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MODELLING WATER FLOW AND NUTRIENT TRANSPORT PROCESSES FROM AGRICULTURAL FIELDS WITH CONTROLLED DRAINAGE-SUB IRRIGATION SYSTEM- REVIEW

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ABSTRACT

Agricultural production has been recognized as affecting ground and surface water quality adversely from both point and non point sources. In particular, losses of N to surface water from agricultural fields via surface and subsurface drainage have been a serious concern for many years. This paper is primarily devoted to a discussion of various issues related to the reduction of solute transport through unsaturated zone using controlled drainage- subirrigation system. Controlled drainage significantly lowered N and P loads in drain outflow and altered N dynamics of soil. Studies that compared DRAINMOD with other commonly used drainage models such as ADAPT and RZWQM indicate that DRAINMOD has equal or better performance in predicting drain flow and NO_3-N losses from subsurface drainage system. The most recent in the DRAINMOD series, the DRAINMOD-NII model, showed success in predicting NO_3-N losses from agricultural system. However these models has not been tested for the high-organic matter soils. Predicted NO_3-N reduction was most effectively accomplished when controlled drainage and a nitrogen management plan were used in conjunction with one another.

Keywords: Agriculture, Drainage, Model, Nitrogen and Management

Introduction

Drainage control is achieved with structures that allow drainage of only the excess water that might damage crops. The same controlled structures can be used to operate subirrigation. These practices have been tested since the beginning of the agricultural water management in areas with improved drainage and with a water table perched on an impermeable layer (**Borin and Bonaiti, 2010**). Observed beneficial effects from controlled drainage - subirrigation are increase in efficiency of nitrogen fertilization and water use, increased yield and decreased nitrogen in outflow, primarily due to the reductions of total drained volumes (**Weestrom and Messing, 2007**).

A drainage water management also called as controlled drainage system consists of installing a water table controlled structure at the outlet of sub-surface drainage systems with which the outlet elevation can be managed at different times of the year. In addition to minimizing some off-site negative environmental impacts, the method may improve N use efficiency of applied fertilizer due to lower NO_3-N losses in drain flow and higher N uptake by the crop (**Wesstrom and Messing, 2007**).

CD- SI decreases the drainage intensity and larger part of the sub-soil is submerged. Hence retention time of water in soil increases potentially leaving more water available for evapotranspiration and for interim storage of soluble nutrients. The decreased drainage intensity reduces the outflow through the drain. The anaerobic conditions created in the submerged soil affect both chemical and biological processes. Improved understanding of how CD-SI could influence the solute transport process requiring understanding nutrient dynamics in the soil-plant-water system, which is regulated by a large number of interacting and sometimes highly dynamic physical, chemical and biological processes. In fact, computer modeling and experimentation complement each other and if used together can lead to better understanding of nutrient dynamics in agro-ecosystem and thus improve the process of development and evaluation of best management practices for sustainable agriculture (**Youseff *et al*, 2006).**

Artificial drainage contributes to the diffuse (or non-point source) pollution of surface water bodies, thus had general agreement that the drainage increases nitrate losses for several reasons; nitrate is rarely conveyed by overland flow, but by leaching, shortens the residence time of the leached water in the soil and often creates a direct connection to the surface water. Further more, the lowering of the groundwater level favours aerobic conditions in the soil and therefore enhances mineralization and fertilizers, while denitrification is inhibited (Bernd Lennartz *et al.*,2011).

Although CD-SI system will certainly reduce the nutrient transport, its effect should be accompanied by an experimental programme to better understand the pathways and transformations of water and solute. Further simulation of nutrient transformations using prediction models were used to estimate the interaction between irrigation, drainage and solutes with set of management practices that are most effective and economically feasible for the agro-ecosystem. Therefore the present work aims at reviewing recent research developments in reducing solute transport and its consequence for agro-ecosystem from an agricultural perspective and additionally, aims at highlighting the importance of simulation models and its reliability before their prediction can be used through different works already tested in some parts of the world by different scientists.

