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# Effect of irrigation amount and water salinity on water consumption and water productivity of spring wheat in Northwest China

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ABSTRACT

Sustainable development of agriculture is restricted by fresh water shortage and water quality deterioration in some arid and semi-arid areas. Therefore, deficit irrigation and saline water irrigation have to be applied for sustaining crop yield. In order to determine the rational irrigation management practice in an arid region of Northwest China, field experiments were conducted in 2008, 2009 and 2010 to study the effects of irrigation amount and water salinity on water consumption and water productivity of spring wheat. Altogether nine irrigation treatments including three levels of irrigation water amount with 375, 300, and 225 mm (w1, w2 and w3) and three levels of irrigation water salinity with 0.65, 3.2, and 6.1 dS m$^{-1}$ (s1, s2 and s3) were arranged in a randomized split-plot design with three replications for each treatment. In 2008, yield increased with increasing irrigation amount under both fresh and saline water irrigation. However, in 2009 and 2010, the highest yield at the same salinity level under saline water irrigation was obtained by w2. Actual evapotranspiration ($ET_a$) decreased with decreasing irrigation amount. Therefore, w2 got higher water use efficiency (*WUE*) (1.25–1.63 kg m$^{-3}$) and irrigation water use efficiency (*IWUE*) (2.11–2.36 kg m$^{-3}$) than w1, which indicated that irrigation amount 300 mm is beneficial to yield and water use efficiency at water salinity 3.2 and 6.1 dS m$^{-1}$. Thus, for the purpose of highest yield and *WUE*, irrigation amount should be controlled at appropriate level under saline water irrigation. The effect of irrigation water salinity on $ET_a$ was significant in 2009 and 2010, while the effect on yield, *WUE* and *IWU*E was only significant in 2010. However, the differences of yield, $ET_a$, *WUE* and *IWUE* between s2 and s1 were statistically insignificant in the 3 years. It can be concluded that irrigation water salinity 3.2 dS m$^{-1}$ has no significant effect on wheat yield and water productivity. The interaction effects of irrigation amount and water salinity on yield, $ET_a$ and *WUE* were statistically insignificant in the experiments.



## 1. Introduction

Increasing agricultural production has become an urgent requirement for the expanding population (Howell, 2001). Yet, there has been a continuous decrease in available fresh water that can be used by agricultural production (Oster, 1994; Cai and Rosegrant, 2003). The scarcity of fresh water restricts sustainable agricultural development in arid regions. At the same time, the quality of irrigation water has also deteriorated. As a result, deficit irrigation and saline water irrigation have been used more prevalently in agriculture to overcome drought and sustain crop yields (Ali et al., 2007; Geerts and Raes, 2009; Ould Ahmed et al., 2010; Kang et al., 2010; Mushtaq and Moghaddasi, 2011).

Wheat, as one of the most widely consumed cereals in the world, is grown in wide range of climatic zone and mostly in irrigated conditions. Several authors (Sharma et al., 1991; Khosla and Gupta, 1997; Ma et al., 2008; Ghane et al., 2009) demonstrated the use of saline water in wheat through field experiments. Jury et al. (1978) grew wheat in lysimeters with irrigation water salinity up to 7.1 dS m$^{-1}$, but there was no detrimental effect of the high water salinity on yield. Rhoades et al. (1989) showed that irrigation using substantial amount of water with salinity 4 dS m$^{-1}$ caused little reduction in yield in their experiment. Sharma and Rao (1998) observed that mean yield reduction of wheat grown in a sandy loam soil in Karnal (India) was 4.2%, 9.7%, 16.3% and 22.2% at irrigation water salinity of 6, 9, 12 and 18.8 dS m$^{-1}$, respectively. The

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simulation results by Singh (2004) revealed that direct use of salinity irrigation water (4, 6 and 8 dS $m^{-1}$) led to relative evapotranspiration varying from 0.70 to 0.85 for wheat. Since the germination and seedling establishment have been identified as the salt sensitive stages for most of the crops, the use of better quality water has been advocated for irrigation during pre-sowing and early stages of crop growth. Then the water is switched over to saline water when the crops are able to tolerate relatively higher salinity levels (Minhas and Gupta, 1993a,b; Oster and Grattan, 2002). In Agra (India), Chauhan et al. (2008) found that replacing part or all of better quality water except pre-sowing irrigation with 8 dS $m^{-1}$ saline water is possible for cultivation of wheat, and saline water with electrical conductivity ranging between 8 and 12 dS $m^{-1}$ could be used to supplement at least two irrigations to obtain 90% or more of the optimum yield. These reported results indicated that the salinity of irrigation water up to 4–8 dS $m^{-1}$ can be applied to wheat, and the threshold of water salinity should be adjusted correspondingly in the prevailing soil and climatic conditions.

Crop yield is one of the most important considerations with utilization of saline water. Beyond the tolerance limit, generally, yields decrease approximately linearly with increasing soil salinity. This threshold value, defined as the maximum average salt concentration in the root zone at which crop yield is not significantly reduced. It depends partly on the crop's salt tolerance. Wheat is classified as a moderate salt-tolerant crop (Maas and Hoffman, 1977; Katerji et al., 2003). Generally, beyond the tolerance limit of 6 dS $m^{-1}$, wheat production decreases by approximately 7% for each 1 dS $m^{-1}$ increase in the electrical conductivity of the soil's saturation extract $EC_e$ (Maas and Hoffman, 1977). Researchers found that the maximum crop yield in fresh water irrigation could not be attained under saline water irrigation even with increasing water quantity (Shani and Dudley, 2001). The maximum yield and the corresponding irrigation water quantity in saline water irrigation decrease with increasing water salinity (Jiang et al., 2011). Thus, more studies should be carried out to maintain or increase crop production by using less quantity of saline water.

