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NITRATE LEACHING FROM SOILS WITH TEXTURAL DIFFERENCES AND CROP TYPES

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INTRODUCTION

Nitrogen is an essential element for plant growth. The use of nitrogenous fertilizers is one of the major reasons for the increased agricultural productivity in the world in the past few decades. There is a steady increase in the use of nitrogenous fertilizers from 1940s. Nitrogen fertilizers applied are not all taken by plants; a large proportion is incorporated into the soil organic matter, lost to atmosphere or runoff to the surface water body and then to groundwater by leaching through the profile. Generally the concentration of ammonium ions is very low in soils as they are readily converted to nitrate. The nitrate ion is negatively charged and it is not retained by the soils, and therefore the major fraction of the applied nitrate is leached. This paper analyses the simulation of nitrate leaching in soils belongs to eight textural groups and three vegetable crops using HYDRUS -1D numerical model. Simulated model results have been compared with results obtained in the field of limestone aquifer in Jaffna peninsula. HYDRUS -1D is already calibrated to estimate the annual average recharge in Thirunelvely in Jaffna Peninsula and there is good agreement with field and model simulated results. Calibration was done using parameters such as recharge, soil moisture deficit and surface runoff of the study area.

METHODOLOGY

In this study three vegetable crops: Carrot, Cabbage and Tomato in eight different soil textural groups: Sand, Loamy Sand, Sandy Loam, Sandy Clay Loam, Loam, Silt Loam, Clay loam and Silt were considered for the simulation of nitrate leaching. Table 01 gives the soil hydraulic properties of each textural group used in this simulation. Additional input parameters took into account was meteorological data of year 2007 for Thirunelvely, Jaffna, and application of nitrogenous fertilizer at appropriate intervals as recommended by the Department of Agriculture, Sri Lanka (Table 02). Since the simulation is rainfed based, urea application was simulated in concentration (mg/cm$^{3)}$ based on rainfall of that particular day.

Table 01: Soil hydraulic properties used for HYDRUS-1D water flow simulations: Q_r and Q_s are the residual and saturated water contents: Alpha and n empirical parameters determining the shape of the hydraulic function; K_s the saturated hydraulic conductivity. Values were taken from the HYDRUS-1D data base.

Soil Type	Q_r ($cm^3 cm^{-3}$)	Q_s ($cm^3 cm^{-3}$)	Alpha ($cm^{-1)}$	n	K_s cm day^{-1}
Sand	0.045	0.43	0.145	2.68	712.8
Loamy Sand	0.057	0.41	0.124	2.28	350.8
Sandy Loam	0.065	0.41	0.075	1.89	106.1
Sandy Clay Loam	0.1	0.39	0.059	1.48	31.44
Loam	0.078	0.43	0.036	1.56	24.9
Silt Loam	0.067	0.45	0.02	1.41	10.8
Clay Loam	0.095	0.41	0.019	1.31	6.24
silt	0.034	0.46	0.016	1.34	6

Table 02: Urea application based on Department of Agriculture Recommendation.

Urea Application	Cabbage kg/ha	Tomato kg/ha	Carrot kg/ha
Basal Dressing	110	65	200
3WAP	110	65	-
6WAP	110	65	250
Totål	330	195	450

(Note: WAP –Weeks after planting)

Water and Solute transport modelling

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. In this study, the HYDRUS-1D model developed by the International Groundwater Modelling 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. A lysimeter field study was conducted to measure the nitrate leaching below 1 m soil zone.

RESULTS AND DISCUSSION

Root Solute Uptake

Figure 01 shows the HYDRUS-1D simulated results on root solute uptake in the form of ammonium (NH_4^+) by Cabbage, Carrot and Tomato on eight different soil types for 365 days. Cabbage, Carrot and Tomato are fertilized according to the Department of Agriculture recommendation as 330, 450 and 195 kg/ha respectively (Table 02). The highest percentage (24%-31%) of the applied nitrogenous fertilizer is used by Tomato as indicated in root solute uptake, even though this crop is fertilized lowest amount of nitrogenous fertilizer (195kg/ha). As shown in Figure 01, root solute uptake was high sand and loamy sand (coarse textured soils).

