Journal of Arid Environments 74 (2010) 1033–1040

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Factors contributing to nitrate accumulation in mesic desert vadose zones in Spanish Springs Valley, Nevada (USA)

Manoj Menon [a,*], Ronald T. Parratt [a], Christian A. Kropf [b], Scott W. Tyler [a]

[a] Department of Geological Science and Engineering, University of Nevada, Reno, NV 89557, USA
[b] Washoe County Department of Water Resources, 4930 Energy Way, Reno, NV 89502, USA

ARTICLE INFO

Article history:
Received 13 May 2009
Received in revised form
20 November 2009
Accepted 4 March 2010
Available online 2 April 2010

Keywords:
Ammonium
Chloride
C:N
Desert
Groundwater
Nitrate
Root density

ABSTRACT

Many desert soil profiles of the southwestern United States show substantial accumulations of nitrate beneath the active rooting zone. At present, the mechanisms and processes for such enrichment are not well understood. This study focuses on the role of availability of water (depth to groundwater), soil (C:N) and vegetation (root density) associated with vadose zone nitrate accumulation in mesic desert regions of Nevada. The field study was conducted at four locations in Spanish Spring Valley, Nevada under native vegetation (*Artemesia tridentata*, *Chrysothamnus nauseosus* or mixed) with varying groundwater depths. Soil samples were collected from shallow root zone (0–45 cm) and deep vadose zones and analysed for nitrate-nitrogen (NO_3^--N), ammonium (NH_4^+-N) and chloride (Cl^-). From the shallow root zone samples root densities and soil C:N were determined. Soil profiles developed under deep water table conditions showed an accumulation of NO_3^--N (800 mg l^{-1}) in the vadose zone, while very little nitrogen accumulation was found in presence of shallow groundwater location. Availability of water controlled vegetation (root growth) and soil C:N. We conclude that soil resources (water and organic carbon) and rare leaching events are the primary factors lead to accumulation of NO_3^--N in this region.

1. Introduction

Until the recent discovery of extremely high soil-water concentrations of NO_3^--N below the root zones of desert ecosystems (Edmunds and Gaye, 1997; Hartsough et al., 2001; Walvoord et al., 2003), it was believed by researchers that desert ecosystems were N limited (Gebauer and Ehleringer, 2000; Whiteford, 2002; James and Richards, 2006). Typically, the subsurface NO_3^--N accumulation is found 1–2 m below the soil surface. The soil-water NO_3^--N concentrations can reach up to 3000 mg l^{-1} which is far beyond the maximum contaminant level for NO_3^--N (10 mg l^{-1}) in drinking water set by United States Environmental Protection Agency. This "reservoir" (Walvoord et al., 2003) of NO_3^--N found in the vadose zone can pose a serious threat to groundwater quality if leached down by natural or anthropogenic influences. Elevated groundwater NO_3^- concentrations have been reported as early as the 1970s (Hess and Patt, 1977) in the area of Las Vegas, United States (Southern Nevada). A recent report shows that soil NO_3^--N reservoirs have caused an abnormal increase of NO_3^--N in the drinking water supplies of Arizona (Bushner et al., 2008).

It was suggested that natural NO_3^--N reservoirs are a result of accumulation (Wallace et al., 1978; Hartsough et al., 2001; Stokstad, 2003; Walvoord et al., 2003) over several thousands of years. The NO_3^--N accumulation is reported mostly below what is considered the "active" root zone. The mechanisms of NO_3^--N accumulation are not very clear (Edmunds and Gaye, 1997). However, the main sources of N inputs are atmospheric deposition (50–60 mg m^{-2} yr^{-1}) and biological N fixation ($\sim$10 mg m^{-2} yr^{-1}) in this region (Wallace et al., 1978; Hartsough et al., 2001). In addition, insects such as termites and vertebrate animals may also be sources of NO_3^--N in the desert subsurface (Barnes et al., 1992). However, these sources are likely to be significant only in limited settings.

