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Bromide and lithium transport in soils under long-term cultivation of alfalfa and wheat

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ABSTRACT

The combined effects of two soil textures and two types of crop management were investigated using lithium and bromide tracers transport under saturated flow conditions. Leaching tests were carried out through intact columns of two soils, a clay loam (CL) and sandy loam (SL), each cropped with either wheat (*Triticum aestivam*) (W) or alfalfa (*Medicago sativa*) (A) for 11 years. A saturated steady state flow condition was established using tap water prior to injecting a pulse of 0.005 M LiBr solution onto the surface of the soil columns. Breakthrough curves (BTCs) for leached Br^- and Li^+ in the soil columns (especially under alfalfa cultivation) exhibited an early arrival time and greater concentrations, indicating preferential flow effects. Relative 5% arrival times were 0.07, 0.11, 0.24 and 0.31 for CL-A, SL-A, CL-W, and SL-W, respectively; its smaller values confirmed the higher possibility of preferential flow under alfalfa than under wheat. The Br^- concentration was higher than the Li^+ concentration. With the exception of soils under alfalfa (CL-A and SL-A), the peak of the BTCs for Br^- occurred earlier than that for Li^+, by about 0.4 and 1.2 pore volumes for the CL-W and SL-W cases, respectively. Clay loam soil under alfalfa showed higher Br^- and Li^+ concentration levels when compared to sandy loam soil under alfalfa crop production. In the soils under alfalfa cultivation, structural cracks, root channels, and earthworm burrows were the cause of higher leached concentrations for both tracers when compared to the soil under wheat. Therefore, alfalfa-induced changes in soil structure lead to continuous macropores, a result of the decomposition of penetrating roots. Our results show that agricultural-management practices (i.e. the type of cropping) can play an important role in making groundwater vulnerable to leached solutes.

1. Introduction

The contamination of water resources by various chemicals is of significant concern for water quality, motivating the need for research into the transport of these chemicals in soils (Caron et al., 1996; Gish et al., 1991a; Edwards et al., 1997; Mohanty et al., 1998). Factors such as rapid preferential flow and the transport of solutes through large pores and cracks in substrates have been linked to high concentrations of solute contaminants in groundwater (Topp and Davice, 1981; Kanwar, 1991). Studies have shown that both soil texture and long term tillage and crop management practices have a strong influence on soil properties such as pore volume, pore-size distribution, and pore-network (Mahboubi et al., 1993; Lal and Van Doren, 1990; Lal et al., 1990, 1994). Aside from the accepted benefits of conservation tillage (decreasing soil erosion and reducing pollution of surface water), researchers have shown that conservation tillage leads to increased leaching of chemicals to groundwater resources (Edwards et al., 1997; Steenhuis et al., 1990b; Gish et al., 1991b). Lal and Van Doren (1990) found that in the soils of central Ohio, no-till plots had higher infiltration rates than tilled plots. Mahboubi et al. (1993) reported that hydraulic conductivity was significantly higher in no-tillage treatments than both moldboard plowing and chisel plowing treatments.

Other important factors that can significantly modify soil structural properties include differences in antecedent soil properties,

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climate conditions, soil texture, history of cultural management and wheel tracks (Mahboubi et al., 1993; Schwartz et al., 2003). It was found by Koestel et al. (2011) that preferential flow is directly related to the soils with more than 8% clay content. It has been reported that soil hydraulic properties, soil structure, pore volume, pore-size distribution, and bulk density are affected by land use and agricultural management practices (Afyuni et al., 1994; Caron et al., 1996; Edwards et al., 1993; Hu et al., 2009). Bormann and Klaassen (2008) noted that soil structure and the geometry and volume of pores can vary over time and are strongly influenced by soil biological activity and the land use.

Numerous studies have shown that the infiltration capacity and leaching behavior of solutes are strongly affected by the type of soil and its hydraulic properties (Knappe et al., 2002; van Es et al., 2006). Zhou et al. (2008) reported that differences in soil hydraulic properties were impacted more by the type of vegetation than by the type of soil. Soil pore networks are believed to be improved by both meadow and leguminous cover crops (Lal et al., 1990, 1994). The strong taproot of alfalfa has also been reported to increase the hydraulic conductivity of soils under or close to saturated conditions (Caron et al., 1996). It was concluded by Caron et al. (1996) that a change from corn to alfalfa significantly impacted hydraulic conductivity and thereby solute transport relative to lands cropped with corn. Perfect et al. (1990) and Chantigny et al. (1997) reported improved soil hydraulic properties attributed to land use and land cover. Alfalfa cultivation has also been reported to significantly increase soil hydraulic conductivity relative to soils that are under corn cultivation (Li and Ghodrati, 1994). Alfalfa, as a perennial and long-lived plant, constructs larger and deeper root systems than wheat as an annual and short-lived plant (Huggins et al., 2001); thereby, preferential flow paths could be created by decaying alfalfa root system as a result of increased total porosity and continuous macropores (Rasse and Smucker, 1998). Gibbs and Reid (1988) reported that the large numbers of pores formed by root were classified as macropores.

