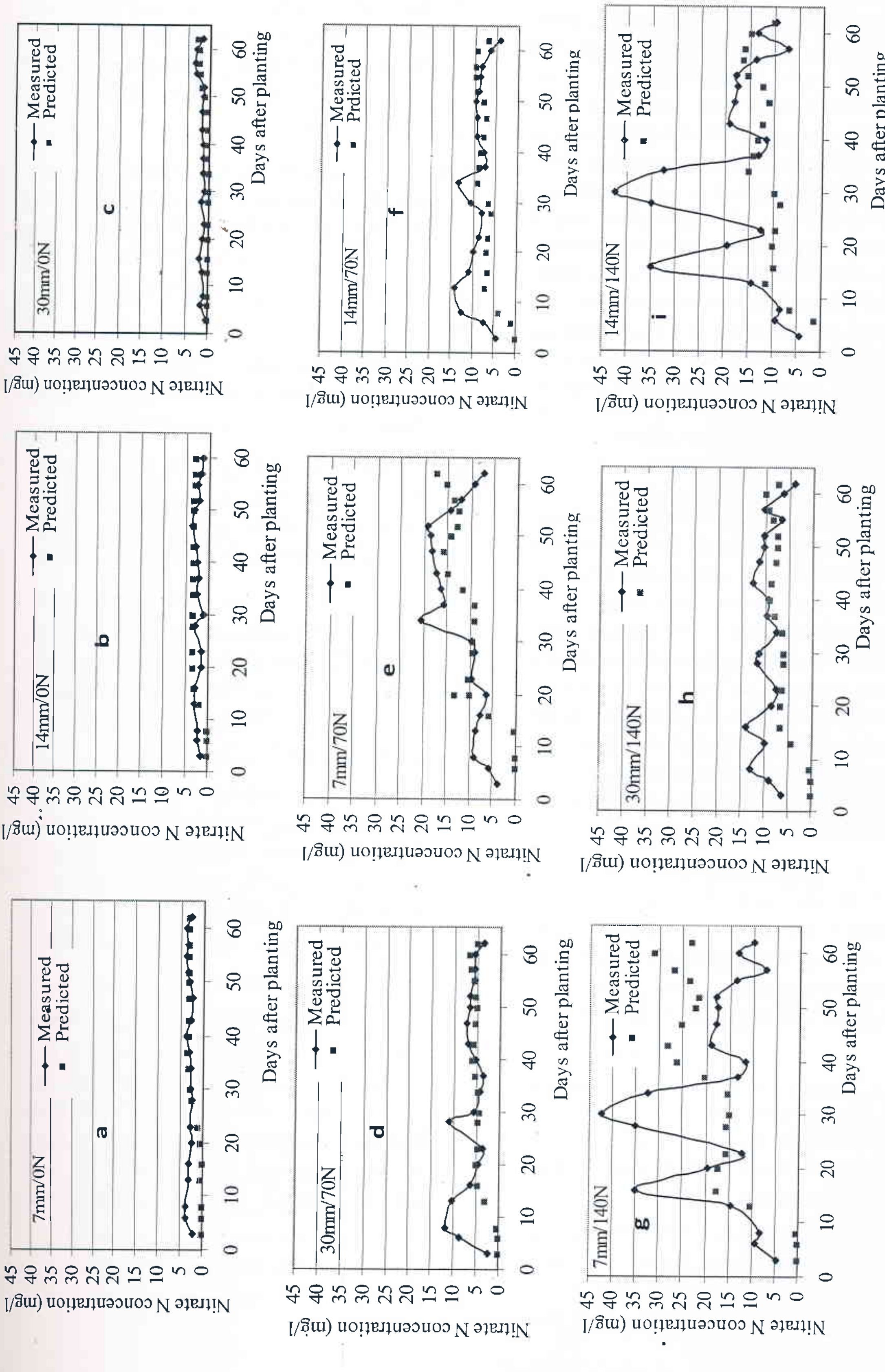

Fig 8 LEACHM-N predicted vs measured NO_3^- - N concentrations from the lysimeters at different treatment combinations in *Yala* 2005

Conclusions

These concentrations Nitrate-N during *Yala* were found to be higher than the concentrations observed during *Maha* in the leachates. The Nitrate-N concentrations were lower than the MCL limit of 10 mg/l in *Maha* where as it exceeded the MCL several times during *Yala*. Maximum peak Nitrate-N concentrations occurred approximately 1-2 weeks (8-14 days) after a fertilizer application in both seasons. Statistical analysis indicated that the LEACHM-N simulated the Nitrate-N concentrations reasonably well in *Maha* than in Y*ala*. Based on the statistical criteria the overall performance of LEACHM-N was better in simulating Nitrate-N leaching in *sandy regosols*.

