Science of the Total Environment 574 (2017) 716–723

Contents lists available at ScienceDirect

Science of the Total Environment

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

Study of the water transportation characteristics of marsh saline soil in the Yellow River Delta

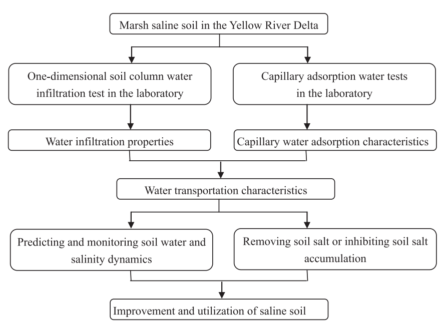
Fuhong He [a], Yinghua Pan [a,*], Lili Tan [a], Zhenhua Zhang [a,*], Peng Li [a], Jia Liu [a], Shuxin Ji [a], Zhaohua Qin [a], Hongbo Shao [b,c,*], Xueyan Song [a]

[a] *School of Resources and Environmental Engineering, Ludong University, Yantai 264025, China*
[b] *Institute of Agro-biotechnology, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China*
[c] *Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China*

HIGHLIGHTS

- Cumulative infiltration capacity increased with the depth of the soil layers.
- Initial rates of capillary rise were lower than the initial infiltration rates.
- Water transportation of wetland saline soil accords to common principle.
- Plant type may be the main factor which influences water and salt transportation.

GRAPHICAL ABSTRACT



Flow chart of improvement and utilization of saline soil

ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 13 September 2016
Accepted 14 September 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Accumulative infiltration capacity
Infiltration rate
Accumulative capillary adsorbed water volume
Capillary rise rate
Marsh saline soil

ABSTRACT

One-dimensional soil column water infiltration and capillary adsorption water tests were conducted in the laboratory to study the water transportation characteristics of marsh saline soil in the Yellow River Delta, providing a theoretical basis for the improvement, utilization and conservation of marsh saline soil. The results indicated the following: (1) For soils with different vegetation covers, the cumulative infiltration capacity increased with the depth of the soil layers. The initial infiltration rate of soils covered by *Suaeda* and *Tamarix chinensis* increased with depth of the soil layers, but that of bare soil decreased with soil depth. (2) The initial rate of capillary rise of soils with different vegetation covers showed an increasing trend from the surface toward the deeper layers, but this pattern with respect to soil depth was relatively weak. (3) The initial rates of capillary rise were lower than the initial infiltration rates, but infiltration rate decreased more rapidly than capillary water adsorption rate. (4) The two-parameter Kostiakov model can very well-simulate the changes in the infiltration and capillary rise rates of wetland saline soil. The model simulated the capillary rise rate better than it simulated the infiltration rate. (5) There were strong linear relationships between accumulative infiltration capacity, wetting front, accumulative capillary adsorbed water volume and capillary height.

* Corresponding authors.
E-mail addresses: panxingxing@126.com (Y. Pan), zhangzh@163.com (Z. Zhang), shaohongbochu@126.com (H. Shao).

http://dx.doi.org/10.1016/j.scitotenv.2016.09.111
0048-9697/© 2016 Published by Elsevier B.V.

1. Introduction

The Yellow River Delta possesses abundant natural resources and plays an important role in the social and economic development, ecological environment construction and conservation in China. The formation time of soil in the Yellow River Delta is relatively short. The soil mainly consists of sediment. However, due to the shallow underground water table and a large ratio of evaporation to precipitation, secondary soil saline-alkalization is likely to occur. Evaporation and infiltration are two opposite processes of soil water transportation, which are also important processes impacting salt accumulation and eluviation of saline soil. Under evaporation, soil capillary action causes salt to move from deeper soil layers to the surface along with moving water. The salt was retained at the soil surface after the water was evaporated. When precipitation or irrigation occurs, water transports salt at the soil surface to deeper layers, which decreases the salt concentration at the soil surface. The extent of salt leaching and water evaporation is closely related to soil water infiltration properties, water adsorption capability of capillary and soil water conductivity. Infiltration and capillary adsorption are important processes of water transportation in saline soil. Therefore, understanding soil water transportation characteristics, predicting and monitoring soil water and salinity dynamics, and removing soil salt or inhibiting soil salt accumulation in a timely manner to reduce its damage to plants are important practices of soil improvement and utilization in this region.

Soil water movement was influenced by various factors, such as soil particle composition, soil mineral composition (Frenkel et al., 1978), soil structure, cultivation modes (Pardini et al., 2003), soil organic matter (Barzegar et al., 2002), plant cover (Turrion et al., 2007), irrigation water quality (So and Aylmore, 1993; Ayars et al., 1993; Moutier et al., 1998; Bagarello et al., 2006; Bardhan et al., 2016) and soil salt content (Crescimanno et al., 1995; Suarez, 2006a, b; Quirk and Schofield, 2013). There were plenty of studies about the effects and mechanism of different factors on water movement in non-saline-alkaline soil (Shao and Horton, 1999; Yan et al., 2007; Wu and Wang, 2007). Among these publications, there was an extensive series of scientific reports on the effects of waters of varying quality on soil hydraulic properties. Agassi et al. (1981) determined that the infiltration rate was more sensitive to the effects of sodicity when applying the water via rainfall simulator compared with changes in hydraulic conductivity in saturated column studies. These differences were attributed to particle disturbance on the soil surface. Kazman et al. (1983) used disturbed soil prepared at various ESP values, packed in soil trays and leached with a rainfall simulator. The results showed that infiltration rate decreased as the ESP increased. Suarez et al. (2006a) examined water infiltration into loam and clay soils irrigated at EC = 1.0 and 2.0 dSm^{-1} at SAR of 2, 4, 6, 8, and 10 in a management system with alternating (simulated) rain and irrigation and drying between irrigations. The results showed a greater sensitivity to SAR than indicated in laboratory column studies and existing water quality criteria.

