Nitrate Leaching as A Function of Fertilization and Irrigation Practices in Sandy Regosols

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

Postgraduate Institute of Agriculture,
University of Peradeniya,
Peradeniya, Sri Lanka

ABSTRACT. *Intensified agriculture associated with higher use of fertilizer and irrigation water has resulted in significant contamination of aquifer particularly in soils with shallow water table and high permeability. Proper management of fertilizer and irrigation could be one of the best ways to attend this problem. A leaching experiment was conducted in the laboratory with soil columns to characterize nitrate movement in sandy Regosols. Soil columns were prepared at 20, 30 and 40 cm depths with sieved sandy Regosols to a bulk density of 1.6 gcm^{-3} and saturated with distilled water. Each column was fertilized at the rate of 0, 70 and 140 kg N/ha. Water was applied at the rates of 7, 14 and 30 mm with each fertilization in each column. Leachate was collected and nitrate concentration was measured. Breakthrough Curves obtained in all runs have shown that NO_3^- concentration increased, reached to a peak and then reduced to zero. The peak nitrate flux and the attenuation varied with irrigation, fertilizer application and depth of soil column. Higher rates of irrigation push down the diluted nitrate solution rapidly as described by 'Piston displacement'. This effect is prominent at lower depths of soil and increases as the rate of fertilization increases. The effect of advection is higher than that of diffusion in the nitrate transfer phenomenon when the rate of irrigation increased. The lowest loss of 5.1%, was observed in 7 mm irrigation and 70 kg/ha fertilizer in 40 cm column. In contrast, 93.3 % loss was observed at 30 mm irrigation with 140 kg/ha fertilizer in 20 cm column. As the interaction between fertilizer application and irrigation had a significant effect on nitrate leaching, nitrogen fertilizer applications should be recommended with the appropriate irrigation rates.*

INTRODUCTION

Nitrogen (N) and water are essential inputs for crop production. N is one of the major elements and is applied to increase crop yields. However, N application rates on agricultural fields often exceed the actual crop use (Mohanty and Kanwar, 1994) and the unused N in the soil profile is either removed through leaching, denitrification or volatilization. Nitrate leaching typically occurs when fertilizer applications exceed crop N requirements (Roth and Fox, 1990; Jokela, 1992; Guillard *et al.*, 1995). This phenomenon is further aggravated under excessive use of water where NO_3^--N rapidly moves thrcugh the soil profile into groundwater. Within this background, ground water contamination due to nitrate leaching increases under excessive fertilizer application on sandy soils and the process further aggravates with indiscriminate irrigation practices. This refers that the N loss and threat of ground water contamination increases under

1 Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Sri Lanka

2 Department of Soil Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka

excessive fertilizer application on sandy soils compounded with indiscriminate irrigation practices. Therefore, N requires careful management on sandy soils.

A high level of NO_3^- in water reduces further usage of water for irrigation and drinking. Nitrate-N concentration in drinking water above maximum contaminant level (MCL) of 10 mg/l causes serious health threat to infants and adults. The most familiar problem associated with levels of nitrate greater than MCL is methaemoglobinemia or "blue baby syndrome" (Salley, 1992). Nitrate consumption has also been implicated circumstantially in a greater incidence of stomach cancer. Higher level of NO_3^- in water induces algal growth, which causes clogging in micro irrigation.

In Batticaloa, the coastal belt of eastern province of Sri Lanka, the predominant soil group is sandy *Regosols*, which contain 95-98% sand with no confining horizons in its soil profile. Higher hydraulic conductivity of this soils type and shallow groundwater in the area provide a favorable condition for leaching of applied fertilizers. The intensive use of inorganic N fertilizers together with excess irrigation on these highly permeable soils has contributed significantly to low efficiencies in nitrogenous fertilizer use and groundwater pollution. In some parts of the intensively irrigated agricultural areas in Batticaloa, there has been an increase in NO_3^-- N concentrations in the groundwater in excess of MCL. Kuruppuarachchi *et al.* (1990) has reported higher nitrate concentrations in groundwater in Kalpitiya. These results are attributed to improper fertilizer management under intensively irrigated agriculture on sandy soils. However, no efforts have been taken yet to find out the interaction between (or combined effect of) the rates of nitrate fertilization and irrigation on nitrate leaching.

