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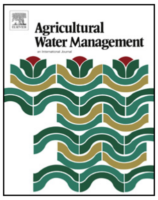

Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District

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ABSTRACT

Processing tomatoes are major cash crops in the Hetao Irrigation District, Inner Mongolia, China. Conventional irrigation practices have resulted in ecological and environmental problems due to the specific climate and groundwater conditions. Field experiments were conducted to investigate the effects of water stress on processing tomatoes yield, quality, and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. Tomatoes were irrigated at 40%, 60%, 70%, 80% and 100% of crop evapotranspiration (ET_c). Results showed that soil water content and salt concentration mainly varied in the upper 60 cm soil layer. Dry aboveground biomass and yield increased with increased ET_c to 80 or 100%. The highest yield was obtained with 80% ET_c treatment both years (70 and 81 t/ha). Increasing water stress led to the increase of soluble solids content and Vitamin C. Actual evapotranspiration (ET_a) ranged from 188 to 323 mm in the two seasons, and increased quadratically when the irrigation depth increased to 80% ET_c. The highest water use efficiency (WUE) was found at 60% ET_c treatment in 2013 and 80% ET_c treatment in 2014. Comprehensive analysis of yield, WUE and ET_a, irrigated at 80% ET_c was recommended as the optimal irrigation strategy in the sandy soil of the Hetao Irrigation District.

1. Introduction

The Hetao Irrigation District, the third-largest irrigation district in China, is a major grain and crop production region. The climate in this region is a typical arid continental climate. The mean annual precipitation is 150 mm and the mean annual potential evaporation is in the range of 2200–2400 mm (Feng et al., 2005). Irrigation for crop production is essential because of the large discrepancy between precipitation and evaporation. Conventional irrigation practice is basin flood irrigation using water from the Yellow River. As the groundwater table is shallow, varying from 0.5 to 3.0 m during the growing seasons, irrigation practices have resulted in various ecological and environmental problems, including soil salinization. In the last few decades, marginal lands have been reclaimed for agriculture and the irrigated area has steadily expanded from 4.0×10^5 ha in the 1980's to 5.7×10^5 ha at present. In contrast, the plan is to reduce the amount of water diverted from the Yellow River to the Hetao Irrigation District by 20% from 5 billion m^3 due to intensifying demand of the Yellow River basin. Thus, water resources per unit farmland have been reduced and future reduction may mean that water scarcity could severely limit agricultural productivity in the Hetao Irrigation District. Therefore, developing water-saving agriculture, establishing efficient irrigation schedules, and improving water use efficiency are essential for the sustainability of agriculture, water resources, and the ecosystem.

Processing tomatoes (*Lycopersicon esculentum Mill.*) are major cash crops in the Hetao Irrigation District due to the site-specific climate, sunlight, heat resources, and marketing opportunities. Processing tomato is an important industry in the Hetao Irrigation District, processing around 22 million tons of tomato and producing 3 million tons of ketchup per year. The cultivated area of process-

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ing tomatoes increased from 11,000 ha in 2004 to 29,700 ha in 2008 (Zhang et al., 2009). Processing tomatoes have high water demands requiring irrigation throughout the growing season in the arid and semi-arid regions, where rainfall is much less than crop evapotranspiration. Implementation of water-saving irrigation strategies may allow higher yields, improve fruit quality, and optimize water use efficiency.

Various water-saving irrigation practices have been utilized for tomatoes, including mulching, drip irrigation and deficit irrigation. Mulching is widely used for tomatoes and other cash crops in the north of China (Liu et al., 2012; Zheng et al., 2013a; Zheng et al., 2013b; Li et al., 2015). Drip irrigation is an effective way to supply water and nutrients to the root zone and not only saves water but can also increase crop yield (Çetin and Uygan, 2008; Ozbahce and Tari, 2010; Patanè and Cosentino, 2010; Marino et al., 2014). Previous research shows that the yields and quality of tomatoes are improved by application of water using drip irrigation alone or in combination with different types of plastic or organic mulches (Shrivastava et al., 1994; Wan et al., 2007; Biswas et al., 2015).

Deficit irrigation is an alternative water-saving strategy by allowing crops to suffer from slight water stress with or without an acceptable decrease of yield and quality (Costa et al., 2007). The effects of water stress on tomatoes growth, yield, quality, and water use efficiency have been studied over the entire or partial growing season (Obreza et al., 1996; Marouelli and Silva, 2007; Ngouajio et al., 2007; Topcu et al., 2007; Berihun, 2011). The effects of water stress on tomatoes yield vary widely by soil and climate conditions (Locascio and Smajstrla, 1996; Nahar and Gretzmacher, 2002; Kirda et al., 2004; Zegbe et al., 2007). In the Mediterranean climate condition, the yield of processing tomatoes was reduced when the irrigated water was only 50% of crop evapotranspiration (Favati et al., 2009). However, Wang et al. (2007) found that yield was not significantly affected under water stressed irrigation (irrigation commenced when soil matric potential reached −10 to −50 kPa) in a silt loam soil in the North China Plain. Kuscu et al. (2014a) found that soil water deficit during flowering and fruit formation stages led to a severe reduction in marketable yield in a clay loam soil of a sub-humid region.

