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RESEARCH ARTICLE

Effects of saline irrigation on soil salt accumulation and grain yield in the winter wheat-summer maize double cropping system in the low plain of North China

LIU Xiu-wei[1, 2], Til Feike[3], CHEN Su-ying[1], SHAO Li-wei[1], SUN Hong-yong[1], ZHANG Xi-ying[1]

[1] *Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050021, P.R.China*

[2] *Texas A&M AgriLife Research and Extension Center, Uvalde 78801, USA*

[3] *Julius Kühn-Institut (JKI)/Federal Research Centre for Cultivated Plants, Institute for Strategies and Technology Assessment, Kleinmachnow 14532, Germany*

Abstract

In the dominant winter wheat (WW)-summer maize (SM) double cropping system in the low plain located in the North China, limited access to fresh water, especially during dry season, constitutes a major obstacle to realize high crop productivity. Using the vast water resources of the saline upper aquifer for irrigation during WW jointing stage, may help to bridge the peak of dry season and relieve the tight water situation in the region. A field experiment was conducted during 2009–2012 to investigate the effects of saline irrigation during WW jointing stage on soil salt accumulation and productivity of WW and SM. The experiment treatments comprised no irrigation (T1), fresh water irrigation (T2), slightly saline water irrigation (T3: 2.8 dS m^{-1}), and strongly saline water irrigation (T4: 8.2 dS m^{-1}) at WW jointing stage. With regard to WW yields and aggregated annual WW-SM yields, clear benefits of saline water irrigation (T3 & T4) compared to no irrigation (T1), as well as insignificant yield losses compared to fresh water irrigation (T2) occurred in all three experiment years. However, the increased soil salinity in early SM season in consequence of saline irrigation exerted a negative effect on SM photosynthesis and final yield in two of three experiment years. To avoid the negative aftereffects of saline irrigation, sufficient fresh water irrigation during SM sowing phase (i.e., increase from 60 to 90 mm) is recommended to guarantee good growth conditions during the sensitive early growing period of SM. The risk of long-term accumulation of salts as a result of saline irrigation during the peak of dry season is considered low, due to deep leaching of salts during regularly occurring wet years, as demonstrated in the 2012 experiment year. Thus, applying saline water irrigation at jointing stage of WW and fresh water at sowing of SM is most promising to realize high yield and fresh irrigation water saving.

Keywords: winter wheat, summer maize, soil salinity, saline water irrigation, salt balance

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LIU Xiu-wei, Tel: +86-311-85871762, E-mail: liuxiuweijun@163.com; Correspondense ZHANG Xi-ying, Tel: +86-311-85871762, E-mail: xyzhang@sjziam.ac.cn

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1. Introduction

The low plain is located in the eastern part of North China, comprising Hebei, Tianjin and Shandong. It is an important grain, cotton and fruit production region of China (Zhou *et al.* 2012). Seasonal drought and the shortage of fresh water

are the major factors limiting agricultural production and its sustainable development in the region. Due to the scarcity of surface water resources especially during dry season and the high salt content of the upper aquifer, crops are largely irrigated using the groundwater of the deep aquifer, resulting in its overexploitation and serious environmental problems (Ma *et al.* 2008). Furthermore, the deep aquifer consists of fossil groundwater, which is not replenished. The vast brackish water resources of the upper aquifer, stored in a depth of 10–20 m, feature a salt content of 2 to 5 g L^{-1} (electrical conductivity (ECe) of 2.8–8.2 dS m^{-1}) (MWR 1998); the utilization of these resources for crop irrigation offers great potential to relieve the tight water situation in the region (Chauhan *et al.* 2008; Ma *et al.* 2008; Pang *et al.* 2010).

