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Effects of zeolite application on nitrate and ammonium retention of a loamy soil under saturated conditions

A. R. Sepaskhah[A,B] *and F. Yousefi*[A]

[A]Irrigation Department, Shiraz University, Shiraz, Islamic Republic of Iran.
[B]Corresponding author. Email: sepas@shirazu.ac.ir

Abstract. Nitrogen (N) loss from irrigated cropland, especially in rice paddies, results in low N-use efficiency and groundwater contamination. Soil conditions that increase ammonium and nitrate ion retention alleviate these problems. Clinoptilolite, a naturally occurring zeolite with high-exchange capacity, may be used to absorb ammonium and retard excess leaching of nitrate. The objectives of this research were to determine the effects of different rates of Ca–K-zeolite application (0, 2, 4, and 8 g/kg soil) on pore water velocity and leaching of ammonium and nitrate applied as ammonium nitrate fertiliser to a loam soil at a rate of 350 kg N/ha under saturated conditions similar to that of a rice paddy. The results indicate that Ca–K-zeolite applications of 4 and 8 g/kg soil increase the pore water velocity by 35% and 74%, respectively. The maximum relative concentration (c/c_o) for the nitrate breakthrough curve occurring at pore volume of about 0.5 was reduced by 15% with a zeolite application rate of 8 g/kg soil. When applying 40 cm of leaching water, leached nitrate was 75% and 63% of total applied nitrate at the soil surface with zeolite applications of 4 and 8 g/kg soil, respectively. Due to the high ion exchange capacity of zeolite, the application of zeolite at 2 g/kg soil is enough to increase the exchange sites in the soil in order to absorb the applied ammonium and prevent its leaching by the inflow water. The maximum ammonium concentration in the breakthrough curve for the zeolite application rate of 2 g/kg soil was reduced by 43% compared with the control treatment. The relationship between the hydrodynamic dispersion coefficient (D) for nitrate and pore water velocity (v) was not linear and it was correlated with squared pore water velocity. The coefficient of the relationship between D and v^2 was dependent on the zeolite application rate and linearly increased with this rate.

Additional keywords: nitrate displacement, ammonium displacement, nitrate diffusion coefficient, mean pore radius.

Introduction

Nitrogen (N) loss from irrigated cropland, particularly sandy soils, due to net repulsion of nitrate (NO_3^-) from negatively charged soil particle surfaces, contributes significantly to nitrate contamination in surface and groundwater and increases N application requirements to crops. Therefore, N-use efficiency is low in crop production (Vlek and Byrnes 1986; Pirmoradian *et al.* 2004). Farmers try to mitigate this problem in several ways, i.e. split nitrogen application, utilisation of slow release fertilisers, and incorporation of soil amendments that increase ammonium and nitrate ion retention. Because of its high exchange capacity, clinoptilolite, a naturally occurring zeolite, has often been used as an inexpensive cation exchanger to control ammonium (NH_4^+) release (Allen *et al.* 1993, 1996). Even so, nitrification of NH_4^+ still contributes to groundwater NO_3^- contamination.

To retard the movement of anionic species, minerals with high affinity for anions are needed. It has been found that surfactant-modified zeolite (SMZ), an inexpensive anion exchanger used as a fertiliser carrier to control nitrate release, can fulfill this requirement (Li and Bowman 2002). The surfactant molecules form bi-layers on zeolite surfaces and the zeolite reverses its surface charge, resulting in a higher affinity for negative charged anions. When a mixture of soluble NO_3^- and zeolite is leached, the effluent NO_3^- concentration is quickly decreased to <0.2 mM with <2 pore volume of water used. In contrast, the effluent NO_3^- concentration remains >0.3 mM when NO_3^- loaded SMZ is flushed with >50 pore volumes of water (Li and Bowman 2002).

Zeolite tuffs are widely distributed in huge deposits in different regions of the Islamic Republic of Iran (Kazemian 2002). Clinoptilolite tuffs with a zeolite content of 75–95% are the most abundant natural zeolites (Kazemian 2002). Although there are a few active zeolite mines providing several types of natural and modified zeolite products for agricultural use and soil amendments, rare official reports are published to the present day on their use.

Pepper *et al.* (1982) applied a clinoptilolite type of zeolite at a rate of 8% to a sandy soil and indicated a decrease in NO_3^- and NH_4^- leaching and an increase in the N-use efficiency of turf grass. Application of 8 t/ha of zeolite along with 60 kg/ha of N as urea to a light-textured soil increased the rice yield, whereas its effect was not pronounced in the heavy-textured soil (Kawoosi and Rahimi 2000). However, no data were shown on the amounts of nitrate leaching for different application rates of zeolite in the light-textured soil, and the water table was high in their experimental field. Um and Jung (1988) indicated that application of zeolite in pots with drainage for

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