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Water movement and fate of nitrogen during drip dispersal of wastewater effluent into a semi-arid landscape

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ABSTRACT

Drip dispersal of partially treated wastewater was investigated as an approach for onsite water reclamation and beneficial reuse of water and nutrients in a semi-arid climate. At the Mines Park Test Site in Golden, Colorado, a drip dispersal system (DDS) was installed at 20- to 30-cm depth in an Ascalon sandy loam soil profile. Two zones with the same layout were established to enable study of two different hydraulic loading rates. Zones 1 and 2 each had one half of the landscape surface with native vegetation and the other with Kentucky bluegrass sod. After startup activities, domestic septic tank effluent was dispersed five times a day at footprint loading rates of 5 $L/m^2/d$ for Zone 1 and 10 $L/m^2/d$ for Zone 2. Over a two-year period, monitoring included the frequency and volume of effluent dispersed and its absorption by the landscape. After the first year of operation in October a ^{15}N tracer test was completed in the sodded portion of Zone 1 and samples of vegetation and soil materials were collected and analyzed for water content, pH, nitrogen, ^{15}N, and bacteria. Research revealed that both zones were capable of absorbing the effluent water applied at 5 or 10 $L/m^2/d$. Effluent water dispersed from an emitter infiltrates at the emitter and along the drip tubing and water movement is influenced by hydrologic conditions. Based on precipitation and evapotranspiration at the Test Site, only a portion of the effluent water dispersed migrated downward in the soil (approx. 34% or 64% for Zone 1 or 2, respectively). Sampling within Zone 1 revealed water filled porosities were high throughout the soil profile (>85%) and water content was most elevated along the drip tubing (17–22% dry wt.), which is also where soil pH was most depressed (pH 4.5) due to nitrification reactions. NH_4^+ and NO_3^- retention occurred near the dispersal location for several days and approximately 51% of the N applied was estimated to be removed by plant uptake and denitrification. Heterotrophic bacteria levels were elevated (up to 1 log) in the subsurface within the DDS but there was effective elimination of effluent fecal coliform and Escherichia coli bacteria.

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1. Introduction

Water supply, wastewater treatment, and landscape management are often viewed as independent components of urban and rural infrastructure. However, approaches and technologies involving decentralized water reclamation can be employed in all three components and provide synergistic benefits. A prime example is subsurface drip dispersal of wastewater to achieve effluent purification and enable reduced consumption of potable water by using effluent water and nutrients for turf irrigation. In a drip dispersal system domestic wastewater is collected and treated onsite or in a decentralized location to produce primary (e.g., by a septic tank) or secondary quality effluent (e.g., by a textile media biofilter). The effluent is then intermittently pumped into a network of small-diameter tubing outfitted with emitters which disperses effluent several times each day to yield low area-based hydraulic loading rates (HLRs) (e.g., 10 $L/m^2/d$) (Lesikar et al., 1998; Converse, 2003). Dispersal is targeted to occur in close proximity to the rhizosphere, the soil zone associated with plant roots and characterized by elevated interactions between the plant roots, soil microorganisms, and the soil itself (Atlas and Bartha, 1998). As an effluent treatment technology, a drip dispersal system (DDS) provides for a long residence time for effluent in the rhizosphere, which has the potential to enhance removal of pollutants and pathogens. Effluent delivered by a DDS might also accommodate plant water and nutrient requirements, thereby minimizing the need for irrigation with potable water amended with chemical fertilizers.

Nitrogen fate in a DDS is of particular interest since nitrogen is a key pollutant of concern in wastewaters and also a critical nutrient required for plant growth. In a DDS the water and nitrogen applied from an effluent can support plant growth due to the close proximity of plant roots to the effluent application zone. If excess nitrogen is applied, it could be removed by nitrification and denitrification, which could be enhanced by the cyclic aerobic/anoxic conditions caused by intermittent effluent dispersal, thereby minimizing the nitrogen input to local groundwater.

