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Effects of Regulated Deficit Irrigation on the Vegetative and Generative Properties of the Pear Cultivar 'Yali'

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ABSTRACT

To investigate the effects of regulated deficit irrigation (RDI) on the growth, yield and quality of 'Yali' pears, field experiments for C (fully watered control), EW [early withholding of irrigation, water stress from pullulation to 25 days after flower bloom (DAFB)], MW (mid-growth withholding of irrigation, water stress from 25 DAFB to 80 DAFB), and LW (late withholding of irrigation, water stress from 120 DAFB to 150 DAFB) were conducted in Handan county, North China, during the 2007 and 2008 seasons. The results showed that leaf relative water content (LRWC) was dramatically reduced during water stress. Water stress reduced shoot growth by 9.6%-18.8%, and the need for summer pruning was marginally decreased. No significant difference was seen in mean fresh fruit weight or yield at harvest for the EW, LW and C treatments. Water consumption during RDI was significantly less than the C treatment. Withholding of irrigation at LW not only led to increases in fruit *TSS* (total soluble solids), soluble sugars and dry matter content but also resulted in an increase in water use efficiency (WUE). Withholding of irrigation at LW and EW can be used in pear production to save irrigation water without adverse effects on the quality of fruits. RDI is a beneficial agricultural practice for the production of pear fruits if it is adopted one month before harvest, and from pullulation to 25 DAFB.

Keywords: Fruit Quality, Pear, Water Consumption.

INTRODUCTION

Pear *(Pyrus bretschneideri* Rehd*)* is a major crop in China, with total national yield accounting for about 56.5% of the global pear yield (Li, 2003). 'Yali', the major Asian pear cultivar, is widely cultivated in the North China Plain (NCP), and its production accounts for about 22% of the total national pear production. Water is one of the most important limiting factors in pear production, especially in arid and semi-arid regions where the production of fruits is fully dependent upon irrigation (Naor, 2006). Water resources are scarce in the NCP region due to limited precipitation. To achieve high yield and optimal quality in 'Yali' pears, the soil water content must be kept between 60% and 80% of the field capacity. Due to the variable annual precipitation in the NCP, flood irrigation at a rate of 5-6 times a year is recommended. Continuous irrigation and overexploitation of groundwater have resulted in severe environmental problems. There is an urgent need to develop an optimal irrigation schedule for 'Yali' pear production to cope with the water shortage problems in the NCP.

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Regulated deficit irrigation (RDI) is an important water-saving technique developed by Chalmers *et al.* (1981). Effects of RDI on water savings, yield, water use efficiency (WUE) and quality in different crops and fruit trees have been widely reported since the 1980s (Dong *et al.,* 2006). RDI techniques have been successfully applied to many fruit trees such as peaches (Chalmers *et al.,* 1981), pears (Chalmers *et al.,* 1986; Mitchell *et al.,* 1986), Asian pears (Behboudian *et al.,* 1994) and grapefruits (Cohen and Goell, 1988). Generally, the RDI technique is only applied during periods in which the fruit growth is less sensitive to water (Chalmers *et al.,* 1981; Girona *et al.,* 1993; Marsal and Girona, 1997). Early investigations of RDI strategies for fruit trees aimed at reducing water use. Overall, the results in fruit trees showed that water deficits and the associated water stresses during developmental stages would not negatively affect fruit yield. Many researchers have reported effects of regulated water deficits on vegetative growth, flowering, fruit growth, and yield in different pear tree cultivars under different climatic conditions (Mitchell *et al.,* 1984, 1986; Caspari *et al.,* 1994; Marsal *et al.,* 2000). Some investigators found that RDI techniques used from the early stages of fruit growth up to the end of shoot growth affected vegetative growth by inhibiting shoot development, but did not affect the final fruit size, number of fruit produced or yield (Chalmers *et al.,* 1984; Li *et al.,* 1989). Girona *et al.* (2005) found that a single RDI regime reduced irrigation by 13–24%, while combined regimes reduced it by 23–35%. Goldhamer et al. (2006) reported variations in the effects of water stress treatments applied at different times on the yield and yield components of almonds. RDI saved 25% of the summer irrigation water used in California but did not reduce the final yield in olive trees (Goldhamer, 1999). There was also no negative effect on loquat quality and yield with RDI treatments (Cuevas *et al.,* 2007).