Therefore, an understanding on the movement of NO_3^- beyond the root zone is very important to minimize the fertilizer losses and to avoid the ground water contamination. The objective of this study is to identify the behavior of nitrate leaching due to fertilizer application and irrigation at different depth of soil in sandy Regosols and there by to provide guidelines to farmers on fertilizer and irrigation management.

MATERIALS AND METHODS

Soil column experiments

Soil collected from Kaluthawalai, 25 km in the south of Batticaloa, were used for this study. Soil parameters such as particles size analysis, bulk density, field capacity, saturated soil moisture content and soil hydraulic conductivity that are important in characterizing nitrate leaching were measured using standard methods. Laboratory experiments were conducted using polyvinyl chloride (PVC) pipes of 20, 30 and 40 cm depths and 8.9 cm internal diameter to represent soil profile at above three depths. The bottom end of the pipes was tightly covered with muslin cloth. These columns were packed with 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. The fertilizer recommendation for onion is 70 kg N/ha (Techno Guide, 1998). Three irrigation treatments (7 mm, 14 mm and 30 mm) were combined with each of these fertilization rates in each column which resulted in 27 treatment combinations (Table 1). Each run was repeated thrice in the same column. The maximum pan evaporation in the dry zone is around 6 mm/day. According to the rate of irrigation, a calculated amount of distilled water was sprayed uniformly over the surface area of the columns to simulate the irrigation. The amount of water added is expressed as pore volumes which is the ratio between the volumes of water added and the pore space in the soil column.

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 water sample, approximately 30 ml, was collected and stored frozen at -4° C for the analysis of nitrate. The samples were analysed for nitrate using spectrophotometer (JENWAY Model 6305 Uv/Vis). Breakthrough curves (BTC) were obtained between the pore volumes of water and nitrate concentrations. The data were analyzed using the GLM procedure to determine the sources of variation in peak nitrate concentrations.

The columns were flushed with one pore volume of distilled water followed by each treatment prior to start of the next experiment to displace any remaining NO_3^-. The moisture contents of columns were maintained at saturated condition prior to the commencement of next water application. The evaporation, volatilisation, denitrification and any other losses of N were assumed to be zero during the experimental period.

RESULTS AND DISCUSSION

Breakthrough Curves (BTC)

The BTC shows the changes in nitrate concentration with the cumulative addition of water. The BTCs, obtained at different levels of irrigation and fertilizer in all three columns are shown in Figs. 1- 6. The nitrate concentration in the leachate increased, reached to a peak and then reduced to zero. The peak nitrate flux and the attenuation varied with irrigation rates, fertilizer application and depth of soil column.

The highest peak nitrate flux was observed at lowest irrigation rate in all columns regardless of fertilizer application. The peak nitrate flux reduced with subsequent increase in irrigation rate. The nitrate concentrations were almost zero in all irrigation rates when there was no fertilizer application in any of the three columns.

The peak concentrations were higher at 140 kg N/ha than that of 70 kg N/ha. The breakthrough of NO_3^--N occurred when the pore volume of water applied was equal to one and the rate of irrigation was 30 mm under 70 and 140 Kg N/ha of fertilizer application.

The behavior of the BTCs is the combined effect of advection and dispersion. The observed reduction of peak NO_3^- concentrations with higher irrigation may be due to the process of dispersion mechanism, which tends to dilute the applied NO_3^-. The heavy hydraulic loading at increased irrigation levels might have facilitated the dispersion process, which has caused a rapid redistribution of NO_3^- in the columns, resulting in reduced NO_3^- concentrations in the leachate. As a result, the peak nitrate concentrations were found to be attenuated with the subsequent increase in the rate of irrigation. Since the effects of advection and dispersion were minimal at 7 mm of irrigation, increased levels of peak NO_3^- concentrations were obtained in all the three columns.

