

## FATE OF NITROGENOUS FERTILIZERS IN THE UNSATURATED SOIL ZONE UNDER RAINFED CHILLI CULTIVATION

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### INTRODUCTION

The quality of soils, ground and surface waters is specifically vulnerable in semi arid regions in the world where agricultural production is intensive. The regular and excessive application of nitrogen fertilizers is likely responsible for the increase in nitrate concentrations of groundwater resources in these areas. Specifically, non-point source pollution of nitrate in groundwater is a major problem in many areas of Sri Lanka in both hard rock and limestone aquifers. As a result nitrate concentrations in groundwater exceeds the drinking water standard in these areas. Therefore, modern irrigation methods and soil management practices are needed that tactically allocate water and fertilizers to maximize their application efficiency, by minimizing fertilizer losses through leaching towards the groundwater (Bar-Yosef, 1999).

Groundwater pollution from use of nitrogenous fertilizer has been at increasing rate during the past decade. With increase in area under cultivation and regular use of nitrogenous fertilizer in vegetable cultivation, there is more scope for nitrogen leaching and groundwater pollution. Higher nitrate levels in groundwater in Jaffna Peninsula is also reported during the past decade (Mikunthan and De Silva, 2008a and 2008b) and it is becoming a major concern in dry zone of Sri Lanka too. This requires appropriate water and nutrient management to minimize groundwater pollution and, maximize the nutrient use efficiency and production.

Application of agricultural chemicals including fertilizers and dumping of industrial and domestic wastes on the land surface or within the unsaturated soil zone may have considerable impact on the quality of groundwater. Agricultural chemicals and fertilizers are generally the most significant anthropogenic source of groundwater pollution. Understanding the fate of such dissolved chemicals within the unsaturated zone can greatly help in the prediction of chemistry of water that reaches the aquifers. Investigation of water movement within the soil zone is essential for understanding the factors controlling recharge and groundwater quality. Persistence of applied fertilizers in soil depends on their solubility and adsorption capability and their rate of degradation during recharge. Adsorption of fertilizers in the soil, as well as their persistence and mobility, determine the degree to which the quality of groundwater is affected. Accumulation of contaminants from agricultural fertilizers in the unsaturated zone is a major concern over the years in many parts of the world. As a result, the unsaturated soil zone has been a subject of greater research interest during the past decade. This paper analyses the fate of nitrogenous fertilizers applied to the field under the rain-fed cultivation of Chilli from March to August and grass during the rest of the period as a system of land use in Limestone aquifer in Jaffna Peninsula.

### METHODOLOGY

#### *Case study*

Under this case study Chilli was cultivated at a field with sandy clay loam soil in Thirunelvely in Jaffna District. The field was covered with short grass from January 2008 and Chilli was planted in late March. Chilli was in the field until end of August and from August it was again covered with grass. Chilli was applied with nitrogenous fertilizers from the second, fourth, eighth and twelfth week after planting at the rate of 65kg /ha (260kg/ha) according to the recommendation made by the Department of Agriculture, Sri Lanka. As it was cultivated under rainfed condition

the nitrogenous fertilizers were applied when there was rainfall. In this study Chilli cultivation was considered as rain fed cultivation and no irrigation water was applied. With the rainfall received during the year 2008 and with the recommended dose of nitrogenous fertilizer, it was analyzed to study the fate of applied nitrogenous fertilizer using the solute transport modeling. Input parameters took into account were rainfall, evapotranspiration, soil hydraulic properties and application of nitrogenous fertilizer at appropriate intervals as recommend by the Department of Agriculture.

#### *Solute transport modeling*

A variety of analytical and numerical models are available to predict water and solute transport processes between the unsaturated zone of the soil and the groundwater table. The most models are based on the Richards equation for variably saturated flow and the Fickian-based convection dispersion equation for solute transport. Deterministic solutions of these classical equations have been used for predicting water and solute movement in the vadose zone. van Genuchten (1985) has published several analytical solutions for simplified transport systems involving consecutive decay reactions. In this study, the HYDRUS-1D model developed by the International Groundwater Modeling Centre, USA, (Simunek *et al.*, 1999) is used. It is a Microsoft Windows-based model for the analysis of water flow and solute transport in variably saturated porous media. HYDRUS-1D numerically solves the Richards equation for saturated-unsaturated water flow and convection-dispersion-type equations for solute transport. The water flow of the model can deal with prescribed head and flow boundaries and boundaries controlled by atmospheric conditions. The governing flow and transport equations are solved numerically using Galerkin-type linear finite-element schemes (Neuman, 1975). In this method, the solution for water flow is obtained by an iterative process using Gaussian elimination. Similarly, the same Galerkin finite-element method is also used to solve the solute transport equation. To obtain a numerical solution of the solute transport process, first, an iterative procedure is used to obtain the solution of the Richards equation (Simunek *et al.*, 1999).

