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RESEARCH ARTICLE

Water and salt movement in different soil textures under various negative irrigating pressures

WANG Jia-jia[1,2], HUANG Yuan-fang[1], LONG Huai-yu[2]

[1] *Department of Soil and Water Sciences, College of Resources and Environmental Sciences, China Agricultural University/Key Laboratory of Arable Land Conservation (North China), Minstry of Agriculture/Key Laboratory of Agricultural Land Quality Monitoring, Ministry of Land and Resources, Beijing 100093, P.R.China*

[2] *Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R.China*

Abstract

This study examined the effect of different negative pressures and soil textures on water and salt movement to improve the efficiency of negative pressure irrigation (NPI). Four soil textures of varying fineness (Loamy Sand, Loam, Silty Loam, and Sandy Loam) and three negative pressure values (0, –5, and –10 kPa) were used. As irrigation time increased, wetting front movement speeds decreased, and as negative pressure increased, wetting front size decreased. Coarse soils had the smallest wetting front under greater negative pressure. Next, water infiltration rate decreased as irrigation time increased, and coarse soils had the lowest average infiltration rate under greater negative pressure. Finally, salt content increased with distance from the irrigation emitter and with increased negative pressure. Further, coarse soils were found to have decreased desalination under greater negative pressure. Thus, soil texture has a strong effect on NPI efficiency. However, by adjusting pressure values in accordance with soil texture, soil water content can be controlled and maintained. These findings are important to the improvement of NPI systems, increasing their practicality for agricultural use.

Keywords: negative pressure irrigation, volumetric water content, soil salt content, soil texture

1. Introduction

Chinese agricultural water consumption is 400 billion m^3 every year, which accounts for 65% of the nation's total water consumption (MWRPRC 2013). Irrigation accounts for more than 90% of the nation's total agricultural water consumption. Due to these extensive irrigation needs, China's effective irrigation water use (0.5), the ratio of irrigated water used by crops to total irrigated water, currently lags behind that of developed nations (0.7–0.8) (Hu 2013). It is therefore of great importance to increase water use efficiency through the improvement of existing irrigation methods. One such technique that has received recent attention is negative pressure irrigation (NPI), which relies on soil matrix suction to irrigate crops. By altering negative pressure, NPI controls water distribution based on the soil texture around crop roots during the entire growth period. NPI is a high-efficiency method that improves crop quality and increases water savings (Nalliah and Ranjan 2010). First, it can potentially be tailored to specific field conditions, and the second, the roots

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WANG Jia-jia, E-mail: jiajia19202080@163.com;
Correspondence LONG Huai-yu, Tel: +86-10-82108776, E-mail: hylong@caas.ac.cn

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are watered *via* capillary action, making it a system that is entirely controlled by plant water demand.

Studies on negative pressure irrigation methods have been performed since the early 20th century (e.g., Livingston 1918) and is now being successfully used in greenhouse production. For example, Wang *et al*. (2007) suggested that a soil matric potential of –25 kPa was the most favorable setting for potato (*Solanum tuberosum*) production, resulting in better crop performance than other treatments, as measured by a host of quality-related variables (e.g., height, tuber bulk rate and grade, water use efficiency, and irrigation water use efficiency). Further, hot peppers (*Capsicum annuum*: Nalliah *et al*. 2009, 2010) under –0.2 m capillary-irrigation performed better in terms of growth and yield parameters when compared with manual irrigation, while saving a substantial amount of water. The capillary-irrigation technique offers a precise water delivery with minimal labor, which is suitable for use in greenhouse pepper production and in areas where both water and workforce are scarce.

Given the promising outcomes of NPI, much research has focused on further improving NPI efficiency (Liu 2006) and the effects of this technique on crop growth. Among the variables of potential interest, previous studies have investigated evaporation rates, wetting body, wetting front, the cumulative amount of infiltration, and the maximum/minimum wetting distance over time (Jiang *et al*. 2004; Moniruzzaman *et al*. 2011a, b). However, relatively few studies have examined the effects of soil texture on NPI efficiency. The available research disagrees on what soil textures are most effective under NPI. For example, Xin (2007) found that more finely textured, cohesive soil results in poorer soil water infiltration. In contrast, Liang *et al*. (2011) found that cohesive soil performs better than less cohesive, sandy soil, as measured by greater cumulative water infiltration and the maximum wetting distance. Similar results were also reported by Jiang *et al*. (2005), comparing Sandy Loam to the more cohesive clay sand. These opposing conclusions may be a result of variation in irrigation equipment used by different research groups. Thus, for studies to draw reliable conclusions, it is necessary to control for the variation in equipment when investigating water movement under different soil textures.

In addition, previous research has shown that irrigation alters salt content in soil. For example, a favorable low salinity zone could be achieved around the roots when the soil matric potential threshold was kept under –25 kPa, at a depth of 20 cm below the drip irrigation emitter (Wang *et al*. 2011). This method greatly improved seed-cotton yield in the area, demonstrating that altering salt content *via* irrigation directly affects agricultural productivity. Next, Siyal *et al*. (2013) found that positive pressure in underground irrigation causes water movement to the surface *via* capillary action, and once this water evaporates, the resultant salt accumulation increases soil salinity to unacceptable levels. In contrast, the negative pressure methods could reduce capillary water content, decreasing both surface evaporation and deep percolation, resulting in more usable water around the root zone (Nalliah *et al*. 2009). Despite these findings, knowledge remains limited with regard to how NPI affects soil salt movement around the root zones of crops. Such information is especially critical for major salt-sensitive crops such as maize (Ding *et al*. 2012) and tomato (Hanson *et al*. 2009). Understanding both water and salt movement when using this irrigation method will be extremely beneficial to improving the design and management of NPI systems for different soil textures.

Thus, the objectives of this study were 1) to examine the effects of soil texture on soil water and salt movement around irrigation emitters in NPI, and 2) to examine how changes to negative pressure values affect water and salt movement within different soil textures, thereby providing a reliable basis for the future application of NPI technology.

2. Materials and methods

The study was conducted from May to September in 2014, at the Institute of Agricultural Resources and Regional Planning Laboratory, Chinese Academy of Agricultural Sciences, Beijing. The site is located at 116°19´18´´N, 39°57´40´´E, about 56 m above average sea level.

2.1. System design

The irrigation system consists of three parts: the negative pressure generator (the solenoid valve and mercury gauge are only used when the irrigation system is actually used for crops), water tank, and irrigation emitter (patented by the Chinese Academy of Agricultural Sciences; patent no. 200710178527.3). The latter consists of a 23-cm long porous ceramic pipe, with inner and outer diameters of 10 and 18 mm, respectively. This NPI system has been successfully used in growing flue-cured tobacco, improving various botanical traits compared with plants grown under other systems (Xiao *et al*. 2015).

The laboratory setup is illustrated in Fig. 1. The irrigation system is connected to a special soil bin (internal dimensions: 250 mm×20 mm×500 mm) made of 5-mm thick, clear polymethyl methacrylate. A polyvinyl chloride film was placed on the front of the soil bin to manually record wetting front boundaries. During the experiments, negative pressure was solely controlled by the height (h) between the irrigation emitter and the air contact point, which yields the most accurate negative pressure (Fig. 1). Prior to the start of every experiment, any water in the intake tube was