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Soil water dynamics and water use efficiency in spring maize (*Zea mays* L.) fields subjected to different water management practices on the Loess Plateau, China

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ABSTRACT

Soil water supply is the main limiting factor to crop production across the Loess Plateau, China. A 2-year field experiment was conducted at the Changwu agro-ecosystem research station to evaluate various water management practices for achieving favorable grain yield (GY) with high water use efficiency (WUE) of spring maize (*Zea mays* L.). Four practices were examined: a rain-fed (RF) system as the control; supplementary irrigation (SI); film mulching (FM); and straw mulching (SM) (in 2008 only). The soil profile water storage (W) and the crop evapotranspiration (ET) levels were studied during the maize growing season, and the GY as well as the WUE were also compared. The results showed that mean soil water storage in the top 200 cm of the profile was significantly ($P < 0.05$) increased in the SI (380 mm in 2007, 411 mm in 2008) and SM (414 mm in 2008) compared to the FM (361 mm in 2007, 381 mm in 2008) and RF (360 mm in 2007, 384 mm in 2008) treatments. The soil water content was lower at the end of growing season than before planting in the 60–140 cm part of the profile in both the RF and FM treatments. Cumulative ET and average crop coefficiency (K_c) throughout the whole maize growing season were significantly ($P < 0.05$) higher in the SI (ET, 501 mm in 2007, 431 mm in 2008; K_c, 1.0 in 2007, 0.9 in 2008) treatment than in the other treatments. Both FM and SI significantly improved the GY. The WUE were increased significantly (23–25%; $P < 0.05$) under the FM treatment. It was concluded that both SI and FM are beneficial for improving the yield of spring maize on the Loess Plateau. However, FM is preferable because of the shortage of available water in the area.

1. Introduction

Spring maize is one of the main crops on the Loess Plateau in China, and its high yield, averaging about 12 t hm^{-2}, is assumed to benefit from prolonged sunshine, providing adequate light and heat during its growing season (Xue et al., 2008). However, drought has long been the primary limiting factor for production of this crop because of the shortage and uneven distribution of water resources in the area (Kang et al., 2002; Wang et al., 2009; Zhang et al., 2009). To improve the efficiency with which the limited water resources are used, it is essential to have detailed knowledge of the crop field water balance and evapotranspiration (ET) in the region.

Water and its movement through the soil–plant–atmosphere continuum is considered to be one of the most important factors affecting crop productivity (Boyer, 1982). Water loss through runoff, soil surface evaporation, plant transpiration, and soil water—storage changes have been studied (Jin et al., 1999; Liu and Zhang, 2007; Liu et al., 2002). Frequently, ET, consisting of soil surface evaporation and plant transpiration, is a major component of water balance in ecosystems (Gentine et al., 2007; Parasuraman et al., 2007). Several studies use estimates for ET to construct water budgets for various ecosystems (Watanabe et al., 2004; Suyker and Verma, 2008). Gain yields (GY) can be described as a linear function of total evapotranspiration (ET) for most crops (Vaux and Pruitt, 1983). However, the relationships between GY and ET appeared to be curvilinear under certain circumstances such as over-irrigation (Sandhu et al., 2002; Liu and Zhang, 2007), e.g., excessive irrigation could lead to an increase in ET without a corresponding increase in crop yield (Liu et al., 2002).

WUE is a comprehensive index that represents the overall efficiency of plant water use (Turner, 1987). Thus, it is commonly used to develop and evaluate optimum water management strategies to ensure the most efficient use of water resources. Several soil and crop management practices can increase the crop GY and WUE (Huang et al., 2005; Fang et al., in press). Mulching has

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long been widely used in crop field management in many parts of the world. The surface mulch favorably influences the soil moisture regime by controlling evaporation from the soil surface (Raeini-Sarjaz and Barthakur, 1997; Wang et al., 2009), improving infiltration and soil water retention, decreasing bulk density and facilitating condensation of soil water at night due to temperature reversals (Acharya et al., 2005). Soil microclimate under mulching also favors seedling emergence (Albright et al., 1989) and root proliferations (Osuji, 1990) and suppress weed population (Lalitha et al., 2001). Thus, it has been widely reported that both the GY and WUE are increased under mulches (Li et al., 2001b; Li and Gong, 2002). However, on occasion, the grain yield of crop can decrease considerably with film mulching for the whole growth period (Li et al., 2001a). Furthermore, the widespread use of non-degradable plastic film mulch over many years may damage the sustainability of rain-fed agro-ecosystems by accelerating the decomposition of soil organic matter, changing the soil structure, and influencing root development (Acharya et al., 2005). Straw mulching effects depend on the climatic condition and soil type (Acharya et al., 2005). The application of straw mulch is restricted in some place, since it is liable to lower the soil surface temperature, leading to reduction in the yield (Gao and Li, 2005; Edwards et al., 2000).