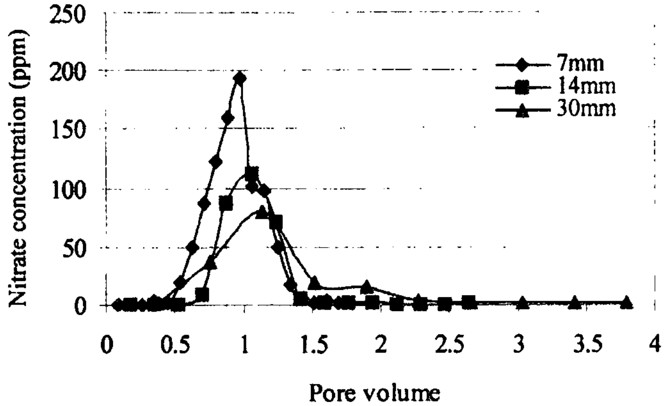

Fig. 1. Nitrate breakthrough curves in 20 cm column at 70 kg N/ha.

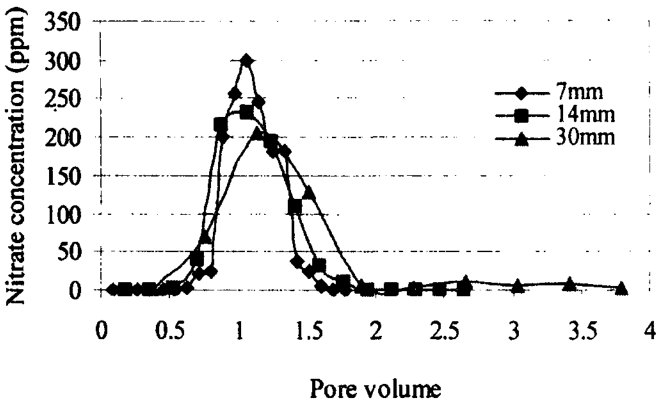

Fig. 2. Nitrate breakthrough curves in 20 cm column at 140 kg N/ha.

The nitrate movement in saturated sandy regosols can be explained by 'piston displacement'. The movement of the soil water displaced the nitrate vertically down in the soil column which is similar to that reported by Iqbal and Krothe (1995). When the hydraulic loading increases as increasing irrigation rates, the pushing down effect is faster along with higher dilution effect. The NO_3^- transport by 'piston displacement' was minimal at 7 mm of irrigation, which is the lowest rate in this experiment causing very slow movement of NO_3^--N. In contrast, at 30 mm of irrigation, higher leaching in all the columns can be attributed to the high rate of water application, which pushes the diluted nitrate solution towards the lower boundary of the soil column in a very short time.

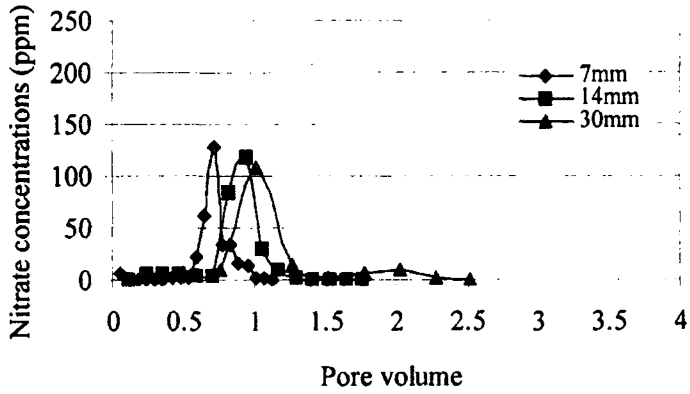

Fig. 3. Nitrate breakthrough curves in 30 cm column at 70 kg N/ha.

