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RESEARCH ARTICLE

Peach yield and fruit quality is maintained under mild deficit irrigation in semi-arid China

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Abstract

We conducted a two-year study of deficit irrigation impact on peach yield and quality in semi-arid northwest China. Over two years, four-year-old peach trees were irrigated at 100, 75, 50 and 25% of peach evapotranspiration (ET_c), here, ET_c= Coefficient (K_c)×Local reference evapotranspiration (ET_o). During the April–July fruit production season we measured root zone soil water depletion, sap flow velocity, net photosynthetic rate (P_n), transpiration rate (T_r), stomatal conductance (G_s), water use efficiency (WUE=P_n/T_r), fruit quality, and yield under a mobile rain-out shelter. Increased soil water depletion reasonably mirrored decreasing irrigation rates both years, causing progressively greater water stress. Progressive water stress lowered G_s, which in turn translated into lower T_r as measured by sap flow. However, mild deficit irrigation (75% ET_c) constricted T_r more than P_n. P_n was not different between 100 and 75% ET_c treatments in both years, and it decreased only 5–8% in June with higher temperature than that in May with cooler temperature. Concurrently under 75% ET_c treatment, T_r was reduced, and WUE was up to 13% higher than that under 100% ET_c treatment. While total fruit yield was not different under the two treatments, because 75% ET_c treatment had fewer but larger fruit than 100% ET_c trees, suggesting mild water stress thinned fruit load. By contrast, sharply decreased T_r and P_n of the driest treatments (50 and 25% ET_c) increased WUE, but less carbon uptake impacted total fruit yield, resulting 13 and 33% lower yield compared to that of 100% ET_c treatment. Irrigation rates affected fruit quality, particularly between the 100 and 75% ET_c trees. Fewer but larger fruit in the mildly water stressed trees (75% ET_c) resulted in more soluble solids and vitamin C, firmer fruit, and improved sugar:acid ratio and fruit color compared to the 100% ET_c treatment. Overall, trees deficit irrigated at 75% ET_c maintained yield while improving fruit quality and using less water.

Keywords: peach, deficit irrigation, fruit quality, yield, sap flow velocity, net photosynthetic rate (P_n)

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1. Introduction

China's fruit production area accounts for 21% of the world's total, but water resources per capita account for only a quarter of the world level (Zhao *et al*. 2014). In arid or semi-arid areas, like northwest to north-central China, low annual precipitation and high evaporation rates requires efficient and effective crop water management (Clarke *et al*. 1991), particularly in the case of fruit trees (Chalmers *et al*. 1981). Not only is water key to maintaining photosynthesis and subsequent fruit yield in dry areas, but can also be important for fruit quality (Kang *et al*. 2007). In recent years, economic development and improved living standards have raised expectations for fruit quality in China, particularly peaches. Rising expectations have changed Chinese fruit production from extensive (more area but low yield and quality) to intensive management for higher yield and quality on potentially less area. More intensive fruit production in Chinese dry regions demands greater crop productivity: acceptable yield and quality using less water compared to current irrigation practices. Peach requires irrigation in arid to semi-arid northwest to north central China from spring to early summer when rainfall is seasonally low and evaporation rates high prior to post-harvest seasonally high rainfall. Deficit irrigation is a demonstrated tool that maximizes fruit production per unit water applied rather than per unit land area by irrigating below recommended levels (Ferres and Soriano 2007). Pre-harvest deficit irrigation as a water savings tool in peach is seldom studied in China.