Materials and Methods

Controlled Drainage- Subirrigation has been employed as a strategy to reduce the solute transport and water movement in agriculture lands by continuous control of the water table with the goal of effectively controlling excessive drainage, implementation on economic irrigation system, saving water and ameliorating water quality (Madromootoo *et al.*, 1993). Drainage control is achieved with structures that allow drainage of only the excess water that might damage crops. The same controlled structures can be used to operate subirrigation. Reduction of nitrogen loss is achieved by the complex mechanism of mineralization and denitrification the latter promoted by the presence of a shallow water table that produces anaerobic conditions and faster development of denitrifying micro-organism in the presence of high organic matter (Skaggs, *et al.,* 1993). Predicting the effects of drainage and solute transport is often difficult. Computer simulation models can help assess the mechanisms controlling these operations. Hydrologic and water quality impacts are dependent upon factors like soil type, land use, management practices, site conditions and climate (Smeltz, 2006).

DRAINMOD-N is a N fate and transport model for artificially drained soils which is a quasi two-dimensional flow model, simulates the movement and fate of nitrogen in the shallow water table. DRIANMOD-N assumes that there is only vertical transport in the unsaturated zone and both vertical and lateral transport in the saturated zone. DRAINMOD-NII is a field scale, process based model that simulates C and N dynamics in drained agricultural lands for a wide range of soil types, climatic conditions and management practices. The model simulate a detailed N cycle (Fig.1) that includes there soil N pools: Nitrate-Nitrogen (NO_3-N), Ammonical Nitrogen (NH_x-N) and Organic Nitrogen (ON) (Youssef *et al.*, 2006). The fertilizer component of the model is capable of simulating the application of the most widely used N fertilizers including an hydrous NH_3 and urea.