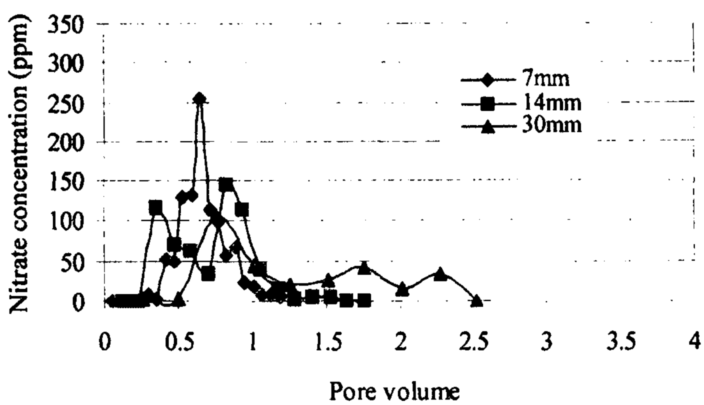

Fig. 4. Nitrate breakthrough curves in 30 column at 140 kg N/ha.

Rapidity of nitrate leaching

The time required for NO_3^--N to breakthrough is higher in 40 cm column, of which leaching at 7 mm irrigation was found to be very slow. Comparatively, NO_3^--N breakthroughs in a very short time in 20 cm column at all three rates of irrigation. Leaching at 30 mm depth of irrigation was very rapid in 20 cm column. In all the three columns, the nitrate moved within a very short time at 30 mm depth of water application.

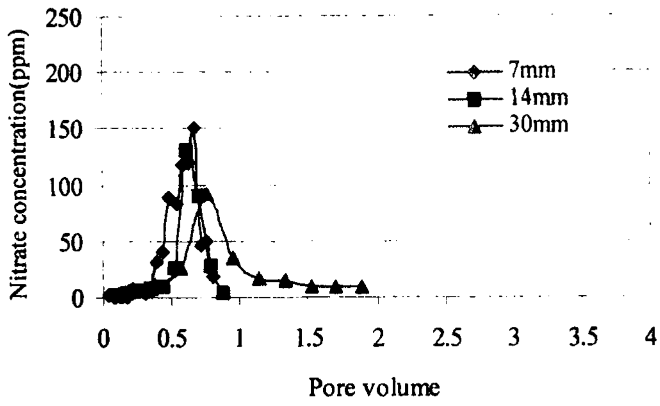

Fig.5. Nitrate breakthrough curves in 40 cm column at 70 kg N/ha.

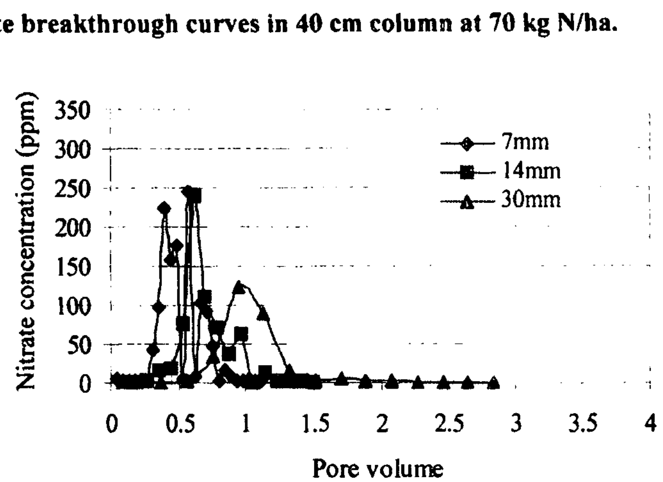

Fig. 6. Nitrate breakthrough curves in 40 cm column at 140 kg N/ha.

Nitrogen loss

The nitrate loss was calculated in each treatment from the nitrate flux. The loss varies regardless of nitrate peak concentration in BTCs. Even though the peak is higher, the amount lost is found to be lower in 7 mm irrigation. This refers that the higher the water application, higher the advection transport of the NO_3^-. Therefore, irrespective of the peak nitrate concentration at lower rate of irrigation, higher nitrate losses were obtained at increased irrigation rates, where the peak concentrations are lower. These findings are supported by the results reported by Diaz-Fierros *et al.* (1973) for a sandy soil. It is evident that the quantity of nitrates lost is high when the rate of irrigation is increased.

