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Impacts of ridge with plastic mulch-furrow irrigation on soil salinity, spring maize yield and water use efficiency in an arid saline area

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ABSTRACT

The inadequate soil and water management has resulted in ecological and environmental problems in Hetao Irrigation District, which is characterized by low precipitation, high evaporation and soil salinity issues. A two-year field experiment was conducted to investigate the effects of the combined application of irrigation methods, irrigation amounts and plastic mulching modes on soil moisture, soil salinity, and water use efficiency of spring maize. This experiment included four treatments: (i) border irrigation partially mulched by plastic film with full irrigation amount (CK), (ii) ridge-furrow irrigation not mulched by plastic film with high irrigation amount (NRF), (iii) ridge with plastic mulch-furrow irrigation with high irrigation amount (PRF), (iv) ridge with plastic mulch-furrow irrigation with low irrigation amount (PRL). The results demonstrated that soil water and soil salinity mainly changed in the upper 80 cm soil layer. The proportion of the amount of deep percolation in the total growing season ranged from 9.3% to 29.5% and the highest deep percolation amount appeared in CK. Less irrigation amount generally resulted in a higher salt accumulation in the upper 40 cm soil layer. At harvest, the highest salt accumulation appeared in PRL and the lowest salt accumulation appeared in PRF among the three ridge-furrow irrigation treatments. Compared with the CK treatment, the average grain yields in the PRF, PRL and NRF treatments were increased by 29.6%, 12.2% and 14.4% in 2015, and increased by 5.5%, 4.2% and 2.5% in 2016, respectively. The highest water use efficiency was found in the treatment with PRF in 2015 growing season, and in the treatment with PRL in 2016 growing season. Irrigation water use efficiency was lower in PRF than in PRL, whereas higher than in CK and NRF. Fully considering maize yield, soil water storage, soil salt balance and water use efficiency in the Hetao Irrigation District, ridge with plastic mulch-furrow irrigation with about 300 mm of irrigation water can be recommended as the effective soil and water management practice.

1. Introduction

The Hetao Irrigation District is one of the main grain production areas in Northwest China, comprising of about 2.8×10^5 ha irrigated cropland on saline soils (Zhao et al., 2014). Irrigation with the Yellow River water plays an important role in crop production and salt leaching because of low precipitation about 160 mm per year and high pan evaporation (Ren et al., 2016). However, excessive application of the Yellow River water and inappropriate drainage management of irrigation water have resulted in rising groundwater levels, which have the potential to bring about salt accumulation in the upper soil layer (Sharma and Minhas, 2005; Qadir et al., 2009; Zhao et al., 2014). Meanwhile, with increasing water demand of the Yellow River basin, the amount of water diverted from the Yellow River to the Hetao irrigation district will be reduced from 5.0 to 4.0 billion m^3 per year in the following decade (Zhang et al., 2017). Therefore, efficient water-saving techniques should be developed to cope with the water reduction and soil salinization problems.

Spring maize is a major grain crop and feed resource in the Hetao irrigation district due to the sunlight, heat resources (e.g. temperature), and breeding requirements. The cultivated area of spring maize accounts for more than 30% of the total arable land in this

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Table 1
Basic properties, electrical of conductivity of saturated paste extracts (EC_e), pH value of initial soil profile of the experimental field.

Soil layers (cm)	Particle size distribution (%)			Soil texture	soil bulk density (g cm^{-3})	Field capacity (g g^{-1})	EC_e (dS m^{-1})	pH
	<0.002 mm	0.002–0.05 mm	0.05–2 mm					
0–10	19.64	49.60	30.76	Silt loam	1.34	0.30	5.96	8.18
10–20	20.35	53.38	26.27	Silt loam	1.34	0.31	5.77	8.31
20–40	23.85	50.29	25.86	Silt loam	1.43	0.32	5.45	8.49
40–60	21.62	32.12	46.26	Silt loam	1.46	0.32	4.92	8.73
60–80	2.51	4.24	93.25	Sand	1.50	0.21	4.51	8.89
80–100	6.93	14.67	78.40	Sandy loam	1.48	0.24	4.33	8.93
100–120	14.01	30.31	55.68	Silt loam	1.42	0.30	3.98	8.87

area (Ren et al., 2016; Liu et al., 2017). Spring maize has an high irrigation water demand during the total growing season because of the high ratio of potential evaporation to precipitation in Hetao irrigation district and thus the combined application of basin flood irrigation and transparent plastic mulching is commonly used for spring maize fields (Zhang et al., 2017). However, about 150 mm water is lost from 500 mm of irrigation water through deep percolation caused by basin flood irrigation (Xu et al., 2010; Liu et al., 2017). Meanwhile, spring maize is more sensitive to soil salinity at the seeding stage (Tong et al., 2012), and control of root zone salinity in saline fields is considered beneficial to seed emergence and stand establishment (Meiri and Plaut, 1985; Abd EI-Mageed et al., 2016). Therefore, reducing irrigation amount within a suitable soil salinity level and increasing water use efficiency without a crop yield decrease are the primary goals of soil and water management in Hetao irrigation district.

