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Effects of Pisha sandstone content on solute transport in a sandy soil

Qing Zhen [a, c], Jiyong Zheng [a, b], Honghua He [a, b], Fengpeng Han [a, b], Xingchang Zhang [a, b, *]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China
[b] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- Pisha sandstone can successfully impede solute transport in a sandy soil column.
- Pisha sandstone impeded the breakthrough of Br^- and Na^+ by decreasing the saturated hydraulic conductivity.
- Pisha sandstone impeded the breakthrough of Na^+ also by increasing the adsorption capacity of the soil.

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ABSTRACT

In sandy soil, water, nutrients and even pollutants are easily leaching to deeper layers. The objective of this study was to assess the effects of Pisha sandstone on soil solute transport in a sandy soil. The miscible displacement technique was used to obtain breakthrough curves (BTCs) of Br^- as an inert non-adsorbed tracer and Na^+ as an adsorbed tracer. The incorporation of Pisha sandstone into sandy soil was able to prevent the early breakthrough of both tracers by decreasing the saturated hydraulic conductivity compared to the controlled sandy soil column, and the impeding effects increased with Pisha sandstone content. The BTCs of Br^- were accurately described by both the convection-dispersion equation (CDE) and the two-region model (T-R), and the T-R model fitted the experimental data slightly better than the CDE. The two-site nonequilibrium model (T-S) accurately fit the Na^+ transport data. Pisha sandstone impeded the breakthrough of Na^+ not only by decreasing the saturated hydraulic conductivity but also by increasing the adsorption capacity of the soil. The measured CEC values of Pisha sandstone were up to 11 times larger than those of the sandy soil. The retardation factors (R) determined by the T-S model increased with increasing Pisha sandstone content, and the partition coefficient (K_d) showed a similar trend to R. According to the results of this study, Pisha sandstone can successfully impede solute transport in a sandy soil column.

1. Introduction

Studies of water movement and contaminant transport in soils are currently receiving increased attention(Al-Qinna et al., 2014). It has been reported that many contaminant transport solutes bypass the soil matrix, including pesticides (Xu et al., 1999; Hantush et al., 2000; Köhne et al., 2009; Larsbo et al., 2013; Prado et al., 2014), viruses (Sim and Chrysikopoulos, 2000; Ojha et al., 2011), nutrients such as nitrogen and phosphorus (Sinaj et al., 2002; Akhtar et al., 2003; Djodjic et al., 2004; Wang et al., 2013), and heavy metals such as Cd, Cu, Zn, and Pb (Lichner et al., 2006; Kim et al., 2008; Sayyad et al., 2010; Chotpantarat et al., 2012; Janetti et al., 2013). These solutes may pose risks to the environment. Therefore, research on the behavior of solutes in soil is driven by the need to manage and prevent the possible means of contamination.

Soil texture and structure significantly impact water flow and the transport of contaminants in soils (Kodešová et al., 2009). Due to its homogeneous particle size and low percentages of silt and clay, sandy soil retains both water and nutrients poorly. Through a lysimeter experiment, Vogeler et al. (2006) showed that 60% of the nitrate content of sewage sludge was lost by leaching when applied to a sandy loam soil. Measures have therefore been taken to

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* Corresponding author. State Key Laboratory of Soil Erosion and Dryland Farming on Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China.
E-mail address: zhangxc@ms.iswc.ac.cn (X. Zhang).

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improve the physical qualities of coarse-textured soils, among which the application of various soil conditioners to soils is widely practiced. Both natural organic soil conditioners (Gupta et al., 1977; Schjønning et al., 1994; Lindsay and Logan, 1998; Nyamangara et al., 2001) and synthetic organic soil conditioners (Al-Darby, 1996) are applied to sandy and sandy loam soils, with these studies finding that the application of both types of soil conditioners can improve some of the physical qualities of soil, such as the soil water holding capacity.

The total area of Shanxi, Shaanxi and Inner Mongolia's border region in northwest China is 5.44×10^4 km^2, and the main soil types are aeolian sandy soil and loess soil, meanwhile, 1/3 of the area are distributed of loose rock known as Pisha sandstone (some people translate it as “Feldspathic Sandstone” or “Soft Rock”). Mu Us Desert is located in this region, and some studies found that the soil nutrients of this area were low and easy to lose (Wang et al., 2009). Pisha sandstone is a type of loose rock that is specifically identified as an interbedded sandstone composed of thick layers of sandstone, sandy shale and shale that formed in the Permian (approximately 250 million years ago), Triassic, Jurassic and Cretaceous (Yuanchang et al., 2007). It is a continental clastic sandstone series. The rock's history of low pressure conditions, which is due to the small thickness of overburden rock, results in a low degree of diagenesis, a low degree of sand cementation and poor structural strength (Yuanchang et al., 2007). However, the rock becomes muddy when exposed to water. As a result of its natural physical, chemical characters and the special local natural and cultural environment, it is easy to be eroded and the local people are deeply endured the hazards of its severe soil erosion. Chinese government attaches great importance to the controlling Pisha sandstone, and have launched a number of research and treatment projects in the region. Due to the properties of becoming muddy with water and a high content of montmorillonite, several studies have found that the incorporation of Pisha sandstones into sandy soils can significantly decrease the water infiltration rate, saturated hydraulic conductivity, and water loss through evaporation of the soil, while increasing the saturated water content and residual water content (Lu et al., 2014; She et al., 2014). Thus, Pisha sandstone were selected as soil amendments for sandy soil, and more than 1600 hm^2 new arable lands have been added by incorporating Pisha sandstone into sandy soils (Han et al., 2012). This showed that it is technically feasible to use Pisha sandstone as soil amendment in this area. However, the long-term effects need to be evaluated and more studies are needed. Until now, information on the quantitative effects of Pisha sandstone content on solute transport in sandy soil is still inadequate.