In addition to yield, tomato fruit quality response to water stress is of great concern. Many studies have shown that certain quality indexes (soluble solids content and Vitamin C) are improved at some extent under certain water stress levels (Mitchell et al., 1991; Pulupol et al., 1996; Zegbe-Domınguez et al., 2003; Ozbahce and Tari, 2010). Large irrigation depths decreased soluble solids content in tomato fruit (Kuscu et al., 2014a). Water stressed irrigation of tomatoes in the typical Mediterranean climate promoted total soluble solids content, titratable acidity, and Vitamin C (Patanè et al., 2011). From experiments conducted in two sites with different soil and climatic characteristics in the Mediterranean region, Patanè and Cosentino (2010) found that water stressed treatment enhanced the soluble tomato solids content, firmness, and Vitamin C. Both total soluble solids content and Vitamin C increased with water shortages in a sandy clay loam soil in an arid climate (Shahein et al., 2012). Johnstone et al. (2005) found that mild to moderate water deficit (20% to 60% ET_0) during fruit ripening resulted in acceptable soluble solids concentration without significant brix yield reduction. In the coastal savannah zone of Ghana, Agbemafle et al. (2014) showed that firmness, total soluble solids, and titratable acidity increased with a decrease in irrigation while the pH did not vary significantly.

Many studies indicate that slight water stressed conditions have the potential to improve water use efficiency (Liu et al., 2008; Patanè et al., 2011; Agbemafle et al., 2014; Patane et al., 2014). Kuscu et al. (2014b) found that the highest water use efficiency occurred in moderate water stressed irrigation treatments in a sub-humid climate. However, with severe water stress irrigation, water use efficiency was reduced (Nuruddin et al., 2003; Mukherjee et al., 2010; Kuscu et al., 2014a). Water use efficiency and its variations are highly impacted by various tomato cultivars, climates and soils.

Previous research has demonstrated that the effects of soil water stress on processing tomato yield, quality and water use efficiency are complicated and site-specific, and are affected by environmental conditions. There are few fields experimental data related to processing tomato crop evapotranspiration, yield, and water use efficiency responses to different irrigation amounts, especially under mulched drip irrigation condition. Thus, site-specific field experiments are required for appropriate irrigation scheduling in the Hetao Irrigation District. The objectives of this research were: 1) to investigate the effects of different water stress levels on processing tomato growth, yield and quality with plastic mulched drip irrigation in sandy soils of the Hetao Irrigation District, 2) to analyze water use efficiency and 3) to propose an appropriate drip irrigation strategy for processing tomatoes by comprehensive analysis of yield and water use efficiency for wider testing in the study area.

2. Materials and methods

2.1. Experimental site description

Field experiments were conducted at Shuguang Experimental Station in the Hetao Irrigation District, Inner Mongolia, China (latitude 40°43′N and longitude 107°13′E, elevation 1042 m a.s.l.) in 2013 and 2014. The soil at the experimental site is a layered soil with a silt loam surface and deep sandy soil. Detailed physical properties of the soil profile are tabulated in Table 1. The high sand percentage in the 60–120 cm soil layer may easily result in water seepage and fertilizer leachate. Therefore, soil water management is important in this region. The mean bulk density is 1.59 g/cm^3 and the average field capacity is 0.22 cm^3/cm^3 for the top 40 cm of soil. The groundwater depth was relatively shallow, varying between 1.8 and 2.8 m at the experimental site.

2.2. Weather conditions

Meteorological variables, including photosynthetically active radiation, maximum and minimum air temperature, rainfall, air relative humidity, wind speed and direction at 2 m above ground, were measured by an automatic weather station (HOBO, Campbell

Table 1
Soil physical properties of the profile in the experimental site.

Soil depths (cm)	Soil particle fraction (%)			Soil texture	Bulk density (g/cm^3)	Field capacity (cm^3/cm^3)
	Sand (>0.05 mm)	Silt (0.002-0.05 mm)	Clay (<0.002 mm)			
0–20	23.1	63.0	13.9	Silt loam	1.59	0.22
20–40	37.9	44.1	18.0	Loam	1.59	0.22
40–60	48.5	43.2	8.3	Loam	1.63	0.16
60–80	74.5	20.1	5.4	Sandy loam	1.63	0.16
80–100	89.3	8.8	1.9	Sand	1.58	0.18
100–120	92.5	6.0	1.5	Sand	1.58	0.18

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