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Leaf physiological responses of mature pear trees to regulated deficit irrigation in field conditions under desert climate

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ABSTRACT

Regulated deficit irrigation (RDI) affects the physiological process of fruit trees. An experiment was conducted to evaluate physiological responses of pear tree to RDI treatments and its impacts on yield under desert climate in 2009 and 2010. Four water stress treatments consisted of moderate and severe (irrigated with 60% and 40% of pan evaporation, respectively) water deficit in the cell division or slow fruit enlargement stage and well irrigation (irrigated with 80% of pan evaporation) during other fruit growth stages. The results showed that leaf photosynthetic, transpiration rate and stomatal conductance all decreased during water stress cycle, and it took 1 to 4 weeks to recover these responses after the irrigation resuming depend on RDI treatments. After severe water stress in cell division stage or moderate water stress in slow fruit enlargement stage, leaf photosynthetic rate effectively enhanced during the fruit enlargement stage following resumption of well irrigation, resulting in the improvement of fruit yield. The leaf water use efficiency was also improved by RDI treatments. The results contributed to understand mechanisms of the yield improvement by RDI and its high water use efficiency.

1. Introduction

The fruit tree planting acreage reached 867,100 ha in 2008 in southern Xinjiang Autonomous Region, China, and most of planting regions are on the oases around Taklimakan desert in which the water resource shortage is severe. Fruit production in this arid region is solely dependent upon irrigation, and the water table declined in recent years due to overpumping of ground water for the irrigation agriculture. The shortage of water resource is becoming a limiting factor for the sustainability of fruit production and stability of oasis ecosystems. Therefore, it is of great importance to apply the water-saving irrigation technique and improve the water use efficiency of the oasis agriculture.

Regulated deficit irrigation (RDI) strategy is a high water use efficiency technique proposed by Chalmers and Van Den Ende (1975), which can be used for saving water, maintaining or increasing the yield and improving water use efficiency and fruit quality (Girona et al., 2005; Topcu et al., 2007; Costa et al., 2007; Hueso and Cuevas, 2010). RDI and deficit irrigation (DI) have been already successfully applied on many crops since 1970s, which include beet, *Olea europaea*, pepper, grape and pear-jujube, etc (Miller and Hang, 1980; Tognetti et al., 2005; Dorji et al., 2005; dos Santos et al., 2007; Cui et al., 2009).

The water stress applied during the slow fruit enlargement stage can reduce the leaf transpiration rate (T_r) and stomatal conductance (g_s), which decrease the water loss from leaves of fruit trees (Marsal and Girona, 1997; Romero and Botía, 2006; Ahmed et al., 2007; Cui et al., 2009). On the other hand, the water stress also reduces the leaf photosynthetic rate (P_n) (de Souza et al., 2005; Pérez-Pérez et al., 2008; Poni et al., 2009), which possibly influences the fruit growth or yield negatively. Thus, resumption of well irrigation is applied during the subsequent fruit enlargement stages in RDI scheduling in the view of improving or maintaining fruit growth. The irrigation resuming recovers the leaf P_n, g_s and T_r of fruit trees (Pérez-Pérez et al., 2008; Cui et al., 2009), and it will take a period of time to restore these responses (Fernández et al., 1997; Angelopoulos et al., 1996).

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Table 1
Accumulated values (mm) of precipitation, pan evaporation and water applied for each treatment in 2009 and 2010.

Year	Growing stage	Precipitation	Pan evaporation	Water applied				
				M-1	S-1	M-2	S-2	Control
2009	Stage 1	2.4	171.5	90.3	58.3	119.4	119.4	119.4
	Stage 2	9.2	364.8	305.6	305.6	222.4	148.6	305.6
	Stage 3	9.6	264.0	226.7	226.7	227.4	226.7	226.7
	Total	21.2	800.3	622.5	590.6	569.2	494.7	651.7
2010	Stage 1	9.2	136.5	71.5	47.7	95.3	95.3	95.3
	Stage 2	12.6	319.3	257.7	257.7	193.3	128.9	257.7
	Stage 3	2.2	317.5	268.0	268.0	268.0	268.0	268.0
	Total	24.0	773.3	597.2	573.4	556.6	492.2	621.0

Effects of water deficit on growth of pear trees have been reported (Mitchell et al., 1984, 1986; Chalmers et al., 1986; Behboudian et al., 1994; Caspari et al., 1994; Marsal et al., 2000, 2002). Water deficits applied during periods of rapid vegetative growth and/or slow fruit growth decrease shoot length, trunk cross-sectional area and weight of summer pruning, and subsequent full irrigation applied during the rapid fruit growth stage increases the pear yield by 10–20% (Mitchell et al., 1984, 1986; Chalmers et al., 1986). The fruit number and yield of pear trees increase due to RDI, while fruit size decrease (Marsal et al., 2002). However, most of the previous RDI studies on the pear trees could not evaluate the water stress imposed in the cell division stage of fruit growth due to too high soil water potential resulting from the excessive winter precipitation and the low spring evaporation (Mitchell et al., 1984, 1986, 1989; Chalmers et al., 1986; Marsal et al., 2002; Wu et al., 2013).

