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Fate of nitrogen for subsurface drip dispersal of effluent from small wastewater systems

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ABSTRACT

Subsurface drip irrigation systems apply effluent from onsite wastewater systems in a more uniform manner at a lower rate than has been possible with other effluent dispersal methods. The effluent is dispersed in a biologically active part of the soil profile for optimal treatment and where the water and nutrients can be utilized by landscape plants.

Container tests were performed to determine the fate of water and nitrogen compounds applied to packed loamy sand, sandy loam, and silt loam soils. Nitrogen removal rates measured in the container tests ranged from 63 to 95% despite relatively low levels of available carbon.

A Hydrus 2D vadose zone model with nitrification and denitrification rate coefficients calculated as a function of soil moisture content fit the container test results reasonably well. Model results were sensitive to the denitrification rate moisture content function. Two-phase transport parameters were needed to model the preferential flow conditions in the finer soils. Applying the model to generic soil types, the greatest nitrogen losses (30 to 70%) were predicted for medium to fine texture soils and soils with restrictive layers or capillary breaks. The slow transport with subsurface drip irrigation enhanced total nitrogen losses and plant nitrogen uptake opportunity.

1. Introduction

Individual onsite wastewater systems serve approximately 25% of U.S. households, and one in every three new homes built today use these systems. The standard onsite wastewater system consists of a septic tank for primary treatment followed by a gravity-fed leach field with gravel-filled deep dispersal trenches. According to the U.S. EPA (2000), failing and improperly managed onsite wastewater systems are a significant source of nitrate contamination in groundwater.

Subsurface drip systems hold promise for the application of effluent from small wastewater systems at shallower depths, over larger areas, and at lower rates than has been possible with other effluent dispersal methods. One of the ancillary benefits of subsurface drip irrigation is that water and nutrients (such as nitrogen) can be supplied more effectively to landscape plants, thereby conserving fresh water and reusing nutrients.

Nitrogen in septic tank effluent can be in the organic, ammonium, or nitrate forms, or some combination thereof, depending upon treatment processes. Organic nitrogen in the form of amino acids or urea is readily mineralized to ammonium. Ammonium is adsorbed by negatively charged clay and organic colloids in soil. The adsorbed ammonium is normally oxidized to nitrite and then nitrate within several days by nitrifying bacteria given warm temperatures and aerobic conditions.

Nitrate is removed through denitrification to nitrogen gas by facultative heterotrophic bacteria under anoxic conditions in

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the presence of adequate decomposable carbon. Nitrous oxide, a potent greenhouse gas, is an intermediate product of denitrification that can be partially lost from soil to the atmosphere. Nitrate can also be removed through denitrification by anaerobic ammonium oxidation (anammox) activity in soils even where there is insufficient organic carbon for heterotrophic denitrification (Gable and Fox, 2003). Remaining nitrate can be taken up by plants or is leached to groundwater (Broadbent and Reisenauer, 1986). The fate of nitrogen compounds in land-applied wastewater is shown graphically in Fig. 1.

Nitrogen fate and transport from subsurface drip irrigation of septic tank effluent have been investigated in several field studies. Sievers and Miles (2000) found localized downward movement of nitrogen from leach fields in the soil, but no nitrate increase in downgradient groundwater monitoring wells. Bohrer (2000) studied the performance of six subsurface drip irrigation septic tank effluent disposal systems in Wisconsin with a special emphasis on performance during winter months. Application rates varied from 0.33 to 3.1 cm/d. Organic nitrogen and ammonia levels were higher immediately under the drip systems than at deeper depths. The nitrogen levels in shallow soil were not significantly higher than background samples taken away from the drip systems.

Using suction lysimeters for vadose zone sampling, Atkins and Christensen (2001) found approximately 50% reduction in nitrogen with subsurface drip dispersal of oxidized septic tank effluent in well drained sandy soils, although they could not determine how much was attributable to losses and how much was attributable to dilution. The Electric Power Research Institute and Tennessee Valley Authority (EPRI and TVA, 2004) developed a comprehensive guide for the design and operation of wastewater subsurface drip distribution. The guide contained a recommended design denitrification factor of 15%, while acknowledging the need for additional studies to compare anaerobic and aerobic drip concepts. Subsurface drip irrigation provides the alternating aerobic/anoxic zones and accumulation of carbonaceous matter at the infiltrative interface that are favorable for high rates of nitrogen removal (McKinley and Siegrist, 2010).

Nitrogen transport from subsurface drip irrigation has been modeled in previous studies. Cote et al. (2003) described results of a simulation study designed to highlight the impacts of soil properties, irrigation frequency, and fertigation timing on water and solute transport from buried drip emitters using the Hydrus 2D model developed by Simunek et al. (1999). Based on the model, they identified the need to account for differences in soil properties and solute transport when designing irrigation and fertigation management strategies. Hanson et al. (2006) used an adapted version of Hydrus 2D to develop irrigation and fertigation tools that maximize agricultural production for surface and subsurface drip while minimizing environmental effects. Hanson used a constant first-order nitrification rate coefficient of 0.2/d and ignored denitrification. The model showed that nitrogen in the form of urea–ammonium–nitrate fertilizer had better effectiveness and less transport below the root zone than straight nitrate fertilizer.

Hassan et al. (2008) developed a 2-dimensional model using Hydrus-3D to simulate nitrogen transport for subsurface drip irrigation of sequencing batch reactor effluent from a commercial onsite wastewater system. The model output nitrate concentrations fit suction lysimeter data very well over a 500 day test period. Hassan used a constant first-order denitrification rate coefficient of 0.00223/h (0.054/d) for soil moisture potential values ranging between −6 and -157 cm. He obtained a 22% denitrification rate in an Evard fine sandy loam.

The scope of this study was to develop a methodology for estimating the fate of nitrogen from subsurface drip

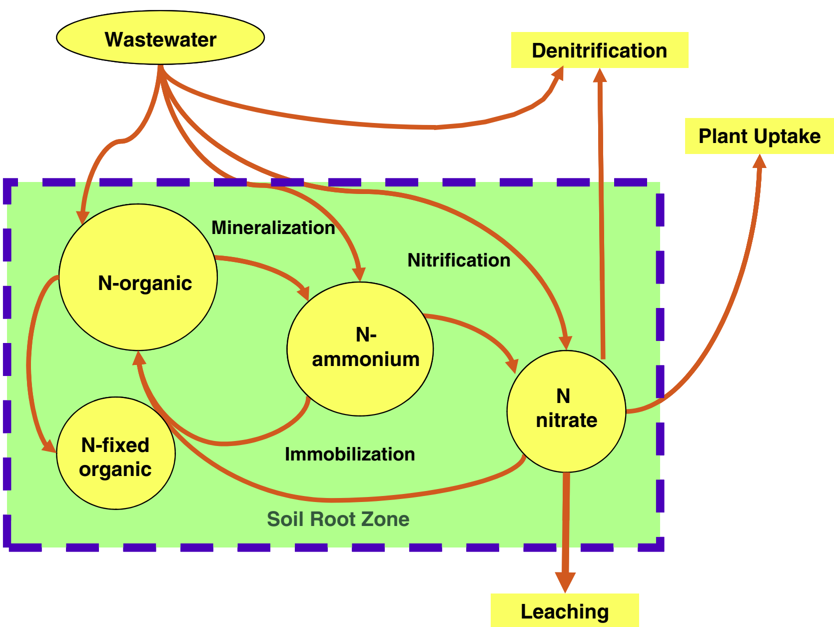

Fig. 1. Fate of nitrogen in wastewater effluent applied to land.