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Spatial distribution and simulation of soil moisture and salinity under mulched drip irrigation combined with tillage in an arid saline irrigation district, northwest China

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ABSTRACT

Hetao Irrigation District, a large irrigation district in arid area, northwest China, is suffering from the decreasing water supply and increasing soil salinization. Mulched drip irrigation is widely used for agricultural production in arid area, and tillage management affects soil environment variously. This study aimed to explore combined effects of tillage and mulching modes on soil water and salt transfer under drip irrigation. The experiment included 4 treatments: ridge tillage with full film mulching (RFM), ridge tillage with partial film mulching (RPM), flat tillage with full film mulching (FFM) and flat tillage with partial film mulching (FPM). The results showed that RFM increased soil moisture in root zone (0–40 cm). Soil salt was pushed to the edge of soil wetting front and, RFM and FFM reduced salt accumulation in 0–70 layer significantly than RPM and FPM, indicating that full film mulching could retard the upward movement of soil salt more effectively. Furthermore, the performance of HYDRUS-2D was calibrated and evaluated by comparing the simulated values with observed values, and further verified model by another year dataset, to simulate the spatial distributions of soil water and salt in the two directions under mulched drip irrigation with different irrigation quantity. The simulation showed that the wetted region was expanded to the middle position of the film and the uniformity of irrigation increased with the increasing irrigation amount. In addition, the increasing of assumed irrigation amount induced soil desalination and make soil salinity spatial movement meet a discipline that the direction parallel to the drip line was lower than that perpendicular to the line at the same distance. In all, RFM could be adopted for optimizing soil water-salt regulation under drip irrigation in Hetao Irrigation District, and the model presented here is an efficient approach for investigating the regulation mechanisms of root-zone water and salt dynamics under mulching and/or tillage.

1. Introduction

Soil salinity, one of the most severe abiotic stresses, inhibits growth and yield of non-halophyte and even halophyte species and threatens both the food security and the sustainable development of agriculture (Debez et al., 2008; Yang et al., 2016). It is estimated that 20% of cultivated lands and 33% of irrigated agriculture lands in the world were salt affected and the amount of land now at risk of salinity is four times of current affected areas. (Foolad, 2004; FAO, 2008). Hetao irrigation district, northwest China, is suffered from severe soil salinity (Qi et al., 2016; Zhang et al., 2017c). Even worse, precipitation deficiency and dry season greatly induce drought occurrence and further aggravate salinity effect (Wang et al., 2015; Liu et al., 2017). Therefore, efficient tillage and irrigation methods are essential to mitigate the negative effects of drought and soil salinity on crops.

Mulched drip irrigation is an effective measure to increase soil moisture and promote soil salinity redistribution in arable soil layer resulting in appropriate crop growth conditions (Zhang et al., 2017a). This measure could increase water and nutrients use efficiency and thus enhance crop yield (Zhang et al., 2017b). Moreover, previous studies indicate mulched drip irrigation efficiently

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Table 1
Soil properties in the 0–70-cm soil layer of the experimental field.

Depth of Soil Layer (cm)	Particles Size Distribution (%)			Bulk Density ($g\,cm^{-3}$)	Organic Matter ($g\,kg^{-1}$)	$EC_{1:5}$ ($dS\,m^{-1}$)	pH
	Sand	Silt	Clay				
0–20	5.6	23.8	70.7	1.4	7.3	0.5	8.6
20–40	5.8	23.8	71.7	1.4	8.1	0.3	8.7
40–70	49.7	8.4	41.9	1.5	6.3	0.2	8.9

Note: The particle size limits were 0.05–2 mm for sand, 0.05–0.002 mm for silt and <0.002 mm for clay. $EC_{1:5}$, electrical conductivity of 1:5 soil-water extract.

Table 2
Values of the model parameters.

Depth (cm)	Soil	K_s ($cm\,d^{-1}$)	θ_s ($cm^3\,cm^{-3}$)	θ_r ($cm^3\,cm^{-3}$)	α ($1\cdot cm^{-1}$)	n	l	λ (cm)
0–20	Clay	6.76	0.438	0.067	0.0097	1.672	0.5	21.27
20–40	Clay	4.84	0.454	0.044	0.0121	1.496	0.5	8.9
40–70	Sandy clay loam	11.56	0.436	0.035	0.0099	1.588	0.5	19

Note: K_s, saturated hydraulic conductivity; θ_s, saturated water content; θ_r, residual water content;α, reciprocal value of air entry pressure; n, the smoothness of pore size distribution; l, pore connectivity parameter; and λ, dispersivity.

reduce soil evaporation and improve topsoil temperature and thus maintain suitable soil hydrothermal conditions (Chakraboyty et al., 2008; Zhou et al., 2009). However, during mulched drip irrigation, solute salt transport is accompanied by water flow and accumulates at edge of the wetting front and lead to form main salt accumulation area below 30 cm soil layer (Wang, 2013; Mirjat et al., 2014). Ridge tillage could promote water and solute horizontal and vertical infiltration due to its loose soil structure (Qi et al., 2016). Therefore, the combination measure of mulched drip irrigation and ridge tillage could be a choice to reduce solute salt concentration and move main accumulation area to deep soil layer.