Meanwhile, an understanding of how water deficit and irrigation affects the physiological process of pear leaves could contribute to the successful application of RDI on pear trees. The leaf g_s and P_n of container-grown pear trees are 20% and 19%, respectively, lower for RDI during the water deficit period than the non-stressed trees (Marsal et al., 2000). Water stress reduce leaf P_n and g_s of the pear trees remarkably (Behboudian and Lawes, 1994), and the leaf P_n of pear trees previously endured water stressed is still lower than those fully irrigated trees till 1 day after full irrigation resumes (Behboudian et al., 1994). Similar results are observed by other researchers (Marsal and Girona, 1997; Marsal et al., 2002). However, these studies did not investigate the recovery trend of the leaf P_n and T_r after re-watering, which are affected by the growing period, span and degree of water stress, and influence the final pear yield.

The aims of this study were to find out (1) the effects of water stress, applied in different growth stages and with various levels, on leaf P_n, g_s, T_r and water use efficiency of RDI pear trees; (2) impacts of irrigation resuming after water deficit on the recovery of leaf physiological parameters; and (3) the fruit yield improvement mechanism of RDI with respect to leaf P_n.

2. Materials and methods

2.1. Experimental material and location

The experiment was conducted in a pear orchard of Bayingolin Agricultural Research Institute, Xinjiang, China (41°43′N, 86°6′E) from middle April to early September in 2009 and 2010. The experimental orchard was located in an oasis under a typical desert climate with mean annual evaporation and precipitation of 1600 mm and 50 mm, respectively, and the average annual temperature is 11.4 °C. During the whole experimental period, the precipitation was 21.2 mm in 2009 and 24 mm in 2010, and the evaporation in 2009 and 2010 was 800 mm and 773 mm, respectively (Table 1). The experimental pear trees (*Pyrus bretschneideri* Rehd) were 24 years old, spaced 6 m between rows and 5 m within rows (333 tree/ha). The orchard was drip irrigated, and the driplines (emitter discharge was 2.8 L/h, spaced 0.5 m) were installed on each side of and 1 m away from the tree rows. The soil of experimental orchard is a silt loam, with 50.4% silt, 44.0% sand and 5.6% clay. The soil bulk density, from the surface to depth of 1.5 m, is 1.5 g/cm^3. Standard commercial practices in the experimental region were applied, with the exception of no fruit thinning.

2.2. Experimental design

According to the research of Yan et al. (2011), the growing season of pear tree was divided into cell division stage (stage 1, middle April to middle May), slow fruit enlargement stage (stage 2, middle May to early July) and fruit enlargement stage (stage 3, early July to harvest).

Five treatments were defined, including the control, which was irrigated with 80% of evaporation of US Class A pan (Ep) during the whole growth season; the moderate (M-1) and severe (S-1) RDI treatment, irrigated with 60% and 40% of Ep in stage 1, respectively, and 80% of Ep in other stages; the moderate (M-2) and severe (S-2) RDI treatment, irrigated with 60% and 40% of Ep in stage 2, respectively, and 80% of Ep in other stages. The experimental plots were watered weekly. The irrigation requirement was calculated by multiplying the pan coefficient times the accumulated pan evaporation of the previous week (Table 1). The experimental design was a randomized completed block with three replicates per treatment. Each replicate plot consisted of twelve trees in three rows, with the sample trees located in the middle.

2.3. Measurements

2.3.1. Soil and plant water status measurements

A portable capacitance probe (Diviner, 2000, Sentek Pty Ltd., Australia) was used to determine the volumetric soil water content, and the access tubes of 1.5 m length were installed just under the driplines, opposite the trunk, and in the middle of the irrigated zone. There were two access tubes per replicate per treatment. The soil moisture was measured immediately before every irrigation event. The soil water potential was transformed from the volumetric soil water content by the soil water characteristics. The undisturbed soil was sampled at five locations in the experimental orchard, at depth of 30 cm, 60 cm and 100 cm from the soil surface, respectively, and the soil water characteristics were measured by a pressure plate extractor (1500, Soilmoisture Equipment Corp., Australia). A plant water status console (ZLZ-5, Ningbo Jiangnan Instrument Co., Ltd., China) was used to detect the predawn leaf water potential in 2010. Two leaves per replication per treatment were sampled randomly and measured before dawn once every growth stage (in all treatments), and additional measurements were made weekly (once in