Recommendations

Frequent small doses of N-fertilizer application are recommended in *sandy regosols* during *Maha* to avoid high Nitrate-N concentrations in groundwater due to heavy leaching. 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. It can be concluded that in extremely sandy soils, leaching losses of Nitrate-N and groundwater contamination due to Nitrate-N could be minimized by using LEACHM-N as a decision making tool.

References

Addiscott, T.M. and A.P. Whitmore (1987). Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. *Journal of Agricultural Science Cambodia* 109:141-157.

Astakie, T., A. Madani., R. Gordon., K. Caldwell and N. Boyd (2001). Seasonal variation of nitrate nitrogen in the soil profile in a subsurface drained field. Canadian Bio systems Engineering. 43:1.1-1.6.

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

Blake, G.R. and K.H. Hartge (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 K.H. Hartge (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.

Clark, J. (1994). Evaluation of nitrogen movement beneath a leatherleaf fernery. Master's thesis. Uni. of Florida, Gainesville.

Clothier, B.R., T.J. Sauer and S.R. Green (1988). The movement of ammonium nitrate into unsaturated soil during unsteady absorption. *American Journal of Soil science Society* 52:340-345.

Dodds, G.T., C.A. Madramootoo and V.K. Serem (1998). Predicting nitrate nitrogen leaching under different tillage systems using LEACHM and NTRM. *Transactions of the ASAE* 41(4): 1025-1034.

Guillard, K., G.F. Griffin., D.W. Allinson., W.R.Yamartino., M.M. Rafey and S.W. Pietrzyk (1995). Nitrogen utilization of selected cropping systems in the U.S. Northeast: 11. Soil profile nitrate distribution and accumulation. *Agronomy Journal.* 87: 199-207.

Hutson, J.L. and R.J. Wagenet (1992). LEACHM: Leaching Estimation and Chemistry Model:A Process based model of water and solute movement, trans form ation, plant uptake and chemical reactions in the unsaturated zone. Water Reso urce Institute, Cornell University, Ithaca, New York.

Jemison, J.M. and R.H. Fox (1994). Nitrate leaching from nitrogen fertilized and manured corn measured with zero tension pan lysimeters. *Journal of Environtal Qualilty* 23: 337-343. (ISI).

Johnson, H., L. Bergstrom., P.E. Jansson and K. Paustian (1987). Simulated nitrogen dynamics and classes in a layered agricultural soil. *Agricultural Ecosystem and Environment* 18:333-356.

Jokela, W.E. (1992). Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. *Soil Science Society of America Journal.* 56: 148-154.

Keeny, D.R. and D.W. Nelson (1982). Nitrogen-Inorganic forms. p.643-698. *In* A.L.Page (ed.) *Methods of soil analysis*. Part II. Second Edition, *Agronomy Monograph,* 9. ASA and SSSA, Madison, WI.

Kendaragama, K.M.A and A.N. Jayakody (1989). Evaluation of nitrogen leaching in a non-calcic brown soil under irrigated rice. *Journal of Tropical Agricultural Research*. 1: 272-286.

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

Kuruppuarachchi, D.S.P. (1995). Impact of irrigated agriculture on groundwater resources of Sri Lanka. *Proceeding of Sri Lanka Association Advancement of Science* 51(2): 49-66.

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

Paramasivam, S., A.K. Alva and A. Fares (2002). Fate of nitrate and bromide in an unsaturated zone of a sandy soil under citrus production. *Journal of Environmental Quality* 31:671-681.

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

Roth, G.W and R.H. Fox (1990). Soil nitrate accumulation following nitrogen-fertilized corn in Penn-sylvania. *Journal of Environmental Quality* 19: 243-248.

Salley, B.W. (1992). Subsurface Transport of Fertilizer-Applied Nitrogen on the East ern Shore of Virginia. Dissemination of Virginia Techniques, September.

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

Staver, K.W. and R.B. Brinsfield (1990). Patterns of soil nitrate availability in corn production systems. Implications for reducing ground water contamination. *Journal of Soil Water Conservation* 45: 318-322.

Tanji, K.K. and S.K. Gupta (1978). Computer simulation modelling for nitrogen in irrigated croplands. In: D.R. Neilson and J.G. Mac donald. ed. Nitrogen and Environment: Volome: 1. Nitrogen Beha viour in Field Soil. Academic Press, New York. p. 79-130.