Fruit quality is an important factor for its market value. Application of inappropriate amounts of irrigation at incorrect time is waste of water resources and can lead to poor fruit quality. Since the 1990s, the effects of RDI on fruit quality and related soil water deficit index have been studied using both qualitative descriptions and quantitative indices (Behboudian and Mills, 1997). Some investigators revealed that RDI could improve fruit quality in terms of physical and chemical attributes (Liu *et al.,* 2001; Verreynne *et al.,* 2001). Li (1993) reported that deficit irrigation during fruit development and post-harvest in peach trees significantly reduced vegetative growth, but fruit production was not affected until the fourth consecutive year. Deficit irrigation in grapevines not only saved irrigation water by 50%, but also increased the *WUE* greatly without any yield reduction and improved berry quality and taste (dos Santos *et al.,* 2007). Marsal *et al.* (2004) also found that the maturation of late-maturing peach was advanced by one week when using the RDI technique. Earlier fruit maturation is beneficial for improving the market value.

To obtain the maximal pear yield and optimal fruit quality, it is necessary to understand the growth phases of trees, especially the most susceptible phase to irrigation. Three stages of pear fruit development were established according to growth corresponding to the main cell division periods. Stage (I) takes place during the first 7-8 weeks after bloom (Bain, 1961), when shoot growth is also active. Slow growth in the fruit cell volume occurs during stage (II), which is the major period of embryo development. The major increase in cell volume occurs in stage (III), from 80 DAFB until harvest. The month before harvest is the key stage in which the fruit shows increased soluble solids and sugar content.

There is little information, however, on the effect of RDI on the physical development, yield and fruit quality in 'Yali' pear trees. The objectives of this study were:

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1). To investigate the role of RDI as an strategy of soil water balance;
2). To determine the effects of RDI on fruit yield (FY) and fruit quality; 3). To interpret the impact of RDI on water use efficiency (WUE).

MATERIALS AND METHODS

Site and Climatic Conditions

Field experiments were conducted at a commercial orchard located in Handan County, Hebei Province, China (36°35′N, 114°30′E) in the years 2007 and 2008. The site is located within a continental semi-arid climate with a mean annual precipitation of 541.9 mm, evapotranspiration rate of 1,143 mm and mean temperature of 13.8℃. To avoid rainwater infiltration, the field was mulched using plastic film during the water deficit stages. Weather data were collected from a meteorological station in Handan County 5 km from the field site. The predominant soil type in the experimental block was fine sandy loam. The volumetric soil field capacity was 34.3%. The monthly pan evaporation and precipitation for the experiment site from 2007 to 2008 are shown in Table 1.

Pear trees of the cv. ‘Yali’ that are pollinated by ‘xuehua’ pollinators were planted at the site in 1988. Trees were planted using a spacing pattern of 5 m within each row and 3 m between the rows. The trees selected for the experiment were healthy and uniform according to the trunk diameter and had been managed with the same cultivation and fertilization regimes. Trees that possessed many fruits were hand-thinned to reduce the crop load differences among the treatments and to ensure an adequate fruit size at harvest.

Fertilizer application was similar to that used by local farmers. Fertilizer was applied mechanically at rates of 225 kg N ha^{-1}, 60 kg P ha^{-1} and 90 kg K ha^{-1} in two strings 8 cm below the soil surface and 100 cm away from the row during the pullulation stage and at the pre-harvest stage, respectively. Fertilizer was also applied at rates of 450 kg N ha^{-1}, 120 kg P ha^{-1} and 180 kg K ha^{-1} 25 days after flowering .

Four treatments were randomly designed and applied according to the development of the ‘Yali’ pear trees. The treatments included: (1) early withholding (EW) of irrigation from pullulation to 25 days after full bloom (DAFB); (2) mid-growth withholding (MW) of irrigation from 25 DAFB to 80 DAFB; (3) late withholding (LW) of irrigation from 125 DAFB until harvest at 155 DAFB; and (4) the fully watered control (C). Furrow irrigation was applied when the soil water content was lower than 60% of field capacity in the period from 80 DAFB to 125 DAFB and irrigation amount was calculated by the difference between actual water content and field capacity in the 2m soil profile. In total, 24 trees were selected as the experimental trees. Each tree was designated as an individual plot and measurements were repeated six times per tree. To prevent the

Table 1. Monthly precipitation and pan evaporation for the experimental site from 2007 to 2008.