#### *Solute transport with Nitrification Chain*

An analytical solution published by van Genuchten [1985] for one-dimensional convective dispersive transport of solutes involved in sequential first-order decay reactions is used in this study. The analytical solution holds for solute transport in a homogeneous, isotropic porous medium during steady-state unidirectional groundwater flow. Solute transport equations used for this situation is as follows:

$$R_1 \frac{dc_1}{dt} = D \frac{d^2c_1}{dx^2} - v \frac{dc_1}{dx} - \mu_1 R_1 c_1$$

whereas  $R$  is solute retardation factor,  $D$  is dispersion coefficient,  $v$  is average pore water velocity ( $q/\theta$ ) in the flow direction,  $\mu$  is first-order degradation constant,  $x$  is spatial coordinate in the direction of flow, and where it is assumed that 3 solutes participate in the decay chain. The specific example used here applies to the three-species nitrification chain



The experiment involves the application of a  $\text{NH}_4^+$  solution to an initially solute-free medium ( $c_i = 0$ ). Therefore the solute 1, 2 and 3 are  $\text{NH}_4^+$ ,  $\text{NO}_2^-$  and  $\text{NO}_3^-$  respectively.

## RESULTS AND DISCUSSION

Figure 1 shows the results of HYDRUS-1D model for Actual surface flux for 365 days (rainfall of the study area) and cumulative surface solute flux for the simulated field conditions applied with nitrogenous fertilizer at the rate of 65Kg/ha for four times during the growing period of Chilli in Sandy clay loam soil at Thrunelvely in Jaffna. Results showed that approximately 19%

of that applied nitrogenous fertilizer has been used for root solute uptake in the form of solute 1 ( $\text{NH}_4^+$ ) and the rest has been transported through the unsaturated root zone while degradation to Nitrite and then Nitrate. Results further showed that there has been no root solute uptake taken place in the form of Nitrite ( $\text{NO}_2^-$ ) or Nitrate ( $\text{NO}_3^-$ ). But the nitrogenous fertilizer applied that has left the root zones as bottom solute flux in the form of Nitrate is almost 48% of the added nitrogenous fertilizer which is  $260\text{kg/ha/year}$  (Figure 2 and Table 1). Further the bottom solute flux had been taken place with the onset of very high rainfall during November and December. Further the bottom solute flux of  $1.2\text{ mg/cm}^2$  which is  $7\text{ mg/l}$ . This value is very close to the nitrate concentrations ( $10\text{-}11\text{ mg/l}$ ) measured in the wells in Thirunelvely, Jaffna (Mikuntahn and De Silva, 2008). Further these results agree with the findings of similar studies reported by other authors. Munoz-Carpena *et al.* (2002) conducted a detailed field study to track nitrogen degradation and transport through the soils of *Banana plantation into the aquifer and reported that* high water fluxes and nitrate concentration at the bottom of the soil profile had produced a yearly loss of 48–52% of the total nitrogen applied ( $202\text{--}218\text{ kg/ha/yr}$ ). Costa *et al.* (2002) reported that high nitrate concentration in the soil profile occurred under irrigated corn. Further, they reported that high fertilization rates and irrigation lead to increased hazards of groundwater pollution

Nitrogen (N) is an essential plant nutrient, which is taken up by the crops throughout the growing season. Most common forms of nitrogen found in the soils are organic N, ammonium ( $\text{NH}_4^+$ ) nitrate ( $\text{NO}_3^-$ ), and gaseous nitrogen ( $\text{NH}_3$ ,  $\text{N}_2$ ). Mineralization and nitrification processes convert the organic N and  $\text{NH}_4^+$  into  $\text{NH}_4^+$  and  $\text{NO}_3^-$  respectively which are absorbed and utilized by crops and termed as available nitrogen. Nitrate is highly mobile and leachable. It has been found that excessive application of nitrogen leads to nitrate pollution of groundwater and surface water (Hayens, 1985; Waskom, 1994). Nitrate leaching mainly depends on soil properties, crops and crop rotation, irrigation methods, management practices and climatic parameters. Therefore it is essential to develop appropriate water and fertilizer application strategies in order to maximize the fertilizer application efficiency and minimize the fertilizer losses through leaching.