Some solutes such as the inert non-adsorbed Br^- and Cl^-, and adsorbed K^+ and Na^+, are used as transport tracers in negatively charged soils. Regardless of the solute used, valuable information on solute transport can be deduced from breakthrough curves (BTCs) (Hillel, 1998). In order to study the effect of soil structure on solute transport, two models have been used to study BTCs of inert non-adsorbed solutes: the convection dispersion equation model (CDE) and the two-region model (i.e., mobile-immobile water content model) (T-R). Work by Abbasi et al. (2003) showed that CDE can predict solute transport parameters more accurately than T-R in homogeneous soils. However, Ventrella et al. (2000) and Beibei et al. (2009) found that the T-R model estimates transport parameters somewhat better than CDE when studying a heterogeneous fine-textured soil or loess-containing rock fragments. The two-site model (T-S) is always used to study the BTCs of adsorbed solutes such as K^+ and Na^+ (Toride et al., 1995).

The objectives of this study were to determine the effects of Pisha sandstone amendments on the transport of bromide and sodium in sandy soils. Bromide and sodium were chosen because they are representative inert non-adsorbed and adsorbed solutes, respectively. The study was focused on the identification of solute transport processes and the determination of parameters fitted to different models, and this work attempted to identify the factors that influence the solute transport characteristics.

2. Materials and methods

2.1. Materials and analysis

Aeolian sandy soil and Pisha sandstone were collected at the towns of Dalu (111°22′6.4″ E, 40°2′45.7″ N) and Nuanshui (110°34′34.3″ E, 39°44′23.6″ N), both of which are located in Jungar Banner, the Inner Mongolia Autonomous Region in northwest China. The soil samples were air dried and sieved through a 2-mm mesh. The properties of the selected soils are shown in Table 1. Soil organic matter was determined according to the dichromate oxidation method of Walkley–Black (Page et al., 1982); particle size distribution was determined by laser diffraction using a Mastersizer 2000 (MS-2000, Malvern, Britain); and the cation exchange capacity (CEC) was determined by shaking 1 mm of air-dried soil with 1 M NH_4OAc at PH 7.0. Exchangeable cations (K^+ and Na^+) were analyzed by flame spectrophotometry (Blakemore, 1987). Soil pH was measured with a soil: water ratio of 1:2.5 using an ion pH meter (Lei-ci PXSJ-216F, Shanghai REX Instrument Factory, China).

Air-dried fine sandy soil samples were thoroughly mixed with Pisha sandstone to obtain five different gravimetric contents of Pisha sandstone (0, 16.7, 25, 50, and 100%). The natural bulk densities of sandy soil and Pisha sandstone are approximately 1.60 and 1.40 g/cm^3, respectively. Mixtures with bulk densities of 1.60, 1.57, 1.55 , 1.50 and 1.40 g/cm^3 were then uniformly packed into Plexiglas columns (height of 24.0 cm, inner diameter of 7.0 cm). The perforated bases of the columns were covered with a coarse filter paper to prevent the soil mixtures from flowing with the solution. The surfaces of the soil mixtures were covered with a circular filter paper to reduce the disturbance caused by the inflowing solution. The well-packed soil columns were allowed to stand for 3 days and then were placed in a deionized water sink until the soil was completely saturated throughout the vertical length of the column.

Vertical soil column solute transport experiments were carried out under steady-state flow conditions, and 0.05 M NaBr was used as a tracer. Flow experiments were carried out by rapidly establishing and then maintaining a constant 2.9-cm head of the tracer solution on the surface of the soil using a Mariotte bottle. The effluent was collected continuously in 30-ml volumetric flasks at timed intervals. The effluent samples were then analyzed by an ion meter (Lei-ci PXSJ-216F, Shanghai REX Instrument Factory, China) with Br^- and Na^+ ion selective electrodes (ISE) to determine the Br^- and Na^+ concentrations until they attained stable levels (close to 0.05 M). The experimental temperature was controlled at 20 ± 3 °C, and the relative humidity was not controlled but remained at $40 \pm 10\%$.

2.2. Theory and model

The analysis of solute transport in porous media was based on a simplified convection dispersion equation (CDE) (Kasten et al., 1952; Lapidus and Amundson, 1952):

$$R\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} - V\frac{\partial c}{\partial x} \tag{1}$$

where R is the retardation factor; C is the concentration of solute in the liquid phase; t is the flow time; V is the pore water velocity; x is the flow distance; and D is the dispersion coefficient.