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# Irrigation scheduling strategies based on soil matric potential on yield and fruit quality of mulched-drip irrigated chili pepper in Northwest China

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ABSTRACT

A two-year field experiment was conducted with drip irrigation and plastic mulch to investigate an appropriate irrigation management strategy for chili pepper (*Capsicum annuum* L.). Five treatments, with the soil matric potential (SMP) threshold range of −10 to −50 kPa at intervals of 10 kPa, were applied in this study and are correspondingly referred to as T1 to T5. Leaf area index, plant height, soil water content, yield, and total soluble solids (TSS) were measured, and seasonal crop evapotranspiration (ET), water productivity (WP), and irrigation water productivity (IWP) were computed regularly. Results showed that the differences in leaf area index, plant height, above-ground biomass, and crop yield in treatments T1 though T4 were similar ($P > 0.05$), but higher ($P < 0.05$) than those of treatment T5. Irrigation amount and crop ET generally decreased with decreasing SMP threshold. Threshold values with SMPs from −10 kPa to −30 kPa caused a reduction of irrigation amount by 22–43% and crop ET reduction by 11–25%. Higher TSS, larger percentage of marketable fruits, and higher WP and IWP were found for treatments T3 and T4 in both growing seasons. The highest SMP threshold (−10 kPa) and lowest SMP threshold (−50 kPa) greatly reduced the WP and IWP. Therefore, a SMP threshold range of −30 kPa to −40 kPa at 20 cm depth was recommended for irrigation management of chili pepper under mulched-drip irrigation conditions in the arid region of Northwest China.



## 1. Introduction

Chili peppers (*Capsicum annuum* L.) are commonly used as a condiment to give special taste to cooked food. In Northwest China, chili pepper is widely cultivated with high capsaicin and hematochrome content, which is mainly due to its special climatic condition, drier climate, less rainfall, more radiation and greater temperature difference between day and night (Guo et al., 1995). Annual precipitation in this region ranges between 150 mm and 300 mm, which does not satisfy pepper water requirements of 406 mm to 534 mm under an acceptable yield condition (Zheng et al., 2010). Therefore, in Northwest China irrigation has been the only way to maintain pepper's yield and quality.

In the past 50 years over-pumping groundwater for agricultural irrigation has caused environmental problems. For example, declining groundwater levels, increasing desertification, increasing soil salinity, and decreasing river flow, all have in turn influenced future agricultural development (Ma et al., 2005; Edmunds et al., 2006; Pereira et al., 2007). With the development of the economy in this region, water allocation for agriculture will decrease, which in turn affects crops' cultivation, especially for those crops sensitive to soil water deficit.

Chili pepper is sensitive to water stress due to its shallow root system (Hulugalle and Willatt, 1987; González-Dugo et al., 2007; Ityel et al., 2012). Proper irrigation scheduling is critical for maintaining a required canopy size for optimal yields (Pereira et al., 2007; González-Dugo et al., 2007). Surface irrigation methods, including border and furrow irrigation are the common irrigation methods used in Northwest China. Hence, most research conducted seeking proper irrigation scheduling of chili pepper was done with surface irrigation. These research studies found that maintaining soil water content at 60% to 80% of field capacity favors chili pepper growth (Wang, 2009), while maintaining soil water content lower than 60% of field capacity caused a decrease in yields and water use efficiency (Huo et al., 2008; Yang et al., 2008).

With the drip irrigation system, crops are generally irrigated at close intervals with a small water amount. Under this condition,

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crops have been found to be under none or minor soil water stress while crop yield has increased and fruit quality improved (Li et al., 2007). Well-designed and managed drip irrigation has the potential for saving water in crop production (Yang and Ren, 2001). Soil evaporation generally accounts for about one third of crop evapotranspiration with relatively small contribution to crop yield (Liu et al., 2002; Xie et al., 2006; Bodner et al., 2007). Therefore, mulching soil surface using crop stubbles or plastic films are common practices to reduce soil evaporation (Xie et al., 2006; Mukherjee et al., 2010), improve soil water condition and increase crop yield (Liang et al., 2011). Recently, mulched soil with plastic sheet and irrigation by a drip irrigation system, has been successfully used in cotton, wheat and soybean cultivations in Xinjiang Autonomous Region in Northwest China, because this system saves more than 30% of irrigation water and fertilizers (Yang, 2009). However, to our knowledge, little work has been conducted to evaluate the effect of soil moisture on chili pepper growth and water productivity under such field agricultural practices in the study region. Thus, optimal irrigation scheduling for chili pepper deserves further investigation under the mulched-drip irrigation condition in this region.

The objectives of this study aim at investigating the effects of various levels of soil matric potential on pepper's growth, yield, fruit quality, water consumption, and water productivity under plastic mulch and drip irrigation condition, and to identify suitable soil matric potential threshold as well as irrigation scheduling for pepper irrigation management in arid Northwest China.

## 2. Materials and methods

### 2.1. Experimental site

The field experiment was conducted from May to October in 2009 and 2010 at Shiyanghe Experimental Station for Water-Saving in Agriculture and Ecology at China Agricultural University, located in Wuwei City, Gansu Province of Northwest China (latitude 37°52′20″N, longitude 102°50′50″E, altitude 1581 m). The experimental site is in a typical continental temperate climate zone with a mean annual temperature of 8 °C, annual precipitation of 164.4 mm, a mean annual pan evaporation of about 2000 mm, an average annual sunshine duration of 3000 h and an annual accumulated temperature (>0 °C) of 3550 °C. The level of groundwater table is 40–50 m below the soil surface (Li et al., 2008).