Parameter	Unit	Solute 1 ( $\text{NH}_4^+$ )	Solute 2 ( $\text{NO}_2^-$ )	Solute 3 ( $\text{NO}_3^-$ )
Cum. Root Solute Uptake	$\text{mg/cm}^2/\text{year}$	0.5 (19%)	0	0
Cum surface solute flux	$\text{mg/cm}^2/\text{year}$	2.6	0	0
Cum bottom solute flux	$\text{mg/cm}^2/\text{year}$	0	0	1.2 (48%)

Table 1. Fate of Nitrogenous fertilizer in the Field

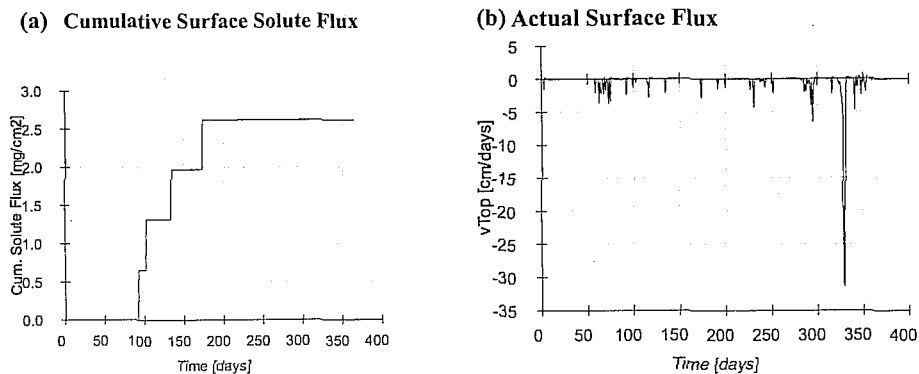


Figure 1. (a) Nitrogenous fertilizer application as concentration with respective rainfall on the application day (b) Rainfall distribution during the study period (2008)

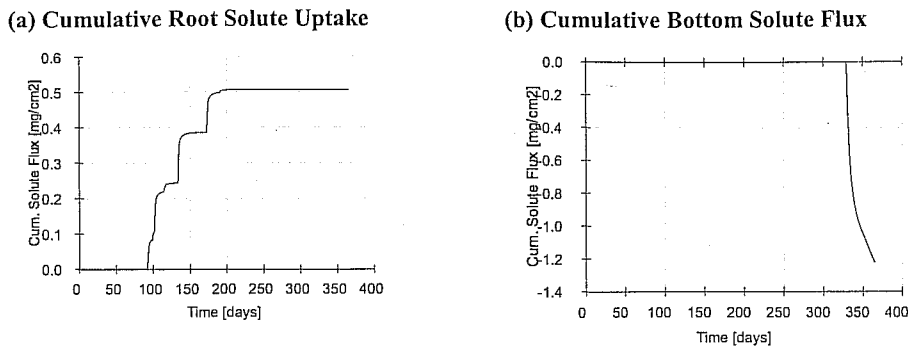


Figure 2. (a) Cumulative root solute uptake by plants of Ammonium (Solute 1) (b) Cumulative bottom solute flux of Nitrate (Solute 3) leaving the root zone

### CONCLUSIONS/RECOMMENDATIONS

This case study results demonstrate that, cultivation of one crop (Chilli) per year with nitrogenous fertilizer dosage (260kg/ha) recommended by Department of Agriculture under rain fed conditions had resulted almost 48% of the added fertilizers leached into the root zone polluting the groundwater. Further, it is evidence that only 19% of the added fertilizer as root solute uptake is used for crop growth. This situation raises a serious concern of groundwater pollution in areas where similar agricultural practices are adopted in the country and the availability of clean and safe water for domestic uses, particularly in the rural areas where agricultural activities are intensive. In addition, using nitrogenous fertilizers over and above the recommended dosage and cultivating more than one crop, mainly shallow crops such as onion, potato and leafy vegetables in sandy and sandy clay loam with over irrigation will have serious impact on groundwater quality. Therefore further solute transport modeling need to undertaken to study different scenarios and the findings need to be made available in order to develop an appropriate policy framework in using nitrogenous fertilizers in agricultural activities in Sri Lanka.

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