While the sources of desert vadose zone nitrogen are now becoming well understood, several key questions remain regarding both the vertical and horizontal spatial variability in nitrogen accumulation. In the vertical, very large concentrations and concentration gradients in NO_3^--N have been observed (Hartsough et al., 2001). Most have attributed these nitrogen "bulges" to idealized root water extraction and exclusion similar to that suggested for chloride accumulation. Rare infiltration events are postulated to move the excess chloride and nitrogen deep in the

* Corresponding author. Present address: School of Earth and Environment, University of Leeds, LS29JT, UK. Tel.: +44 113 343 1635; fax: +44 113 343 6716.
E-mail address: m.menon@leeds.ac.uk (M. Menon).

0140-1963/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaridenv.2010.03.005

vadose zone, where it accumulates and subsequently concentrates as soil water is removed by scavenging roots. While perhaps appropriate for chloride, which may be excluded from uptake, it is more challenging to accept that such exclusion would always hold for nitrogen, an essential nutrient. Although not the focus of this work, further consideration of the concentration mechanisms for both chloride and nitrogen are warranted (Yin et al., 2008).

In the horizontal, not all desert soil profiles show the same magnitude of accumulation of NO_3^--N and it has been suggested (Jackson et al., 2004) that the distribution of native vegetation and precipitation patterns may strongly influence the degree of NO_3^--N accumulation. Marion et al. (2008a, b) demonstrated the dynamics and accumulation of NO_3^--N using CALGYP model and concluded that the NO_3^--N patterns may simply reflect the modest N needs of these low productivity desert vegetation. However, data on N requirement are not available for many native desert plants.

The root zone of vegetation provides the energy source, i.e., carbon, for the heterotrophic microbial population by different processes such as root turn-over, litter fall (Uselman et al., 2007) and root exudations (Berg and Smalla, 2009). These processes control the carbon to nitrogen ratio (C:N) in the soil. The C:N ratio determines the balance between ammonification and immobilization processes and release of N in soils (Reddy and DeLaune, 2008). Soils with low C:N are susceptible to N leaching (Rowe et al., 2001). Both the spatial distribution of root growth and downward extent of the root zone were shown to affect the dynamics of N cycling in desert soils (Schlesinger and Pilmanis, 1998). Schaeffer et al. (2003) compared the difference between microbial processes (nitrification and denitrification) in interspace and under the canopy (root zone) of *Larrea tridentata*, *Pleuraphis rigida,* and *Lycium* spp. Interspace soil exhibited substantially lower rates of net nitrification and denitrification compared to soils from under plant canopies, which may be due to the difference in availability of C in the root zone. Availability of C in the root zone could favour microbial activity and cause immobilization of N. When the soil water depletes, microbes die and release the immobilized N (Schaeffer and Evans, 2005). Loss of NO_3^--N can also occur via denitrification, which also requires organic carbon and water (Peterjohn and Schlesinger, 1990; Peterjohn, 1991; Schlesinger and Peterjohn, 1991). Due to sparse vegetation and low organic matter reserves in many deserts (West et al., 1994), the denitrification processes may be limited in time and space. Therefore, apart from availability of water the role of organic carbon (C:N) appears to be an important factor to be considered to explain the NO_3^--N accumulation in the desert vadose zones.

Although there were several studies focused on biogeochemical cycles in deserts, particularly in the root zone, there is still a missing link between studies of biological processes in shallow root zones and the accumulation of nutrients in the deeper vadose zones. In order to observe an NO_3^--N accumulation in the soil, sources must exceed biological sinks (processes such as plant uptake, microbial immobilization, denitrification, volatilization, etc.) and leaching losses. Quantification of these processes at the same time is extremely difficult. However, it is well established fact that these biological processes are controlled by the availability of water (e.g. Austin et al., 2004) and organic carbon (e.g. Peterjohn, 1991) in desert settings. In desert ecosystems, precipitation pulses are often small and hence the possibility of deep leaching events is limited (Tyler et al., 1996; Scanlon et al., 1997). Therefore, biological processes are mostly restricted to the root zone of the vegetated deserts (Schaeffer et al., 2003). Based on this, we hypothesise that the availability of soil resources (water and carbon) in the shallow root zone controls enrichment of N in the desert vadose zone.