As indicated above, most studies have evaluated how various factors affect soil hydraulic properties near the soil surface or the leaching of nutrients (Bormann and Klaassen, 2008; Bachmair et al., 2009). However, knowledge about their indirect influence on water flow, groundwater recharge, and solute transport is lacking. The question remains whether these changes near the soil surface, resulting from different land use and land cover, have any net effect on groundwater recharge over long time periods or whether they just impact soil structure. Particularly for semiarid region agricultural soils, it is important that we understand the influence of land use (tilled or no tilled) and different plant covers, not only on the development of soil structure and soil hydraulic properties, but also on water flow and solute transport. As mentioned above, structural heterogeneities, such as changes in soils due to vegetation and treatment, can result in water flux heterogeneities and/or preferential flow.

The objective of this study is to provide a better understanding of tracers transport through undisturbed soil columns collected from cultivated soils in natural conditions under land cover as well as land use effects on soil saturated hydraulic properties over long time periods. Soil hydraulic properties, solute transport and leached concentrations were measured to develop an understanding of differences between different land covers (alfalfa, and wheat) and common annually tillage implantation in wheat cultivation and no-tilled condition in alfalfa cultivation. Since there is a demand for a better understanding of the environmental and management controlling factors on solute leaching, the present study assesses the impact of (i) two contrasting land use systems (alfalfa and wheat) and (ii) two texturally different soil (clay loam and sandy loam) on the leaching of two conservative and non-conservative tracers (Br^- and Li^+).

2. Materials and methods

2.1. The study site and soil properties

The soils were collected from the 0 to 30 cm horizon of two sites of sandy loam (SL) and clay loam (CL) soils that were classified as Typic Xerorfluvents and Typic Haploxerepts, respectively, according to USDA classification (Soil Survey Staff, 2010). These soils were collected from the province of Hamadan in western Iran during the early fall in 2008. Each soil had been under cultivation of either wheat, *Triticum aestivam* L. (Gramineae) (conventionally tilled) or alfalfa, *Medicago sativa* L. (Legume) for 11 years. It should be noted that the samples were taken from a small flat plot (50 cm × 50 cm) with minimum sampling space. The plots were under the same plant density and no visible crack and fracture was observed in the plots.

Selected physical and chemical properties of the soil are given in Tables 1 and 2, respectively. The soil pH was measured in water (ratio of soil:water 1:2.5) (Jackson, 1967). Soil electrical conductivity (EC) was determined using an EC-meter in 1:5 soil:water suspension (Rhoades, 1996). Calcium carbonate ($CaCO_3$) content of soil was measured using the back-titration method (Sims, 1996). Total organic carbon was determined using the wet-digestion method (Walkly and Black, 1934). Cation exchange capacity (CEC) was measured using 1 mol L^{-1} ammonium acetate (pH = 7 NH_4OAC) method (Kacar, 1995).

The particle size distribution was determined using the hydrometer method (Bouyoucos, 1962). The particle density was measured by the pycnometer method (Gee and Bauder, 1986). Bulk density was measured on the undisturbed soil cores with 5 cm diameter and 7.5 cm height (Klute, 1986). Total porosity was calculated from bulk density (BD) and particle density (PD), (TP = 1 − BD/PD). Pore size distribution was determined from the water retention curve obtained with the pressure plate method. The relative volume of the pores with effective diameters greater than 30 μm was defined as macropores (Macro-P) (Danielson and Sutherland, 1986). Mean weight diameter (MWD) of soil aggregates was determined by the wet-sieving method (Yoder, 1936). Saturated hydraulic conductivity (K_s) of the soil was measured by the constant-head procedure (Klute and Dirksen, 1986).

2.2. Soil column samplings procedure

The laboratory experiments were conducted on undisturbed soil columns that had two different textures (sandy loam, SL and clay loam, CL) and were cultivated with two different cropping practices (wheat, W and alfalfa, A) under saturated flow condition. It is known that root morphologies and physiologies of alfalfa and wheat significantly differ, as a consequence the movement of water and solutes through the soils could be considerably different. Alfalfa has an extensive taproot which may penetrate the soil 7–9 m. It is not unusual, however, for the root system to be highly branched whereas the mature root system of wheat ordinarily reaches a maximum depth of 30–150 cm (Meek et al., 1990; Mitchell et al., 1995; Caron et al., 1996; Aggarwal et al., 2006).

The undisturbed soil column samples were taken using galvanized cylinders with a 3 mm wall thickness, a 16 cm inner diameter, and a 32 cm length. The inner wall of the cylinders was moistened by liquid paraffin to prevent the possibility of flow along the soil column interface and to facilitate the insertion of the cylinder into the soil. In total, four column types were sampled: (1) sandy loam columns under wheat cultivation (SL-W); (2) sandy loam columns under alfalfa cultivation (SL-A); (3) clay loam columns under wheat cultivation (CL-W); and (4) clay loam columns under alfalfa cultivation (CL-A). All columns were sampled in four replicates for a total of sixteen soil columns.