Deficit irrigation is either regulated, and applied to certain periods during crop phenology when mild water does not reduce yield, or sustained at a constant level over the growing season (Steduto *et al*. 2012). Deficit irrigation of mild water stress improved fruit quality and flavor in grape (Santos *et al*. 2007), and increased vitamin C concentration and soluble solids in several fruit species (Peng and Rabe 1998; Mpelasoka *et al*. 2001; Leib *et al*. 2006; Maria *et al*. 2013; Laribi *et al*. 2013), as well as sugar:acid ratio, color, appearance and flesh quality (Ginestar and Castel 1996; Gelly *et al*. 2004; Ma *et al*. 2006; Santos *et al*. 2007; Laribi *et al*. 2013). Therefore, deficit irrigation may not only save irrigation water but also improve fruit quality and value, benefitting the consumer and farmer income. However, there are few studies in China on using deficit irrigation to balance water use against fruit yield and quality, and particularly consumer acceptance.

Successful deficit irrigation requires monitoring tree water status to manage stress and irrigation (Liu *et al*. 2016). Sap flow velocity has proven to accurately reflect the status of plant water stress and on transpiration and photosynthesis. Measured sap flow accurately represented tree water stress levels in olive (Fernandez *et al*. 2001), peach (Remorini and Massai 2003), lemon (Ortuno *et al*. 2004) and grapes (Sousa *et al*. 2006). Measured photosynthesis and transpiration have also been used as indicators of deficit irrigation and degree of water stress in pear trees (Morandi *et al*. 2014). However, deficit irrigation has been studied in peach, but largely applied post-harvest (Goldhammer *et al*. 2002; Gelly *et al*. 2004; Dichio *et al*. 2007; Wang and Gartung 2010; Abrisqueta *et al*. 2012; Qassim *et al*. 2013).

Here we seek to determine if regulated deficit irrigation can maintain peach quality and yield in semi-arid areas of China. Therefore, we measured soil water depletion, sap flow velocity, net photosynthetic rate (P_n), transpiration rate (T_r), stomatal conductance (G_s), water use efficiency (WUE), yield and fruit quality of peach trees under progressively decreasing irrigations rates.

2. Materials and methods

2.1. Experimental conditions and plant materials

The experiment was conducted at the water-saving irrigation experimental station of Northwest A&F University in Yangling, Shaanxi Province, China (latitude 34°17´N, longitude 108°04´E, 521 m altitude) under a mobile rain-out shelter (used only during rain) over two consecutive years (2010 and 2011). Twenty-four years of climate records at the experimental site showed average annual temperature of 12.5–13°C, annual rainfall of 490–520 mm (most falling in mid-late summer) and evaporation of 1 300–1 400 mm. Soil at the experimental site was an alluvial silt loam (1.6% sand, 69.3% silt, 29.1% clay), with soil field capacity of 23–25% (mass water content), available water content of 18% to a depth of 100 cm, and soil bulk density of 1.44 g cm^{-3}. This soil had high organic matter content 8.4 g kg^{-1}, total N content 0.94 g kg^{-1} (31.7 mg kg^{-1} available), total P content 0.76 g kg^{-1} (13.1 mg kg^{-1} available) and total K content 14.9 g kg^{-1} (116.3 mg kg^{-1} available). The study was located in a large experimental orchard of four-year old peach trees in 2010 (cultivar FX2000-1, grafted on GF677 rootstock).

The central Shaanxi region of China where the study was conducted is semi-arid, based on low spring–early summer rainfall but correspondingly high local reference evapotranspiration (ET_o) during the early phenological stages of peach fruit development as shown in Fig. 1. During this early period, the chance of rain falling on any given day fluctuates between 20–25%, but rainfall increases from an average 3 mm day^{-1} up to 10 mm day^{-1}, and can vary wildly from 70 mm during the three-month spring period up to 250 mm, but irrigation is required in the rain-free breaks of 10–14 days. Average ET_o varies less than rainfall for this region, but during 2010–2011 was higher than the long-term average. 2011 was particularly hot and dry from mid-April to mid-May, with daily ET_o ranging up to 7 mm, and rainfall was also variable, then peach trees were under high evaporative demand during vegetative growing and fruit seting period. Post-harvest in this region coincides with the wettest period where irrigation is not necessary