Numerical simulation is an effective way to investigate the law of spatial distribution and movement of soil water and solute salt, and then evaluate effects of different tillage and mulching combination methods under drip irrigation, which can be used to optimize soil water and salt conditions for effective soil water utilization. Previous studies indicate the relevant assessment between soil water and salt could be done mathematically using the HYDRUS-2D. The HYDRUS model has been proved to be an efficient tool for simulating soil water and solute salt transport in many cases (Kodesova et al., 2014). Zhao et al. (2010) investigated the impact of vapor flow on predictions of soil water content using HYDRUS model. Shan et al. (2011) also used the HYDRUS model to simulate soil wetting patterns for overlap zone under double points sources of drip irrigation. In a winter wheat planting system, Wang et al. (2013) reported the changes of water flow and heat transport in soil under plastic film mulching with drip irrigation conditions. However, there is little information regarding the spatial distribution of soil water and salt under plastic film mulching with drip irrigation conditions.

In this study, the main goal is to investigate the spatial distribution of soil water and salt distribution associated with mulched drip irrigation in Hetao Irrigation District China. Moreover, we calibrate the HYDRUS-2D model for simulating soil water and salt migration with plastic film mulch. Finally, different irrigation amounts (90, 130, 180 mm) were involved to perform numerical simulations during the growth period of maize to document influence of different irrigation amounts on spatial distribution of salt accumulation in soil profile.

2. Materials and methods

2.1. Field experiment

The field experiments were conducted at the Shuguang Experimental Station (40°46′N, 107°24′E; 1039 m a.s.l.) in 2014 and 2015. The station is in the west of the Hetao Irrigation District in the Inner Mongolia, China. The average annual rainfall is 180 mm, but it ranges between a minimum of 139 mm and a maximum of 222 mm·year^{-1}, average annual temperature is 6.9 °C, and mean potential evaporation is 2200–2400 mm. During the experimental years (2014–2015), the change in water level was approximately 2.5 m. The experimental soils are alluvial silt sediments and begin to freeze by the middle of November and do not thaw completely until late April (Qi et al., 2016). The soil properties and model parameters of the experimental field are shown in Tables 1 and 2.

Four replications were adopted for the test, and irrigation water was obtained from groundwater well. The average electrical conductivity (EC) of groundwater is 1.76 dS m^{-1}. The irrigation water and was delivered by a pump with the exact amounts of water supplied monitored by water meters. The experimental crop was maize (Xi-meng 6, Inner Mongolia, China). During maize growth period, urea plus $(NH_4)_2HPO_4$ was supplied as the base fertilizer and urea, phosphate fertilizer and KNO_3 were used as the top dressing.

Four field management treatments were studied (Fig. 1): ridge tillage with full film mulching (RFM), ridge tillage with partial film mulching (RPM), flat tillage with full film mulching (FFM), flat tillage with partial film mulching (FPM). The experimental field was divided into plots (each 12 m long and 3 m wide) and four groups of mulched drip irrigation system were arranged on each plot. The ridge and furrow for ridge tillage were 40 cm wide (20 cm high) and 60 cm wide (20 cm high), respectively. After the plots were mulched with plastic film according to four treatments requirements, two rows of maize were planted on both sides of the drip tape with dibblers. The drip tapes spacing and emitter spacing were 100 cm and 30 cm, respectively.

To study the impact of different treatments on soil water and salt transfer, the ECH$_2$O-5TE sensors were installed beneath the emitter at the soil depths of 10, 30, 55, 85 and 110 cm at three locations to record profiled soil moisture of 20-, 40-, 70-, 100- and 120-cm layers (Fig. 2). Soil samples were collected by auger before and after each irrigation event. Part of soil samples were used for measuring gravimetric water contents by oven drying method and the rest were air dried and sieved through 1 mm mesh for preparing dilute soil extract solutions. The soil soluble salt was estimated by the extracts with a 1:5 soil: water ratio ($EC_{1:5}$), measured with a conductivity meter (dS m^{-1}). The mixed solutions of soil and water were oscillated for about 5 min; although small amounts of non-soluble salts remained in the final mixed solution, their proportion was very low. The conductivity of saturated paste extract (EC_e) was measured using the soil samples with a wide range of $EC_{1:5}$ values and developed the relationship between EC_e and $EC_{1:5}$ ($R^2 = 0.966$)

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