Year	Growth phase	Budding to DAFB25	25DAFB to 80DAFB	80DAFB to 125DAFB	125DAFB to 155DAFB
2007	Precipitation (mm)	50.6	65.2	216.1	42
	Evaporation (mm)	215.7	274.3	197.7	99.5
2008	Precipitation (mm)	47.4	190.2	191.5	22.1
	Evaporation (mm)	235.6	223.85	148.50	103.2

irrigation water and rainfall from infiltrating through lateral movement during the RDI treatments, an irrigation ditch measuring 20 cm in width and 60 cm in depth was dug between the different treatments, and was covered with double layers of plastic film. The amount of applied irrigation water was measured using a water meter installed at the water outlet. The treatments without RDI consisted of irrigation at a level that maintained the relative soil water content at least 60% of the field capacity.

Measurements

Soil water content was measured before each irrigation treatment using oven-drying method. In total, five measurements were taken during the entire growing season. The soil water content of the vertical profile was determined from measurements at 0.2 m intervals across a 2 m soil layer. Over the entire growing season of the pear trees, the amount of water and the date of application were recorded for each irrigation event and for each treatment type. Water consumption in different treatments was obtained from the water balance equation (determined from the 2 m soil layer).

The *ET*, both for the entire growing season and individual growing periods, was calculated using the soil water balance equation as follows:

$$ET = SWD + P + I + Wg - R \qquad (1)$$

where *ET* is evapotranspiration (mm); *SWD* is soil water depletion at the measured soil depth during the growing stage (mm); *P* is rainfall (mm); *I* represents the irrigation application (mm); *R* is surface runoff (mm); and *Wg* is water used by the crop through capillary rise from the groundwater (mm). When groundwater table is lower than 4 m below the surface, *Wg* is negligible and can be ignored (Liu and Wei, 1989). There was generally no runoff in the study area, and *R* can also be ignored.

Leaf relative water content (LRWC) is defined as the ratio of the water volume in a leaf to the maximum water volume in the same leaf at full turgor. Full turgor can be controlled by the plant in response to water stress. *LRWC* was described as follows:

$$LRWC = (W_f - W_d)/(W_s - W_d) \times 100\% \quad (2)$$

LRWC was measured using a weighing method (Gong and Zhang, 1995) that involved taking 15 leaves from each tree at six o'clock in the evening every 20 days.

Wf and Wd were leaf fresh weight and dry weight respectively. Ws was the leaf weight at saturation conditions.

Six fruits per tree located on the outer rim of the mid-canopy were selected for measurement of fresh weight (FW). These fruits were enclosed in plastic bags, picked from the tree, and transported to the laboratory for analysis. Dry weight (DW) was measured using oven-drying to a constant weight at 70℃.

Dry matter content (%) was calculated by determining the ratio of *DW* to fresh weight. The shoot length was measured in autumn and consisted of the average measurement for six shoots located in the outer canopy. Summer pruning occurred at 80 DAFB. The vigorously growing shoots that were eliminated in this pruning were weighed using electronic digital scales.

During commercial harvesting, all of the fruits present on the tree were picked. The yield and average fruit weight were determined using an automatic calibration machine.

Quality factors were measured for six fruits per tree at the end of every growing stage. Soluble sugar content was measured using the Anthrone colorimetric method (Shi, 2006). Fruit organic acid content was measured using the NaOH titration method. Soluble solid content was measured with a WYT-1type hold refraction instrument.

The water-use efficiency was calculated as (Hussain *et al.,* 1995):

$$WUE = \frac{GY}{ET} \qquad (3)$$

where *WUE* (kg m^{-3}) is the water-use efficiency for the *GY* (kg m^{-2}) and *ET* (m) is calculated as in Equation (1).

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Data Analysis

Analysis of variance was conducted using Statistic Analysis Software (SAS). All treatment means were compared for significant differences using LSD multiple comparison method with significance accepted at P= 0.05 level.