Research concerning DDS for onsite and decentralized applications has occurred during the past decade and applications have grown in the U.S. To date, most research has focused on effluent dispersal hydraulics (e.g. Berkowitz, 1999; Lesikar et al. 2002) including modeling (e.g. Berkowitz and Harman, 1999; Beggs et al., 2004, 2011); dispersal effects on soil hydraulic properties (e.g. Jnad et al., 2001); comparisons of DDS receiving different effluent qualities (e.g. Bohrer and Converse, 2001); and comparisons of DDS with other soil infiltration technologies (e.g. Costa et al., 2002). DDS design and operation guidance has been published (EPRI, 2004; NOWRA, 2006).

Drip dispersal of partially treated wastewater appears to be well suited for onsite water reclamation and beneficial reuse of water and nutrients in a semi-arid landscape. However, few systems have been installed and limited research had been carried out under landscape and environmental conditions typical of those in semi-arid regions. This paper describes controlled field research carried out in Colorado to investigate water movement and nitrogen behavior during drip dispersal of domestic septic tank effluent under conditions present in a semi-arid landscape.

2. Materials and methods

Two separate but otherwise identical DDS layouts were established at the Mines Park Test Site in Golden, Colorado (hereafter referred to as the Test Site) to enable effluent dispersal at two different HLR into landscapes with native buffalo and blue grama grasses or Kentucky bluegrass sod. Startup monitoring of general operation and performance was completed during November to January before adjustments were made to the effluent dispersal regime. Beginning in March the DDS was operated continuously over the next 23 mon. During this period the HLR and water quality applied to each zone of the DDS were measured and the ability of the landscape to absorb the effluent water was observed. Detailed examination of the DDS at the end of the first year of operation was conducted to gain an understanding of relevant flow and transport processes representative of a DDS after a full growing season. For this purpose, a ^{15}N tracer test was completed by adding $^{15}NH_4Cl$ to the effluent dispersed into Zone 1 (receiving 5 $L/m^2/d$). Then a section of the DDS was excavated and samples of vegetation and soil materials were collected within a 3-D region and analyzed for water content, pH, bacteria, nitrogen species, and ^{15}N enrichment.

2.1. *Description of the drip dispersal system*

The Test Site was established in 1998 on the Colorado School of Mines (CSM) campus in Golden, Colorado. At the Test Site, domestic wastewater is acquired from an 8-unit apartment building used for housing student families. Over the past decade the Test Site has been used for controlled research of onsite and decentralized systems for water reclamation including studies examining effluent characteristics, treatment units, and land-based treatment systems (e.g., Lowe et al., 2008; Siegrist et al., 2013). The Test Site is located at 1820–1823 m above mean sea level and includes a parcel of landscape in a natural undeveloped state with a slope of 5–7% (easterly aspect). The native vegetation is comprised of buffalo and blue grama grasses and the soil profile consists of Ascalon sandy loam (USDA, 1983; Lowe and Siegrist, 2002). Groundwater occurs between 3.1 and 6.2 m below ground surface (bgs) and the saturated hydraulic conductivity is in the range of 50 cm/d (at 75-cm bgs). During the first year of the study, the average monthly air temperatures ranged between 0.8 and 23.8 °C with the daily extremes ranging from −23.3 to 38.9 °C. The total precipitation amounted to 32.0 cm/yr with an average monthly values ranging from 0.58 to 6.9 cm/mon. The reference evapotranspiration rate (ET_{OS}) for the site amounted to 1.46 m/yr with a monthly range of 5.8–21.2 cm/mon (calculated using the standardized Penman–Monteith equation and ET parameter values from the National Renewable Energy Laboratory database: http://www.nrel.gov/midc/srrl_bms/).

The DDS established at the Test Site included two zones with the same layout details but separated by 4.6 m of undisturbed landscape. The layout for Zone 1 is presented in