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The response of processing tomato to deficit irrigation at various phenological stages in a sub-humid environment

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ABSTRACT

Field studies were conducted to determine the response of processing tomato (*Lycopersicon esculentum* Mill.) to deficit irrigation (DI) to guide programs for the development of improved irrigation management practices for sub-humid zones. Field experiments were conducted in Bursa province, Turkey. Industrial tomato plants (cv. *Shasta*) were subjected to different levels of irrigation using a drip system in the field on a clay–loam Entisol soil for 2 years. Well-watered plants were irrigated at100% crop evapotranspiration (ET_c) with 3-day intervals. In other treatments, irrigation was not applied during the vegetative, flowering, yield formation or ripening stages or during combinations of these stages. Fruit weight, marketable yield (MY) and net income decreased with decreases in the amount of irrigation depending on the irrigation timing, but the effect of soil water deficit on the shape index was minor. The highest MY and fruit weight were obtained with the full irrigation (100% ET_c) treatment. Water deficit by non-irrigation during the flowering and/or yield formation stages substantially reduced MY values in both years. The results showed that full irrigation during the whole growing season is preferable for higher yield and net income. However, in regions of water scarcity, irrigation managers should adopt the DI approach to achieve economically sustainable crop production. As an alternative to full irrigation during the entire growing season, the application of full irrigation until the beginning of the fruit ripening stage and the cessation of full irrigation after that time can be recommended as optimal because it achieved irrigation water savings of 33%, an increase of 42% in irrigation water use efficiency (IWUE), a satisfactory fruit soluble solids content (SSC) and an acceptable net income with a yield loss of only approximately 5% compared with full irrigation.

1. Introduction

Tomato is an important vegetable, widely cultivated throughout the world. The leading tomato-producing countries are the European Union countries, China, USA, India, and Turkey. Turkey produced 8% of the tomato fruit worldwide in 2010 (Esengun et al., 2007). The total area used to cultivate vegetables in Turkey is 1,089,805 ha, 28% of which is devoted to tomato crop (FAO, 2012). The total tomato production in 2010 was 10,052,000 tons, grown under cover and in open fields (FAO, 2012; TUIK, 2012). Approximately half of the whole tomato production is assigned to the processing tomato industry in Turkey (Ozbahce and Tari, 2010). The Marmara region contributes approximately 50% of the processing tomato production of Turkey. About 65% of this production is obtained in Bursa province, in this region (TUIK, 2012).

The nutritional composition of the tomato fruit is affected by the variety, state of ripeness, year, climatic growing conditions, light, temperature, soil, fertilization, and irrigation (Smith and Hui, 2004). Because water is one of the most important environmental factors affecting the fruit growth and production of tomato, irrigation scheduling is crucial for increasing tomato yield and quality (Wang et al., 2011). The irrigation scheduling that determines the timing and amount of irrigation water is governed by many factors, but microclimate plays the most important role (Imtiyaz et al., 2000). According to the literature, tomato has high water requirements (Ngouajio et al., 2007; Patanè and Cosentino, 2010; Patanè et al., 2011). Although Bursa province is located in a sub-humid environment, rainfall is very low in the summer, which is the growing season for processing tomato (average seasonal rainfall for 1960–2012 is 65 mm). The total precipitation does not meet the water requirements of tomato crop. Therefore, irrigation is necessary for optimal vegetative and reproductive development in the periods of insufficient precipitation during the growing season in the Marmara region. Optimizing water use is an economic and environmental concern for agricultural producers (Ngouajio et al., 2007). Traditionally, processing tomatoes have been

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Table 1
Physical and chemical characteristics of the soil.

Depth (cm)	Texture			Bulk density (g cm^{-3})	Organic matter (%)	pH	Total P (ppm)	Total K (ppm)
	Sand (%)	Silt (%)	Clay (%)					
0–30	23.9	47.4	28.7	1.44	1.8	7.8	79.0	142.3
30–60	23.5	41.4	35.1	1.36	2.5	7.8	39.2	74.9
60–90	23.5	42.0	34.5	1.44	1.9	8.0	35.7	75.2
90–120	29.1	44.4	26.5	1.49	–	–	–	–

irrigated by furrow irrigation; however, the use of drip irrigation has increased rapidly in the Turkish tomato cultivation. The major reasons for the conversion from furrow irrigation are the improved water application efficiency and precision placement provided by drip irrigation. These features increase efficient agricultural water use and minimize nitrate leaching (Hartz, 1993; Yohannes and Tadesse, 1998; Singandhupe et al., 2003). However, the limited fresh water resources and the energy cost of pumping water for irrigation are the most important reasons that induced many farmers to decrease irrigation in the Marmara region. This condition is forcing growers and water managers to consider the DI option for reducing agricultural water use. In Bursa province, the knowledge of soil–water–yield relationships is particularly important for processing tomato because this crop covers more irrigated area than other crops in the region.

