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Experimental and Simulation studies on Nitrogen Dynamics in Unsaturated and Saturated Soil using HYDRUS-2D

C.Mekala[a], Indumathi M Nambi[*]

*[a] *Environmental and Water Resource Engineering, Civil Engineering, IIT Madras, Tamilnadu 600036, India*

Abstract

Effective irrigation practices have become an optimal means of providing water and nutrients to crops as well as preventing the vulnerability of ground water contamination. This could be achieved by understanding the fate and transport processes of nitrogen compounds in the subsurface. However, nitrogen dynamics in the plant rhizosphere is very complex, which depends on many factors such as soil temperature, pH, water content, soil microbes, soil type and plant characteristics and cannot be easily quantified. Using state-of-the-art modelling techniques, an attempt was made to evaluate the reactive transport of ammonium nitrogen under continuous and alternate wetting and drying mode (AWD) of irrigation in soil columns using a HYDRUS 2D model. The model quantifies the soil sorption, microbial transformations such as nitrification and denitrification, leaching, and final release to aquifer for ammonium and nitrate input fluxes. This quantification helped in designing an optimal fertigation and irrigation schedule. Soil column study was done with variable saturation and in a combined unsaturated (45 cm) and saturated (5 cm) representing vadose and aquifer. Drip irrigation with wastewater containing 100 mg/L of ammonium and 500 mg/L of organic carbon (acetate) was applied based on the recommended total quantity of nutrients in continuous and pulse modes to the column. The soil parameters, initial and boundary conditions used in the model were obtained through experimental studies. The HYDRUS-2D model was developed, calibrated and validated with experimental results. The model performed could predict well the experimental data. Under continuous irrigation, nitrification (0.23/d) was the predominant process whereas both nitrification and denitrification occurs simultaneously in AWD with the overall nitrate removal efficiency of 60%. Consequently, the scenario prediction using this model for optimal fertigation schedule was done for groundnut crop. Further this model could be extended for various scenario predictions for designing optimal irrigation-fertigation schedules for sustainable agricultural practices.

Keywords: Fertigation; HYDRUS2D; Nitrogen dynamics; Irrigation

* Corresponding author. Tel.: +914422574289;
E-mail address: indunambi@iitm.ac.in

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1. Introduction

Nomenclature	
h	pressure head
K	hydraulic conductivity
θ_w, θs, θr	Volumetric water content, saturated and residual water conten
q	Darcy flux
D	Dispersion coefficient
S_e	Saturation
Q_{nm}	Plant uptake
Φ_1, Φ_2	First order nitrification and denitrification constant
α,β,η	Fitting parameters
ρ_b	Bulk density
τ	Tortuosity
z	Vertical coordinate

Over the decades, the intensive use of agriculture practices consumes tons of agrochemicals to increase crop productivity. This probably leads to diffusion and leaching of excess chemicals creating various environmental pollution, the significant being groundwater contamination. [1]. Excessive nitrogen containing wastewater irrigation, over fertigation and build up of soil residuals leads to severe nitrate contamination. Numerous ways as numerical modelling and experimental studies are present to estimate irrigation losses, leaching potential by different irrigation methods (drip, subtape, furrow, and sprinkler), crop and soil types. [2,3]. Efficient irrigation with proper fertilizer application to deliver water and nutrients to plants involves a scientific planning based on crop needs, soil conditions, and hydro geological conditions.Hence a holistic approach for water dynamics and scientific understanding of nitrogen compounds in soil and groundwater is essential for design operation and planning of scheduling of irrigation and fertigation[4].

Most widely adopted technology was alternate wetting and drying irrigation rather than continuous flooded irrigation because it not only reduces water and fertilizer load to soil and plants but prevents excess leaching and groundwater contamination [5]. Quantifying water and nitrogen losses in plant root zone is complexes due to uncertainties in estimating the actual water content and solute movement even under controlled environment such as lysimeter studies and column experiments [6]. In addition, field experiments will provide a realistic data but there would not be any control in the experimentation, also it is laborious, time consuming and tracking of water drainage flux and solute concentrations will be uncertain. Hence, computer simulations became a valuable tool for understanding the complex nitrogen dynamics and their interaction with soil, crops and the role of water content, soil microbes and soil conditions affecting their transport. Also, assessment of management options for better cropping and safeguarding the environment based on scenario analysis through models will make the work easier [7,8,9].

Several models were present in literature simulate flow and transport processes, nutrient uptake and biological transformations of nutrients in the soil [10] numerical models showing the effect of temperature and dissolved oxygen, water and N dynamics in paddy fields [11], SWMS [12], HYDRUS [13,14,15] HYDRUS 2D/3D [6] has been used extensively for evaluating the effects of soil hydraulic properties, soil layering, dripper discharge rates, irrigation frequency and quality, timing of nutrient applications on wetting patterns and solute distribution [e.g.,16,17,18,] because it has the capability to analyze water flow and nutrient transport in multiple spatial dimensions [19]. Most of models obtain their input data from field studies which were not representative due to uncertainties in sampling, climatic conditions, environment etc. Hence, this study was taken up to develop a model which was calibrated and validated by experimental results which helps in better understanding and predictions. The objective the present study was to develop a model for the transport of nitrogen compounds and simulate water fluxes in an unsaturated and unconfined aquifer system under continuous and alternate wetting and drying irrigation for the scientific understanding and investigate the critical factors.