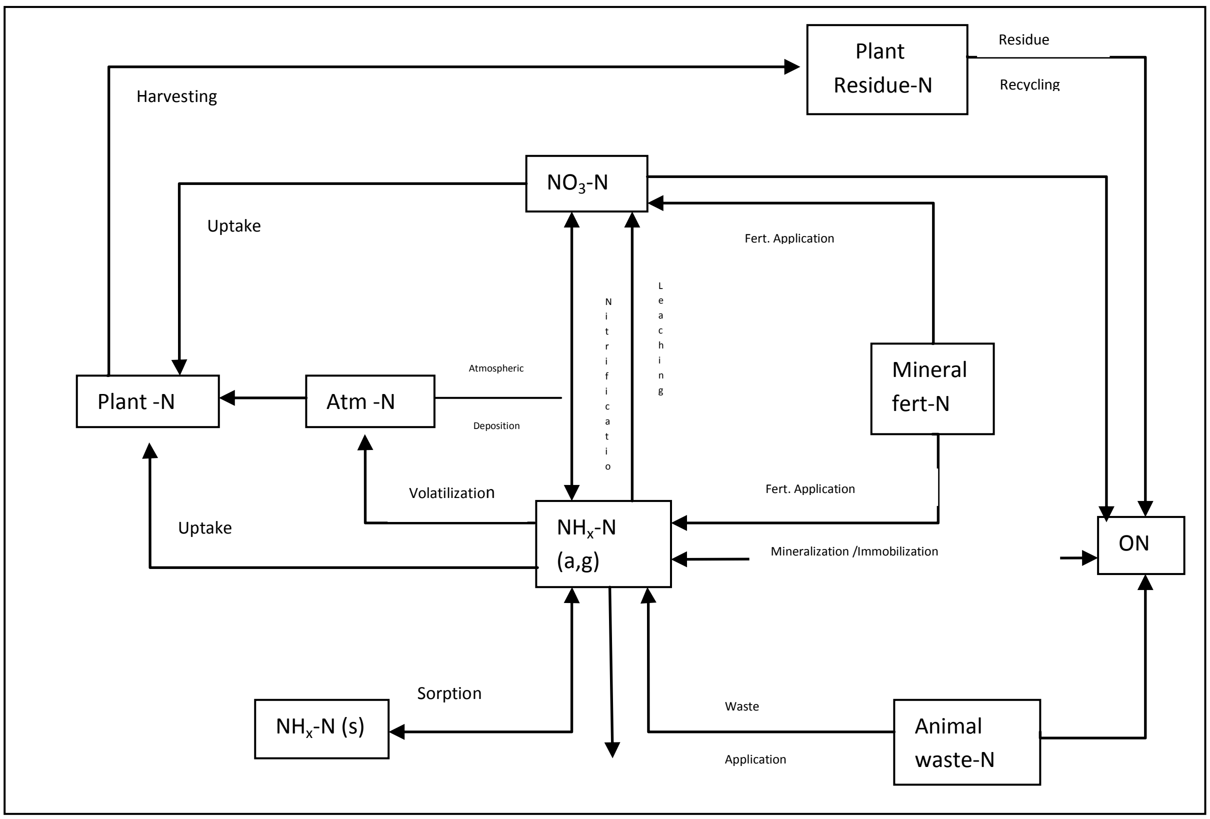

Fig. 1. The N cycle modeled in DRAINMOD-NII

Results and Discussion

Controlled Drainage – Subirrigation to minimize nutrient leaching

Bonaiti and Borin (2010) tested CD-SI as a strategy for continuous water table management with the benefits of optimizing water use and reducing nitrogen losses from agricultural field. The study revealed that CD-SI reduced total measured drainage flow by 77% and total nitrate-nitrogen losses by 70% when applied to subsurface drainage system as compared with open ditches drainage system where CD-SI reduced total measured drain and nitrate-nitrogen losses by 47 and 72 per cent respectively. Test also identified that nitrate-nitrogen concentration in ground water did not differ significantly at different depths and assumed that denitrification played a minor role in reducing nitrate-nitrogen losses.

Ingrid Wesstrom and Ingmar Messing (2007) conducted a 4 years field experiment with three plots having one conventional subsurface drainage and two by controlled drainage. In the study, positive effects of a temporarily raised groundwater level were seen during the vegetation season in three out of four years when controlled drainage plots compared to conventional drainage and improved N efficiency for applied fertilizer due to lower N loads in drain outflow and higher N uptake by crop. The yields in controlled drainage were 2-18 per cent larger and the crop uptake of N increased by 3-14 kg/ha, compared to conventional drainage. However the timing in peak losses of N did not differ between conventional and controlled drainage and positive correlation in N concentrations in drain outflow were found between drainage systems.

Borin *et al.,* (2001) quantified the order of magnitude of the NO3-N and salt balances in water for wetland, CD+SI conditions using lysimeter studies. The study shows the reduction of N losses because of enhanced evapotranspiration, which increased plant absorption as suggested by the fact that, at the end of the cycle, the plant biomass and N uptake were around 20 per cent higher than plants under conventional drainage. As a consequence, there is a lower amount of NO_3-N in the soil at the end of the growing season in CD + SI lysimeters. The effects of treatments were more evident referring to free drainage; NO_3-N losses were reduced by 46 to 63 per cent in controlled drainage and 95 per cent in the average wetlands. Wetlands also reduced losses of total dissolved solids from 250 gm^{-2} (average of crop treatments) to 175 gm^{-2} (average of wetlands).

A three year field study was conducted by Z. Jia *et al.*, (2006) and the effectiveness of controlled drainage and vegetative buffers on reducing the transport of wastewater nutrients was evaluated. Study showed a 30 per cent reduction in phosphorous concentrations and average concentration of nitrogen was not affected. Controlled drainage reduced the total drainage volume by 13 per cent; maintained by water tables for longer periods.

Simulation of water flow and Nutrient Transport

Understanding the factors influencing water and nutrient transport through soil profile is helpful for nutrient management to minimize the fertilizer losses, adverse impacts on environment and nitrate leaching below root zone. One of the mechanism by which controlled drainage reducing NO_3-N losses due to increased denitrification by maintaining a high water table, but the greatest reductions appears to be the result of a decrease in total drainage overflow (Gilliam, *et al.*, 1999). Subirrigation probably increases denitrification and crop N uptake, but also increases outflow volume (Skaggs and Breve, 1995). A wide range of simulation models developed by various agencies and available for simulating the water and nutrient transport. These models differ in the way they simplify the flow system and aggregates the process in a space and time domain. Therefore the projections of transport are likely to vary depending upon the choice.