The objective of this research work is to identify the role of water availability, soil C:N and vegetation (e.g. root growth) and link to NO_3^--N accumulation in desert vadose zones. The study sites are chosen to represent undisturbed soils, i.e., sites which have not experienced significant vegetation or land use changes due to urbanization. Although some sites do show evidence of change in the net infiltration due to urbanization and agricultural practices in the past, the nitrate accumulation processes can still be elucidated. In this work, we present data showing, surprisingly, that accumulation of NO_3^--N is also occurring under the more mesic and cold desert conditions found in the Great Basin province of the western United States. We report and analyze the root zone parameters (soil C:N and root density) from locations with various degree of NO_3^--N accumulation in vadose zone.

2. Materials and methods

2.1. Study area

This study was conducted in Spanish Springs Valley (39°66′–39°40′ N and 119°44′–119°40′ W), northeast of Reno, Nevada, USA. The valley is ~155 km^2 and is considered to be a mesic, cold, high elevation (1377 m above MSL) desert. The average summer and winter temperature is 22 °C and 2 °C, respectively. Precipitation in the area is primarily received during the winter months. The average precipitation for the area is 188 mm yr^{-1}, with January generally being the wettest month with an average of 28 mm. (National Weather Service, http://www.cnrfc.noaa.gov/rainfall_data.php).

There are no natural perennial streams in the valley, although historically, springs have discharged in the southern end of the closed valley (Fig. 1). From the early 1970s to the mid 1990s over 2000 septic systems were installed within Spanish Springs Valley, Nevada (Rosen et al., 2006). The area is rapidly becoming urbanized and water for both domestic use and irrigation is acquired via wells throughout the valley and via wholesale water provided by a water purveyor. Water is also imported from the Truckee River via the Orr Ditch into Spanish Springs Valley and is estimated to provide 54% of the annual recharge to the groundwater in the valley (Berger et al., 1997). Groundwater discharges into the North Truckee Drain where it flows out to the south end of the valley. Groundwater also discharges through evapotranspiration and subsurface outflow to the southern and northern parts of the valley (Berger et al., 1997). The depth to groundwater varies significantly through the valley, ranging from ~60 m to at or near the land surface. The basin-fill aquifer in the valley is primarily unconsolidated, interbedded deposits of gravel, sand, silt, and discontinuous lacustrine clay. These deposits are highly permeable and commonly transmit water rapidly (Berger et al., 1997; Rosen et al., 2006).

The Washoe County Department of Water Resources is now closely monitoring this valley because of the increased NO_3^--N concentrations in many of their monitoring wells (MW). Our research has been conducted at four separate monitoring well locations (MW19, MW25, MW32, and MW33) within the Spanish Springs Valley area (Fig. 1) installed in support of a groundwater monitoring program. The depths to groundwater (yearly average) of MWs were 118.16, 12.10, 74.17 and 105.65 for MW19, MW25, MW 32 and MW33, respectively. The NO_3^--N concentration in groundwater in these wells are showing increasing trend over the past years and the latest values are 8.21, 1.13, 0.2 and 1.34 mg l^{-1} for MW19, MW25, MW32, and MW33, respectively (source: Washoe County Deparment of Water Resources, Reno, Nevada).

The criteria used in choosing these four “representative” sites were based on the vegetation, the accessibility for future vegetation sampling and shallow coring, proximity to monitoring wells (as close as possible), the geographical location (away from residential areas or other disturbances of the land surface conditions), the depth of the water table and the concentration of NO_3^--N in the