Even though Carrot was fertilized with 450 kg/ ha of nitrogenous fertilizer, it is the crop used lowest percentage (on average 10%) of applied nitrogenous fertilizer as shown as root solute uptake in Figure 02. Further root solute uptake by Carrot was almost same in all the eight types of soils in the range of 8%-10%. In Cabbage the root solute uptake was in the range of 21% to 24% of the applied nitrogenous fertilizer. These results agree with the findings of Di and Cameron ((2000) as stated the recovery of applied nitrogenous fertilizer by vegetable crops is often less than 50%, and can be as low as 20% when analyzed different agro eco systems.

Nitrate Leaching

Overall nitrate-N leaching is shown in Figure 02. The effective nitrate leaching was computed at the bottom of the 1 m soil domain during 1 year period. This was effectively quantifying the mass nitrate moving out of the root zone. Thus it was assumed that the soil nitrogen below the root zone would not be available for root uptake after the simulation period. Accordingly, the leaching potential is higher for coarse textured soils compared to the fine textured soils which agree with the findings of Gardenas et al (2005). This is because the water will be lost if redistributed water moves below this root zone. This is the main cause for the coarse textured soils to have larger leaching potential than the fine textured soils. Further for fine textured soil types, the infiltration capacity is limited, causing a significant fraction of the water move laterally across the root zone into the furrows or drains. This water moves subsequently back into the soil but it is essentially lost because the furrow or drain depth is usually below root zone depth. The lowest leaching losses for silt soil are the result of lateral movement of water and dissolved fertilizer, thereby making more efficient use of the whole rooting system. When considered the nitrate leaching in different crops, the nitrate leaching varies from 61% to 73% (9-11mg/l) in Tomato cultivation. The lowest nitrate leaching was obtained in silt soil (9 mg/l) which is below the World Health Organization (WHO) drinking water limit of 10mg/l. Further the nitrate concentration reaching the groundwater table will be much less than this (9mg/l) as the simulation was done only below 1m soil depth. However the nitrate leaching in Cabbage cultivation varies from 74% to 78% (16-20 mg/l) of the applied nitrogenous fertilizer which agrees with the findings of Whitmore (1996). According to Whitmore's modelling studies in The Netherlands, the nitrate leaching during winter periods after cabbage cultivation almost exceeded the EU drinking water limit of 11.3 mg of NO_3-N/l. In Carrot cultivation the nitrate leaching was almost 73% to 83% (25-31 mg/l) which will induce severe groundwater pollution if remedial measures are not taken.

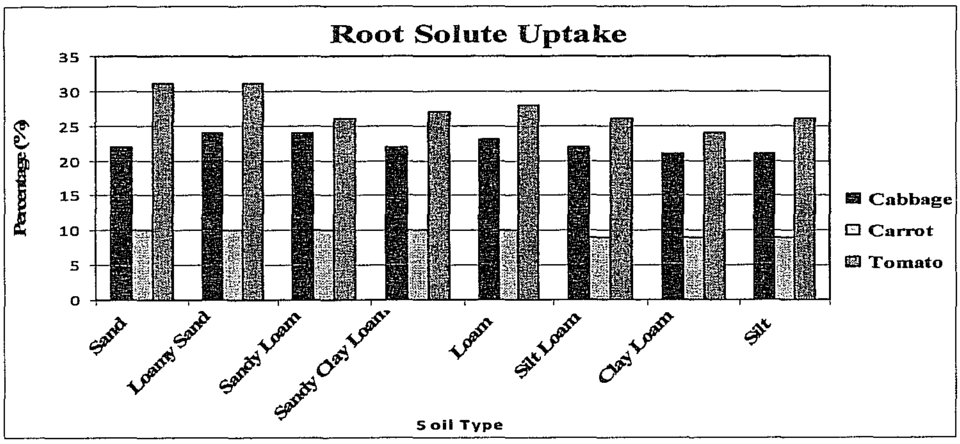

Figure 01. Root solute uptake by Cabbage, Carrot and Tomato grown on eight different soil types.