Smeltz *et al.*, (2006) calibrated DRAINMOD-N on a field–by-field basis and predicted long-term hydrology and nitrate losses based on best management practices implemented. Daily simulated discrete NO_3-N concentration were compared with observed grab samples, predicted lower concentration in the drainage outflow that what were observed through field investigation. The results is attributed towards incorporating the best management practices and were partially dependent upon crop due to varying fertilization requirements. The study also revealed that the use of a nutrient management plan alone caused a greater NO-N reduction than controlled drainage alone.

Rahbari and Afshar Asl (2006) calibrated LEACHN and DRAINMOD-N to simulate nitrate transportation by adjusting nitrification, denitrification rate constants to reach the best fit between measured and predicted data. Results indicated that predicted nitrate concentration by models was close to measured nitrate concentration and the moisture and its process in growth period was predicted with considerable accuracy.

The performance of DRAINMOD-NII was evaluated by Youseff *et.al.*, (2006) using 6 years data set from an artificially drained agricultural research site, North Carolina. Authors explained about prediction of DRAINMOD-NII, as an excellent predicting tool for cumulative NO_3-N leaching losses over the entire simulation period. The strong dependence of DRAINMOD-NII performance in predicting NO_3-N leaching losses on the accuracy of sub-surface drainage prediction was manifested in the close association between predicted cumulative drainage and NO_3-N leaching losses. DRAINMOD-NII can be effective tool for the design of crop production systems on drained lands that minimize N losses to environmentally sensitive surface water. By simulating a wide range of management scenarios, it is easy to identify the set of management practices that are most effective and economically feasible for the agro-ecosystem.

Srinivasulu *et al.*, (2012) showed potential to provide information about the water and N mass balance and to quantify the effects of fertilizer application rate and controlled drainage on NO3-N losses using DRIANMOD-NII. The simulated N mass balance at the water quality field station showed N budget surpluses ranging from 36 to 54 kg ha^{-1} for the conventional drainage treatments from 1 to 15 kg ha^{-1} for the controlled drainage treatments, indicated that the fertilizer application rates to corn could further be reduced from the lowest rate at the site. Further simulation was done for N leaching to groundwater and results shows reduction by 3 to 10 per cent under controlled drainage and this is attributed to reduce nitrate concentration in soil water due to increased denitrification rates.

However majority of these studies did not include an examination of the internal cycling of N as affected drainage water management and other crop and fertilizer management practices. DRAINMOD-NII has not been tested for the high organic matter soils such as peat, silty ad mixed clay soils. The model might show negative effects from unsuitable conditions such as poor trafficability, yield reduction and biological clogging of sub-surface drains when controlled drainage is combined with reuse of outflows. It is difficult to accurately predict monthly N leaching losses due to the complex nature of N dynamics in soil-water-plant system. Therefore, field evaluations of models that simulate N dynamics are often based on yearly rather than monthly model predictions.

Conclusions:

Detailed understanding of solute transport is needed for reduction of drainage volume from non-point sources. The excessive use of fertilizers and pesticides in agriculture has been recognized as a potential source of environmental pollution especially in water quality and soil resources. Hence understanding the factors influencing water and nutrient transport through soil profile is helpful for nutrient management to minimize adverse impacts. Observed beneficial effects from controlled drainage- sub irrigation are increased efficiency of nitrogen fertilization and water use, increased yield and decreased nitrogen in outflow, primarily due to the reduction of total drained volumes. Hence controlled drainage - subirrigation system responses to watertable management and reduction in solute transport are crucially important technique from sustainable management of natural resources. Therefore, the technique should be considered in reduction of nitrogen losses through drain outflow compared to conventional drainage system because of temporarily raising the water table and consequence is more N uptake by plants and further denitrification will reduce the load in drainage volume. Giving the concern about the quality of the environment, many scientist and decision makers are interested in prediction of nutrient losses and hence developed different models as it provide useful insights into the flow and transport phenomena even though their solutions may not be adequate for describing transport processes in natural soils under field conditions.

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