In terms of the infiltration properties of saline and alkaline soil, most studies focus on soils in arid and semi-arid regions (Shi et al., 2007). The formation mechanism of saline-alkaline soil in arid and semi-arid regions are different from that in the Yellow River Delta. The main formation mechanism of saline-alkaline soil in arid and semi-arid regions is that underground water rises to the soil surface in association with atmospheric evaporation, whereas the formation of saline soil in the Yellow River Delta is due to secondary saline-alkalization. Therefore, the improvement of saline-alkaline soil in the Northwest region of China is mainly to inhibit evaporation and reduce salt accumulation at the surface, whereas the improvement in the Yellow River Delta includes evaporation inhibition in the dry seasons and increasing leaching and salt elimination in the rainy seasons. For saline-alkaline soil, whether through inhibiting evaporation or elimination of salt, understanding soil hydraulic properties and monitoring the water and salt dynamics are an important basis for taking proper measures of soil improvement (Churchman et al., 1993; Levy et al., 2005; Zhang et al., 2007; Jayawardane et al., 2011).

Based on the analysis mentioned above, the present paper aims to study: (1) the water infiltration properties of marsh saline soil in the Yellow River Delta; (2) the capillary water adsorption characteristics of marsh saline soil; (3) dynamic simulation of infiltration and capillary adsorption; and (4) the relationship between one-dimensional water infiltration processes and the capillary adsorption process.

2. Materials and methods

The soil samples were taken from the Ecology Experimental Station of the Chinese Academy of Science in Yellow River Delta Coastal Wetland. The experimental station is located in Kenli County of Dongying City in Shandong Province of China (37°45′36.32″ to 37°46′15.56″N, 18°58′38.74″ to 118°58′58.77″E). Usually, plants can reflect the soil qualities and some soil physical and chemical properties (Turrion et al., 2007). So, at the station, lands with three typical types of vegetation cover were selected, including *Tamarix chinensis*, *Suaeda* and bare land. For each vegetation cover type, three soil sampling plots were randomly selected and sampled by layers. The sampling depth of *Suaeda glauca* (*Bunge*) Bunge. covered land and bare land were both 0–50 cm. Because of the waterlogged conditions *Tamarix chinensis* covered land, the sampling depth was 0–30 cm. All soil samples were taken at intervals of 10 cm in terms of depth, then air dried and sieved through 1 mm griddle. The basic properties of different soil profile layers are shown in Table 1. Seen from Table 1, for three vegetation covered soils, sand content was the highest, followed by the silt content, and the clay content is the lowest. According to the international soil classification standard, three-type vegetation covered soils are all sandy loam. According to electrical conductivity (EC), pH and total salt content, the soil in this region belongs to typical saline soil. The salt content is highest on the surface of bare land and decreases with depth, reaching a stable value at depths of 30–50 cm. The salt content is relatively low at the surface layer of soil covered by *Suaeda glauca* (*Bunge*) Bunge. and insignificantly increases with depth. The salt content is high at the surface layer of *Tamarix chinensis* covered soil and decreases with depth. Within 0–30 cm depth, the total soil salt contents in three vegetation covered soils differed greatly, and the total salt contents of bare soil in all layers are higher than those in other two types of soil.

In the laboratory, to ensure the same basic soil conditions, disturbed soil column experiments were carried out to study the water transportation characteristics of marsh saline soil. Two types of experiments were carried out: one-dimensional constant head water ponding infiltration and investigation of capillary water adsorption capability. The experimental soil columns were 5.4 cm in inner diameter and 20 cm high. Soil was packed in the columns layer-by-layer (2 cm at a time), and the bulk density was approximately 1.35 g/cm^3. Water heads were 1 cm for one-dimensional water ponding infiltration, controlled by Mariotte flask. In the capillary water adsorption ability tests, soil columns were placed on sand (2–3 cm in diameter) surface in beakers Before the experiment, sand in beakers was cleaned by diluted hydrochloric acid and pure water to prevent the adsorption and infiltration of other salt ions and their potential effects on the final results. The sand in the beakers was submerged to simulate the underground water interface of soil profiles under natural conditions. The outlet of the Mariotte flask was kept in line with the sand surface, and placed soil columns on the sand surface. After the experiment began, the water infiltration capacity and advancing distance of wetting front were recorded.

3. Results and discussion

3.1. Analysis of the water transportation characteristics in marsh saline soil profiles

3.1.1. Infiltration properties in soil profiles under one-dimensional water ponding infiltration with constant head

Figs. 1, 2 and 3 showed the dynamic processes of accumulative infiltration and infiltration rate of *Tamarix chinensis* Lour. covered and