Assessment of nitrate transport parameters using the advection-diffusion cell

Taiseer Aljazzar$^1$ · Mohammed Al-Qinna$^2$

Received: 17 February 2016 / Accepted: 10 August 2016
© Springer-Verlag Berlin Heidelberg 2016

Abstract This study aimed to better understand nitrate transport in the soil system in a part of the state of North Rhine-Westphalia, in Germany, and to aid in the development of groundwater protection plans. An advection-diffusion (AD) cell was used in a miscible displacement experiment setup to characterize nitrate transport in 12 different soil samples from the study area. The three nitrate sorption isotherms were tested to define the exact nitrate interaction with the soil matrix. Soils varied in their properties which in its turn explain the variations in nitrate transport rates. Soil texture and organic matter content showed to have the most important effect on nitrate recovery and retardation. The miscible displacement experiment indicated a decrease in retardation by increasing sand fraction, and an increase in retardation by increasing soil organic matter content. Soil samples with high sand fractions (up to 94 %) exhibited low nitrate sorption capacity of less than 10 %, while soils with high organic matter content showed higher sorption of about 30 %. Based on parameterization for nitrate transport equation, the pore water velocity for both sandy and loamy soils were significantly different ($P < 0.001$). Pore water velocity in sandy soil (about $4 \times 10^{-3}$ m/s) was about 100 to 1000 larger than in loamy soils ($8.7 \times 10^{-5}$ m/s). On the other hand, the reduction in nitrate transport in soils associated with high organic matter was due to fine pore pathways clogged by fine organic colloids. It is expected that the existing micro-phobicity increased the nitrate recovery from 9 to 32 % resulting in maximum diffusion rates of about $3.5 \times 10^{-2}$ m/s$^2$ in sandy soils (sample number CS-04) and about $1.4 \times 10^{-7}$ m/s$^2$ in silt loam soils (sample number FS-02).

Keywords Nitrate · Soil · Groundwater · Advection-diffusion cell · Transport · Sorption · Retardation

Introduction

Nitrate pollution is a worldwide environmental problem (Andrade and Stiger 2009; Choi et al. 2007; Wakida and Lerner 2005; Addiscott 2006). Nitrate can bypass the vadose zone and leach into groundwater system and thus might undergo different processes, mainly sorption and denitrification (Scott 2000). Therefore, understanding nitrate dynamics in the soil system is crucial for land use management, soil and groundwater protection and remediation. This understanding should thoroughly assess nitrate transport processes such as retardation and adsorption. These processes depend on a wide set of parameters in the subsurface system, e.g., soil mineralogy, soil organic matter, nitrate concentration, pH and the presence of other solutes (Qafoku et al. 2000; Haag and Kaupenjohann 2001; Luo et al. 2003; Al-Darby and Abdel-Nasser 2006).

Several previous studies attempted to understand nitrate adsorption and retardation in soil showed that nitrate transport in heavy clay soil occurred mainly via preferential flow (Bronswijk et al. 1995). A nitrate adsorption from 0 to 34 % was found in 18 samples representing 11 soil types based on a series of batch experiments (Kowalenko and Yu 1995).