Several studies indicate that brackish water can successfully be used for irrigated crop production (Al-Karaki and Ghazi 2005; Niu *et al.* 2010; Wan *et al.* 2010; Jiang *et al.* 2012; Malash *et al.* 2012; Singh and Panda 2012). However, negative effects on crops may occur from using saline water due to accumulation of salts in the soil (Rengasamy 2010; Wang S *et al.* 2010; Huang *et al.* 2011; Wang *et al.* 2015). The extent of salt accumulation in different soil layers is affected by the specific irrigation management and local climatic conditions. Under northern Chinese crop production conditions, Fang and Chen (1997) assessed a high desalinization potential of the upper soil layer in years with more than 300 mm rainfall in July and August, but a significantly low chance for soil desalinization in years with less rainfall during those months. In the study region, the major share of the 400–600 mm average annual rainfall concentrates on the four summer months (Jun–Sep), with the rest of the year experiencing rather arid conditions (Sun *et al.* 2010). Under such climatic conditions, including a distinct rainy season, the use of saline water is especially promising during the dryer season, as the salt brought to soil during that time can be leached during the following rainy season (Hamdy *et al.* 2005; Kiani and Mirlatifi 2012). To decrease the potentially harmful effects of saline water on crop production and soil salinization, an alternating use of saline water and fresh water (Fang and Chen 1997; Kafi *et al.* 2010) as well as mixing of saline water and fresh water to reduce the water's salinity (Malash *et al.* 2005) are recommended options.

Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) constitute the most important crops in the study region. They are generally cultivated in an intensive winter wheat (WW)-summer maize (SM) double cropping system in sequence within one year. This system requires significantly more water than that available from natural precipitation (Liu *et al.* 2002; Sun *et al.* 2010). While the water requirements of SM are the major part covered by natural precipitation in most years, WW inevitably depends on additional irrigation. Though saline water irrigation was widely reported for different crops in North China (Fang and Chen 1997; Wan *et al.* 2007, 2008, 2010; Wang *et al.* 2007, 2012; Kang *et al.* 2010; Sun J *et al.* 2012), only few studies have been conducted on the WW-SM system so far (Ma *et al.* 2008; Pang *et al.* 2010). Both previous studies tested the effect of saline irrigation throughout the irrigation season. In contrast, the present study aims at evaluating the effect of a single saline irrigation event at the peak of dry season in spring. During that season, farmers' limited access to surface water and deep wells, and consecutive untimely irrigation, was identified as a major yield-reducing factor in the WW-SM system in North China (Liang *et al.* 2011). As WW is especially water stress sensitive from recovery to jointing stage, at least one irrigation is recommended during this growth phase (Kang *et al.* 2002; Qiu *et al.* 2008; Chen *et al.* 2014). Regarding the timing of the use of saline irrigation water, it is additionally important to consider the crops' susceptibility to salt stress during different growth stages. While plants are generally very sensitive to salt stress during germination, emergence and seedling stages, they become more salt tolerant during later growth stages (Ashraf *et al.* 1986; de Albuquerque and de Carvalho 2003). Therefore it seems viable to apply saline irrigation only after successful establishment of WW, i.e., after recovery in spring.

Another important aspect for irrigation management in this system is the difference in salt tolerance between the two crops. Rhoades *et al.* (1992) reported that the values of the ECe of an extract of a saturated soilthat cause a yield reduction of 50% for wheat and maize are 13 and 5.9 dS m^{-1}, respectively. They also report that the threshold values beyond which yield reduction occurs for wheat and maize are 6.0 and 1.8 dS m^{-1}, respectively. Hence, wheat is classified as moderately tolerant and maize as moderately sensitive to salinity (Rhoades *et al.* 1992; Ma *et al.* 2008). Considering the above described seasonal distribution of rainfall in the study region, the water sensitivity of WW after recovery and the significantly higher salt tolerance of WW compared to SM, the use of saline water for irrigation during spring season seems a viable option to bridge the peak of dry season in the WW-SM system. It needs to be thoroughly evaluated under which irrigation management WW performs well, and the consecutive SM, which is less salt tolerant, is not negatively affected. Such strategies would help to maintain fresh water resources and grain production in North China.

Therefore the purpose of the present study is to investigate the effects of different saline irrigation treatments applied to WW after recovery stage on soil salt balance development, as well as growth and yield of WW and the following SM.