RESULTS

Soil and Plant Water Status

Soil Moisture Content

Figure 1 shows the changes in soil water content for different irrigation treatments in the 2007 and 2008 growing seasons. Similar trends were observed for soil water content in both growing seasons. The soil water content varied from 16.1% to 24.6%. The lowest soil water content occurred at 80 DAFB under treatment MW, whereas the highest soil water content occurred between 125 DAFB and 155 DAFB under treatment EW and in the control. The water content increase was caused by the increased precipitation and irrigation applied in these treatments. The water deficit was applied before 25 DAFB in the EW treatment and most of the precipitation and irrigation occurred from 80 DAFB. Therefore more water was supplied to the trees. Water loss during the RDI periods was mainly caused by plant transpiration; the mulched films prevented not only the rainfall from entering the soil but also the evaporation of soil water. Soil water content significantly decreased during the RDI periods, especially in MW treatment. The difference between different growing seasons might have been caused by different precipitation patterns, irrigation and other meteorological factors. The RDI had significantly different effects on soil water content under different treatments.

Leaf Relative Water Content

Figure 2 shows *LRWC* for different treatments during the 2008 season. The *LRWC* was higher in the control than in any of the other treatments from 25 DAFB to 140 DAFB. The *LRWC* measured in treatment EW was lower than that of the control (treatment C) or treatments MW and LW from 20 DAFB to 40 DAFB. The *LRWC* in MW treatment remained at a lower level than that with the other treatments from 40 DAFB to 80 DAFB. When irrigation was resumed in the EW and MW treatments, the *LRWC* increased and reached a similar level to that of the control. The *LRWC* under treatment LW was lower than

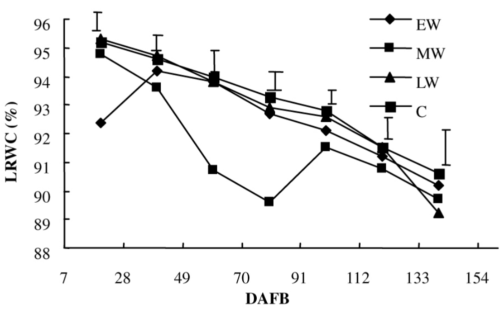

Figure 1. Seasonal changes in leaf relative water content under different treatments.

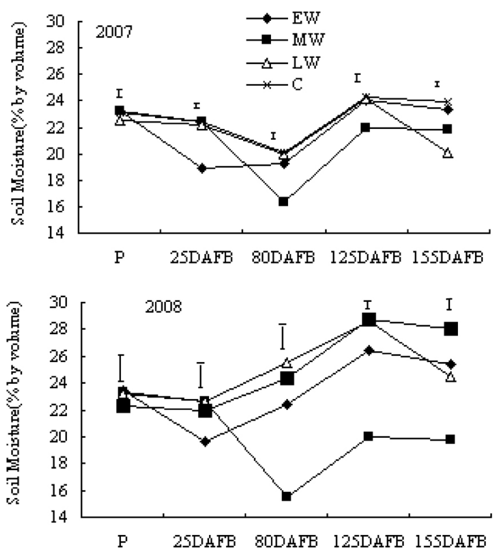

Figure 2. Seasonal changes in soil water content under different treatments.

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that of the other treatments before harvest (140 DAFB). This demonstrates that water stress significantly affected the utilization of water by the trees.

Plant Water Consumption

Figure 3 shows the seasonal daily water consumption for different treatments during different growth stages in 2007 and 2008 seasons. The trends were similar in 2007 and in 2008. However, daily water consumption (DWC) during different growing stages was different. Previously the *DWC* of trees at 125 DAFB had shown only a small increase under the high water treatment that was followed by a decrease. The *DWC* varied from 1.55 mm to 1.60 mm under the water deficit treatment, and from 2.31 mm to 2.51 mm during pullulation to 25 DAFB for all other treatments. With the growth of the trees and higher potential in the *ET*, *DWC* increased from 2.09 to 2.56 mm under the MW treatment and from 3.20 to 3.96 mm for the other treatments. The annual difference in water consumption was due to varying precipitation, different irrigation regimes and meteorological factors. The highest water consumption occurred during periods of rapid fruit tree expansion; the *DWC* during these periods was approximately 4.63 mm. Water consumption under the RDI treatment significantly decreased compared to the other treatments. This might have been caused by a lower level of plant transpiration due to lower soil water content, and less soil evaporation due to the plastic film mulching. Water consumption during different growing stages also varied. The highest water consumption occurred from 80 DFAB to 125 DAFB and was caused by the physical development of the trees.