Table 1 shows the nitrate leaching losses at different treatment combinations. Maximum loss of 93.3% was observed in 20 cm column at 30 mm irrigation and 140 kg N/ha and the loss was at its lowest in 40 cm column at 7 mm irrigation and 70 kg N/ha. Subsequent reduction in losses in columns at all treatment combinations could be attributed to the distribution of nitrate when the depth of the column was increased. This indicates that deeper the profile, slower the leaching. These findings imply that the groundwater tables, which are closer to the soil surface, are vulnerable to be contaminated by leaching losses of nitrates owing to the heavy losses at lower depths. This will lead to reduction of the availability of N to the plants, which have shallow root system.

Interaction between irrigation and fertilizer application

The results show that (Table 2) the effects of fertilizer and irrigation significantly affect the variation in maximum nitrate concentrations in all the 3 columns ($P<0.05$) suggesting that the fertilizer and irrigation are responsible for maximum nitrate concentrations.

Table 1. Effects of irrigation and fertilizer application on nitrate leaching

Depth of column (cm)	Fertilizer (kg N/ha)	Irrigation (mm)	Loss* (kg N /ha)	Loss (%)
	70	7	31.1	44.5
20	70	14	34.4	49.1
	70	30	47.7	68.1
	140	7	41.9	29.9
	140	14	114.5	81.8
	140	30	130.6	93.3
	70	7	5.3	7.5
30	70	14	33.9	48.5
	70	30	43.3	61.9
	140	7	25.0	17.9
	140	14	84.3	60.2
	140	30	118.8	84.9
	70	7	3.5	5.1
40	70	14	25.2	36.0
	70	30	32.6	46.5
	140	7	26.5	18.9
	140	14	55.7	39.8
	140	30	102.8	73.4

*Losses up to the first ten irrigation applications in each treatment combination were considered

The data were also analyzed using the same procedure to determine the sources of variation in nitrate N losses in the columns, for which the first 10 water applications in each treatment combination were considered. The results show (Table 2) that the effects of column depth, fertilizer, irrigation and the interactions except those between depth and irrigation and three way interaction between depth, fertilizer &irrigation are significant at $P<0.05$. This indicates that all three variables have direct effects on the NO_3^- leaching phenomena. Mean comparison of NO_3^--N losses indicate that the losses in 20 and 40cm columns are significantly higher ($P<0.05$). However, there is a marked increase ($P<0.05$) in nitrate loss among the three levels of fertilizer application at 30mm of irrigaticn, which is due to the high permeability of the soil.

Table 2. Interaction between irrigation, fertilizer rates and depth of soil

Source of variation	Degrees of freedom	P-value*
Column depth	2	0.0039
Fertilizer	2	0.0001
Depth*Fertilizer	4	0.0122
Irrigation	2	0.0001
Depth*irrigation	4	0.2791
Fertilizer*irrigation	4	0.0001
Depth*fertilizer*irrigation	8	0.1089

* P-value of less than 0.05 suggests the significance of the effect at the 5% level of significance)

CONCLUSIONS

This study explains the mechanism of NO_3^- movement and highlights the interactions between fertilizer application, irrigation and soil depth on NO_3^- leaching on sandy Regosols. Breakthrough Curves have shown that NO_3^- concentration in the leachate increased, reached the peak and then reduced to zero. The peak nitrate flux and the attenuation varied with irrigation, fertilizer application rates and depth of soil column. Higher rates of irrigation push down the diluted nitrate solution rapidly as described by 'Piston displacement'. This effect is prominent at lower depths of soil and increases when the fertilizer application increases. The effect of advection is higher than that of diffusion in the nitrate transfer phenomenon in sandy Regosols when the rate of irrigation increases. The lowest loss of 5.1% was observed in 7 mm irrigation and 70 kg/ha fertilizer application in 40 cm column. In contrast, 93.3 % loss was observed at 30 mm irrigation with 140 kg/ha fertilizer application in 20 cm column. Leaching losses get delayed with the increase in the depth of soil column. Therefore, the aquifers which have shallow ground water table are highly vulnerable to nitrate contamination. As the interaction between fertilizer application and irrigation had a significant effect on nitrate leaching, N fertilizer applications should be recommended with the appropriate irrigation rates, so that NO_3^- leaching could be minimized in sandy Regosols due to their extreme permeability.

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