DI strategies have the potential to optimize water productivity to produce higher yields per unit of irrigation water applied in horticulture (Costa et al., 2007; Fereres and Soriano, 2007). In DI, the crop is exposed to a certain level of water stress during the whole growing season or at a particular stage of it (English and Raja, 1996). However, not all stages of crop growing season are equally sensitive to water stress. For example, water-sensitive stages occur during the yield formation stage in onion (*Allium cepa*), during ripening growth in cabbage (*Brassica oleracea*), at the beginning of the flowering stage in pepper (*Capsicum annum*), during the late vegetative, flowering and yield formation stages of watermelon (*Citrullus vulgaris*) and at the flowering stage of tomato (Doorenbos and Kassam, 1979). Water stress level and irrigation application timing significantly affect the tomato yield and fruit quality (Wang et al., 2011). It is well known that the application of DI to tomato crops can increase water use efficiency (WUE) and improve processing tomato quality (Zegbe-Dominguez et al., 2003; Favati et al., 2009). Conversely, DI applications may cause the development of small size fruits, lower marketable yields, early senescence of the plants and higher vulnerability to various diseases (Pulupol et al., 1996; Hanson et al., 2006; Favati et al., 2009).

In general, most research on the irrigation of tomato is devoted to the study of the yield and quality responses to water stress under greenhouse conditions (Yuan et al., 2001; Harmanto Salokhe et al., 2005; Mahajan and Singh, 2006; Topcu et al., 2007; Ismail et al., 2008; Li et al., 2010). Less information is available on DI effects on open-field grown tomato (Çetin and Uygan, 2008; Favati et al., 2009; Patanè and Cosentino, 2010). However, water shortage is often a much less important problem for farmers than soil limitations (e.g. insufficient water holding capacity, soil salinity and shallowness, etc.) because their primary objective is to maximize their income per cultivated area (Luquet et al., 2005). Before DI can be accepted as a management strategy, its effect on marketable yield, quality and net income should be determined based on water–yield relationships and an economic evaluation.

The objectives of this study were to (1) quantify the yield and quality response of processing tomato to DI in a sub-humid environment; (2) determine water–yield relationships with respect to seasonal water use, yield response factors (k_y), water use efficiency (WUE) and IWUE; (3) examine the profitability of DI from an economic perspective; and (4) specify the best DI regimes for achieving the goal of reducing irrigation water use.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted for two consecutive summer seasons (2010 and 2011) in the experimental field of Mustafakemalpaşa Vocational School of Uludağ University located in Bursa province, Turkey (co-ordinates are: latitude 40°02′ N, longitude 28°23′ E). The altitude is 22 m above mean sea level. The experimental site has a clay–loam Entisol soil. Table 1 presents information on the physical and chemical properties of the soil in the field area. The soil is poor (1.8–2.5%) in organic matter and rich in potassium. The volumetric moisture content at field capacity (FC) and permanent wilting point (PWP) in each 0.30 m layer up to 1.20 m depth were determined using a pressure plate apparatus (Richards, 1965). The measured FC (−33 kPa) and PWP (−1500 kPa) averaged 36 and 21%, respectively (Cassel and Nielsen, 1986; Walker, 1989). The water holding capacity (the difference between the water content at FC and PWP) of the experimental site was determined to be 184 mm in a 0.90 m soil profile. The average bulk density of the soil was 1.41 g cm^{-3}.

The local climate is temperate, the summers are hot and dry, and the winters are mild and rainy. According to long-term meteorological data (1975–2010), the annual mean rainfall, temperature, and relative humidity are 681 mm, 14 °C, and 68%, respectively. The climate in this part of the country is classified as sub-humid according to the Thornthwaite climate classification system (Feddema, 2005). The rainfall during the growing season is shown in Fig. 1.

2.2. Agronomy

The experimental design was a randomized complete block with 3 replications. Each experimental plot was 5.10 m long by 5.60 m wide (28.56 m^2), with 4 rows per plot. A buffer zone spacing of 2.00 m was provided between the plots. The row spacing and plant–plant spacing were 1.40 and 0.30 m, respectively. The hybrid cultivar Shasta variety (Campbell's Seeds^{TM} Inc.,

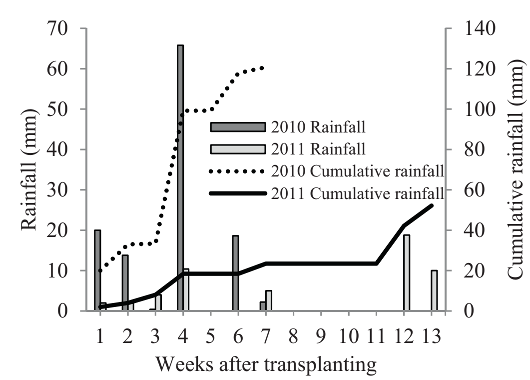

Fig. 1. Weekly rainfall during the tomato growing season in 2010 and 2011.