Currently, mulched drip irrigation and mulched ridge-furrow irrigation with transparent plastic film are utilized in the arid and semiarid regions of northwest China. Plastic mulching can efficiently conserve soil water, reduce evaporation losses, increase soil temperature, reduce salt accumulation within the shallow soil depth, and enhance biological activity and crop yield (Pang et al., 2010; Li et al., 2013; Zhao et al., 2016). Mulched drip irrigation with transparent plastic film is an effective method to reduce irrigation amount without decreasing crop yield in arid and semiarid regions (Wang et al., 2015; Liu et al., 2013). However, the application of mulched drip irrigation in Hetao irrigation district may be subject to emitter clogging induced by the Yellow River water with high sediment concentration. Ridge-furrow irrigation with plastic mulch is currently the most common irrigation practice in northwest China. Compared with border irrigation, ridge-furrow irrigation can significantly improve water use efficiency (Wu et al., 2015), but salts tend to accumulate in surface soil layers below the ridges because leaching occurs primarily below the furrows (Saggu and Kaushal, 1991). Plastic mulching may induce pronounced changes in soil water flow and salt transfer paths and the mulched treatments can retain 40–60% more water than the un-mulched treatment (Humberto and Lal, 2007; Zhou et al., 2009; Bezborodov et al., 2010; Chen et al., 2015). However, no research has been conducted to study the combined effect of plastic mulching and ridge-furrow irrigation on water saving and salt leaching in Hetao irrigation district. Therefore, this modified soil and water environment caused by plastic mulching and ridge-furrow irrigation needs to be recognized when reducing irrigation amount and changing local irrigation method.

In this study, we assume that the dynamics of soil water and salinity, and their distributions in the soil profile as well as water use efficiency of spring maize would be affected by ridge-furrow irrigation method and plastic mulching modes. Therefore, the objectives of this research are: (1) to determine the effect of ridge-furrow irrigation and plastic mulching on soil water and salt content; (2) to investigate how spring maize yield and water use efficiency are affected by plastic mulching and ridge-furrow irrigation method in Hetao Irrigation District.

2. Materials and method

2.1. Experimental site

Field experiments were conducted from April 2015 to September 2016 at the Shuguang Experimental Station in Hetao Irrigation District, western Inner Mongolia Autonomous Region, China (latitude 40°46′N, longitude 107°24′E, and altitude 1039 m). The area has a typical arid continental climate with an annual precipitation of 105 mm occurring mainly between May and September (Wang et al., 2014) and the mean annual pan evaporation exceeds 2000 mm (Hao et al., 2015). The mean annual temperature is 7.8°C and the mean annual total sunshine duration is 3156 h (Wang et al., 2014). The groundwater level varies from 1.7 to 2.8 m below the soil surface during the two crop growth seasons. The soils are alluvial silt sediments, with an upper layer (0–60 cm) of silt loam, a lower layer (60–100 cm) of sand and sandy loam, and a sand layer of about 30 cm thick between 60 and 90 cm below the soil surface. The climate and special geographical conditions of this region make it liable for salt accumulation on the soil surface. The physical and chemical properties of the soil at the experimental site are summarized in Table 1. Weather data for the two growing seasons were obtained from the standard meteorological observation station located approximately 150 m from the experiment.

2.2. Experimental design and field management

Ridge-furrow irrigation system and border irrigation system were used to apply the Yellow River water. This experiment included four treatments: (i) border irrigation partially mulched by plastic film with full irrigation amount (CK), (ii) ridge-furrow irrigation not mulched by plastic film with high irrigation amount (NRF), (iii) ridge with plastic mulch-furrow irrigation with high irrigation amount (PRF), (iv) ridge with plastic mulch-furrow irrigation with low irrigation amount (PRL). The four treatments were replicated three times in a completely randomized block design. Each plot consisted of 8 rows of spring maize planted on a flat ground mulched by plastic film (CK) or four raised ridges (NRF, PRF and PRL). For the two experimental years, each plot was 4.8 m Í 45 m and each ridge-furrow was 1.2 m Í 45 m (Fig. 1). The ridge and furrow for any group were 50 cm wide (20 cm high) and 70 cm wide (20 cm high), respectively. The furrows were closed at the end of the plot to withhold the irrigation water. Irrigation is important for spring maize in this rainfall scare region. The amounts and dates of irrigation for spring maize plants (Table 2) were applied during the two growing seasons depending on climatic condition, plant growth, water allocation for irrigation managed by Hetao Irrigation District Authority and the previous publications (Duan et al., 2005; Xu et al., 2010; Miao et al., 2015; Wang et al., 2015). In both years, the total N application rate was 300 kg N ha^{-1} for all treatments. Before sowing, P_2O_5 (diammonium phosphate) was spread at level of 600 kg ha^{-1} as a base fertilizer and N was broadcast at levels of 150 kg N ha^{-1} (urea) as a base fertilizer before mulching in