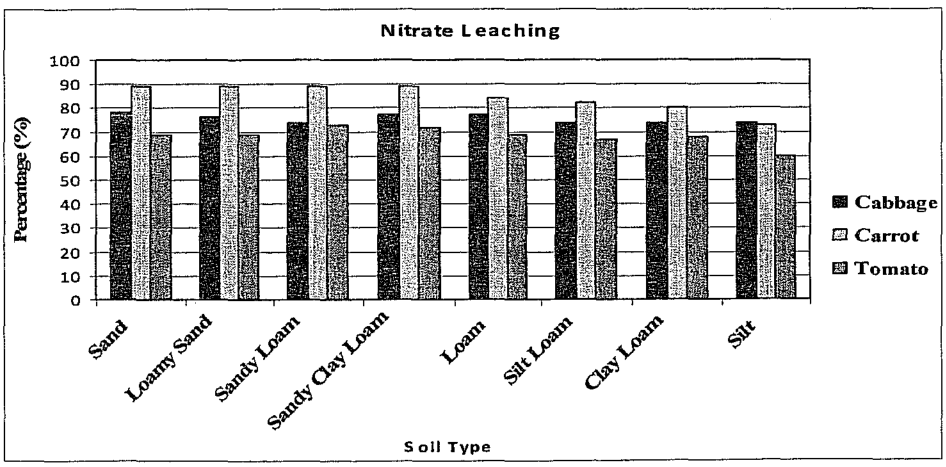

Figure 02. Nitrate Leaching below the root zone in Cabbage, Carrot and Tomato in eight soil types

The simulated daily nitrate-N leached below 1m depth of Cabbage cultivation over the whole year 2007 in sand type soil was with peaks of nitrate leaching on days with heavy rains. This means that the higher leaching predicted by HYDRUS-1D was due to higher concentration of nitrate in the drainage water. As the drainage is high in sandy soil the nitrate leaching too is high. Further it is interesting to note that the nitrogenous fertilizers were applied for cabbage on 96^{th}, 116^{th} and 166^{th} days but the leaching took place during the heavy rain periods because the rainfall on fertilizer applied days were not sufficient to induce considerable drainage. Due to this effect the nitrate concentration is high in well water during wet season which agrees with the findings of Mikunthan and De Silva (2008) in Thirunelvely, Jaffna and Amarasinghe and De Silva (2006) in Vavuniya.

CONCLUSIONS

Study results show that Tomato has highest nitrogenous fertilizer use efficiency (highest root solute uptake of 24% to 31%) despite the lowest recommended dosage of nitrogenous fertilizer (195kg/ha). Further it is best suited to cultivate Tomato in sand or loamy sand soils with drip irrigation which will minimize the nitrate leaching. If it is basin irrigation it is advisable to cultivate in silt or silt loam soils to minimize the nitrate leaching for about 9 mg/l. Cabbage is best suited in loamy sand and sandy loam soils. Carrot is having the very low fertilizer use efficiency as the root solute uptake is only around 10% of the applied urea and nearly 73% to 89%of nitrate leaching. The lowest leaching is obtained in silt soil (25mg/l) which is well above the WHO standards for drinking water. Further Department for Environment, Food and Rural Affairs (Defra) (2000) provides detailed guidelines on fertilizer application to agricultural land, along with the relationship between crop yield and nitrogen application. It shows that the application rate around 200 kg N/ha at which crop yield is maximized and the associated loss of nitrate leaching is minimized. Therefore the department of Agriculture may seriously rethink about the recommended dosage of urea for vegetable crops such as carrot considering the findings of this study in the view of water and solute transport in unsaturated and saturated soil conditions and other related studies on nitrate leaching. Nitrate leaching is the potential source of pollution to groundwater which is harmful to humans who are dependent on groundwater for drinking water purposes.

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