To cope with scarce supplies, deficit irrigation, defined as the application of water below full crop-water requirements (*ET*), is an important method to achieve the goal of reducing irrigation water use (Fereres and Soriano, 2007). Generally, an appropriate deficit irrigation schedule with fresh water can increase irrigation efficiency by reducing water consumption but without significantly decreasing agricultural yield (English and Raja, 1996; Zhang et al., 1998; Kang et al., 2000; Zhang et al., 2008). For example, Zhang et al. (2006) found that appropriate degree of regulated deficit irrigation at jointing, booting, heading, and the end of filling or filling and maturity could result in high grain yield and water use efficiency in spring wheat in an arid environment of Northwest China. Du et al. (2010) reported that the maximum grain yield of winter wheat would be acquired at 84% of maximum *ET* in Haihe River Basin of North China. Recent findings have confirmed that appropriate deficit irrigation of wheat using fresh water could increase water productivity through reducing water consumption without decreasing grain yield significantly. However, water consumption and water productivity of wheat under deficit irrigation with saline water irrigation have been rarely reported.

In arid and semi-arid areas, water scarcity and quality deterioration frequently occur together and interact with each other. Many researches about effects of saline water irrigation or deficit irrigation on wheat have been conducted. However, there is still little information on the interaction of saline water irrigation and deficit irrigation on water consumption and productivity of wheat. Therefore, deficit irrigation with saline water should be further investigated in order to identify the potentials of saline water and to develop deficit irrigation efficiently.

Shiyang River Basin is an arid region in Northwest China. Groundwater is the main water resource for agriculture in this region. Over-exploitation of groundwater resources from shallow and deep aquifers in this area leads to a decline of the groundwater table and an increase of groundwater salinity, which in return creates more environmental problems. As a result, there is no sufficient fresh water for agricultural irrigation. Consequently, saline water for deficit irrigation has to be taken into account in this area. The objectives of this study were (1) to quantify water consumption of wheat under different irrigation amount and water salinity and (2) to evaluate water productivity of wheat under different irrigation amount and water salinity.

## 2. Materials and methods

### 2.1. Site description and experimental design

The experiment was conducted from 2008 to 2010 at the Experimental Station for Water-Saving in Agriculture and Ecology of China Agricultural University (ESWAE-CAU) (102°52′E, 37°52′N) located in Shiyang River Basin, Northwest China. The experimental region is a typical arid desert area where climate is temperate dry, annual sunshine duration is over 3000 h, average annual precipitation is around 160 mm, and open water evaporation is around 2000 mm. The physical–chemical properties of each layer in a soil profile are shown in Table 1.

Evapotranspiration in 2005, 2006 and 2007 calculated with meteorological data using the Penman–Monteith formula is 412, 383 and 318 mm, respectively. In this area, Zhang (1998) reported that irrigation amount of 375 mm got the highest spring wheat yield. Sun et al. (2010) recommended irrigation amount is around 340 mm. The traditional irrigation amount in the study area is about 360 mm. Take average evapotranspiration ($ET_c$) of 2005–2007, reported and traditional irrigation amounts into consideration, irrigation amount of 375 mm was used for the reference to control irrigation levels in the study. Irrigation was performed with three levels of water salinity: 0.65 dS $m^{-1}$ (s1), 3.2 dS $m^{-1}$ (s2), and 6.1 dS $m^{-1}$ (s3), and three levels of irrigation amount: 100% $ET_c$ with 375 mm (w1), 80% $ET_c$ with 300 mm (w2), and 60% $ET_c$ with 225 mm (w3). Nine irrigation treatments in total were conducted in the experiment. Irrigation was applied four times according to local farming customs, specifically, at tiller to jointing, jointing to heading, heading to grain-filling, and grain-filling to maturity stages. The detailed irrigation treatments can be found in Table 2.

The experiment was laid out in split-plot designs with three replications. There were 27 elementary micro-plots in total. Each

**Table 1**
Physical–chemical properties of the soil before the experiment.

| Depth (cm) | Textural class | Bulk density (g $cm^{-3}$) | Total nitrogen (g $kg^{-1}$) | Total phosphorus (g $kg^{-1}$) | Total potassium (g $kg^{-1}$) | Cation exchange capacity (mmol $kg^{-1}$) | Soil salinity $EC_e$ (dS $m^{-1}$) | pH | Organic matter (g $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0–20 | Sandy loam | 1.56 | 0.477 | 0.685 | 15.80 | 271 | 1.09 | 8.70 | 7.86 |
| 20–50 | Sandy loam | 1.61 | 0.338 | 0.403 | 16.00 | 273 | 0.92 | 8.68 | 6.66 |
| 50–85 | Clay loam | 1.38 | 0.412 | 0.857 | 17.40 | 294 | 1.40 | 8.64 | 6.72 |
| 85–125 | Loam | 1.41 | 0.213 | 0.463 | 18.70 | 281 | 1.67 | 8.71 | 2.64 |
| 125–150 | Silt clay | 1.49 | 0.397 | 0.560 | 22.00 | 277 | 1.62 | 8.46 | 4.67 |