Soils in the experimental site are sandy loam in the 0–30 cm soil layer and silt loam in 30–60 cm soil layer. The bulk density ranges from 1.44 to 1.58 g $cm^{-3}$, field capacity ranges from 0.24 to 0.28 $cm^3$ $cm^{-3}$, and wilting point from 0.11 to 0.13 $cm^3$ $cm^{-3}$. The soil physical properties of the experimental site are presented in Table 1.

### 2.2. Experimental design, irrigation and cropping systems

The experiment consisted of five treatments based on soil matric potential (SMP). They were −10 kPa, −20 kPa, −30 kPa, −40 kPa and −50 kPa, correspondingly referring to T1, T2, T3, T4 and T5 treatments in the text. Treatment T1 was the control. Each treatment was replicated three times in each season. The area for each experimental plot was 4.6 m in width and 5.0 m in length (Fig. 1a). Each plot included three raised beds with a buffer of 0.4 m between two adjacent raised beds. The width and height of each bed was 1.0 m and 0.15 m, respectively (Fig. 1b). All experimental plots were set following a randomized complete block design in each season (Fig. 1a).

Water was applied by drip irrigation with thin-wall drip tapes, which were placed in the middle of the chili pepper plant rows and spaced at 30 cm, with each irrigating two crop rows (Fig. 1b). The emitter spacing was 30 cm and the emitter flow rate was 2.7 L $h^{-1}$ at the operating pressure of 0.1 MPa (Lvyuan Inc., China). Discharges and pressure were regularly observed throughout the season and did not show any major variation due to careful design and management. Each plot had a valve to control irrigation; a pressure gauge and a water meter were installed upstream in the system to manually adjust the operating pressure and measure irrigation water applications (Fig. 1a) when initiating irrigation. Irrigation started when measured SMP was close to target value for each treatment.

The irrigation amount for each event was determined using the measured soil water content following the equation:

$$I = A \times Z \times (0.95FC - \theta), \quad (1)$$

where $I$ is the irrigation amount for each plot ($m^3$); $A$ is the bed surface area of each plot ($m^2$); $Z$ is the designed wet soil depth (m). 72% of the chili pepper roots were developed in the upper 25 cm of the soil when the crop was irrigated (Hulugalle and Willatt, 1987). Hence, a $Z$ value of 0.25 m was set in this study, to provide enough water in the main root zone to compensate the water loss caused by plant evapotranspiration, and simultaneously not much to percolate through the bottom of the root zone (0.6 m). $FC$ is the field capacity in the soil layer at $Z$ depth, given in Table 1. $\theta$ is the volumetric soil water content before each irrigation. The soil water content was calculated using the measured SMP and soil water characteristics curve, which was a statistically regression curve using in situ measured soil water contents and soil matric potentials in the 0–25 cm layer. These data were measured at 1–2 day intervals simultaneously in a SMP range of 0 to −70 kPa (equivalent to volumetric soil water content of 10–32%) before the experiment. The regression curve was

$$\Psi = -94.66 \ln(\theta) - 130.83 \quad (n = 21, \quad R^2 = 0.96) \quad (2)$$

where $\psi$ is the SMP, −kPa; and $\theta$ is the volumetric soil water content ($cm^3$ $cm^{-3}$). It must be noted that, Eq. (2) is valid for SMP ranging from 0 to −70 kPa and the experimental location being considered, not out of that range or in different sites.

Meiguohong (*Capsicum annum* L.), a chili pepper variety widely cultivated in the study area, was used in this experiment. The chili peppers were seeded in a raised bed on May 4th through 6th and harvested around September 20th in the two seasons. Irrigation treatments started on June 20th and 28th in the 2009 and 2010 growing seasons, respectively, when the seedlings were about 10 cm high. In each raised bed, there were four pepper rows, with row spacings of 0.3 m–0.4 m–0.3 m and plant spacing of 0.3 m (Fig. 1b). Two pepper rows were irrigated using one drip tape. The raised beds and drip tapes were covered with black polyethylene sheets to reduce surface evaporation and control weed growth during the experimental period. After sowing the peppers, all experimental beds were immediately irrigated until soil water content in the upper 25 cm soil layer was close to the field capacity, indicated by a SMP value higher than −5 kPa. All beds were irrigated once every 4–7 days to maintain a soil water condition suitable for pepper seedling development before water treatment (i.e. June 20th in 2009 and 28th in 2010). Following the local practices for chili pepper cultivation, organic fertilizer (cow manure) was applied uniformly to the experimental field with a rate of 12,000 kg $ha^{-1}$ when the soil was plowed, and nitrogen fertilizer (urea) was applied three times with a seasonal amount of 180 kg $ha^{-1}$ using the drip irrigation system.

### 2.3. Crop evapotranspiration

The actual evapotranspiration (ET) of the chili pepper was estimated for each treatment using a soil water balance method as

$$\mathrm{ET} = I + P_e \pm \Delta S + \mathrm{CR} - D - R \quad (3)$$