Irrigation can also have beneficial effects on plant water relations and yields. For instance, scheduled irrigation at different growth stages can improve WUE according to several studies (Wang et al., 2002; Fang et al., in press). However, Jin et al. (1999) reported that excessive irrigation can reduce crop WUE, while effective deficit irrigation may result in higher production and WUE. While Olesen et al. (2000) augued irrigation had little or no effect on WUE or harvest indices, and that its effects were almost entirely due to increased transpiration. Hence, the reported effects of irrigation are variable, and the responses of grain yield (GY) and WUE to irrigation were strongly influenced by soil water contents and irrigation schedules (Kang et al., 2002).

Most studies have concentrated on examining the soil water balance in farmland exposed to only one water management practice; few studies have made comparisons among a variety of water management practices. Our objectives were to: (i) quantify the soil water storage (*W*) and ET during the maize growing season; and (ii) determine the effects of field water management practices on soil water balance and WUE.

2. Materials and methods

2.1. Site description

The present study was conducted from 2007 to 2008 at the Changwu Agri-ecological Station on the Loess Plateau (35.2°N and 107.8°E) in Shaanxi Province of China. The experimental site is located about 1206.5 m above sea level. The loess is more than 100-m thick. The soils are Cumuli-Ustic Isohumosols, according to the Chinese Soil Taxonomy (Gong et al., 2007), and contain 37% clay, 59% silt, and 4% sand and have a pH of 8.4 and a bulk density of 1.3 g cm^{-3}. The amounts of organic matter, total nitrogen, available phosphorus, available potassium and inorganic nitrogen present are 11.8 g kg^{-1}, 0.87 g kg^{-1}, 14.4 mg kg^{-1}, 144.6 mg kg^{-1} and 3.15 mg kg^{-1}, respectively. The average annual precipitation is 578 mm, with 55% falling between July and September. The annual average temperature is 9.2 °C. The common regional cropping system is one crop a year (wheat or maize). Rain-fed agriculture is the dominant production system.

2.2. Experimental design and treatments

Four water management practices – a rain-fed (RF) system (Fig. 1a), supplementary irrigation (SI) (Fig. 1b), film mulching (FM) (Fig. 1c), and straw mulching (SM) (Fig. 1d) (in 2008 only) – were used in spring maize fields. The soil water supply for the RF, FM and SM treatments relied on natural rainfall, while for the SI treatment, sufficient moisture in the soil (70–85% of the field water capacity) was maintained using tap water delivered by furrow irrigation. In the SI treatment, the crop was irrigated five times in 2007 (May 8, May 20, June 14, July 14 and August 15) and four times in 2008 (May 22, June 5, July 7 and August 4), and the irrigation quota on

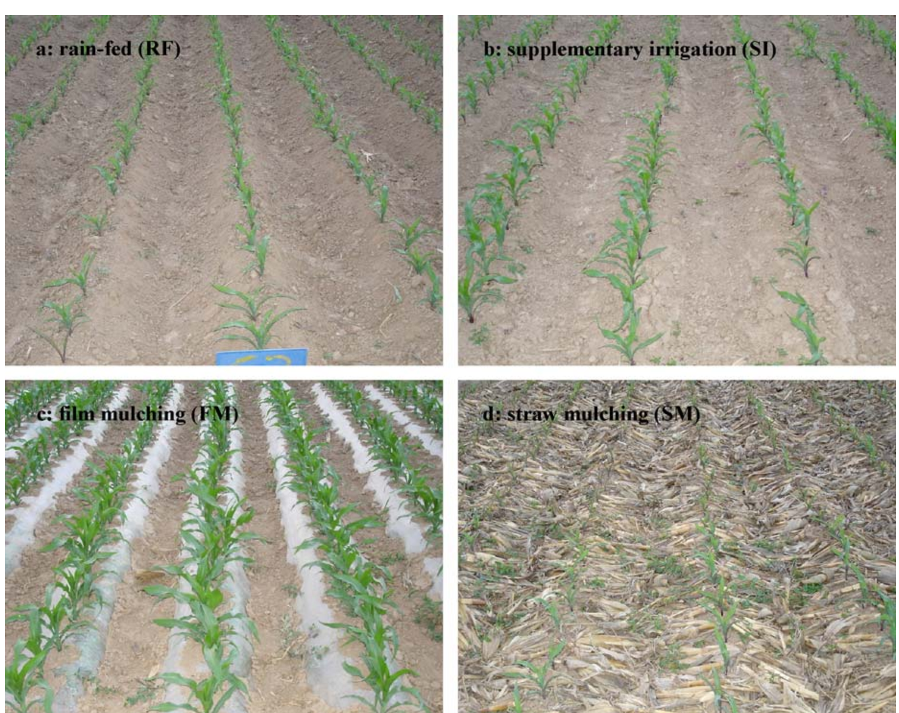

Fig. 1. Photographs showing (a) rain-fed (RF), (b) supplementary irrigation (SI), (c) film mulching (FM) and (d) straw mulching (SM) treatments.