Vegetative and Generative Properties

Shooting Growth and Pruning

Table 2 shows the effect of water deficit during different growth stages of the fruit trees in 2007 and 2008 seasons. Shoot growth ranged from 49.2 cm to 60.6 cm and from 51.4 cm to 60.6 cm in 2007 and 2008 seasons, respectively. The trend was similar between the years; however, there was a significant difference among the treatments in each year. Shoot growth with the LW and C treatments was significantly higher than those with EW and MW treatments. Summer

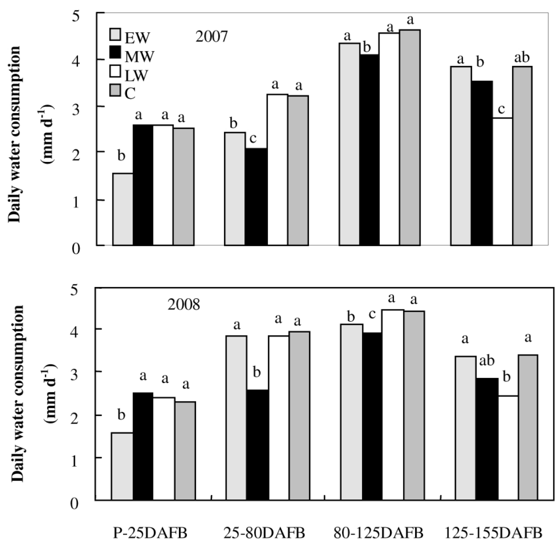

Figure 3. Seasonal patterns in average daily water consumption during fruit development under different treatments in 2007 and 2008 seasons.

Table 2: Effects of water deficit during different phases of vegetative growth.

Treatment	Shoot length (cm)	Summer pruning (kg tree^{-1})	Shoot length (cm)	Summer pruning (kg tree^{-1})
	2007		2008	
EW	49.2b	2.42c	51.4b	2.88b
MW	51.0b	2.58b	53.0b	3.07b
LW	59.6a	3.25a	60.6a	3.65a
Control	60.6a	3.35a	58.6a	3.42a

Note: Different letters in the same column mean significant difference by LSD at 5% probability level.

pruning had a similar trend, ranging from 2.42 kg tree^{-1} to 3.35 kg tree^{-1} and 2.88 kg tree^{-1} to 3.65 kg tree^{-1} in 2007 and 2008 seasons, respectively. The results indicated that early water deficit treatments (EW and MW) restrained shoot growth and reduced the need for summer pruning. Compared to the control, the EW and MW treatments reduced the length of new shoots by 18.8% and 15.8% in 2007, and by 12.3% and 9.6% in 2008, respectively. Summer pruning was reduced by 27.8% and 22.9% in 2007 and by 15.8% and 10.2% in 2008, respectively, for EW and MW treatments. This result was similar to that recorded for Bartlett pear vegetative growth during RDI by Chalmers *et al.* (1986).

Fruit Growth and Quality

Figure 4 shows the development of fruits under different treatments in 2007 and 2008 seasons. Similar growth trends were displayed across the different seasons. There was no significant effect on the fruit growth rate under EW treatment. A significant effect was seen with LW treatment from 140 DAFB to 155 DAFB, where the growth rate was lower than that of the control. There were some differences between MW treatments in 2007 and 2008. The fruit weight was significantly lower at 77 DAFB in 2007 and at 63 and 155 DAFB in 2008. There was no significant difference during other growth stages for different RDI treatments. This lack of difference indicates that the RDI technique did not restrict the fruit growth rate from pullulation to 25 DAFB. The growth rate was significantly reduced under the RDI treatment at 25 DAFB and 80 DAFB, but recovered afterward. These results indicate that the effect of RDI on fruit growth rate generally

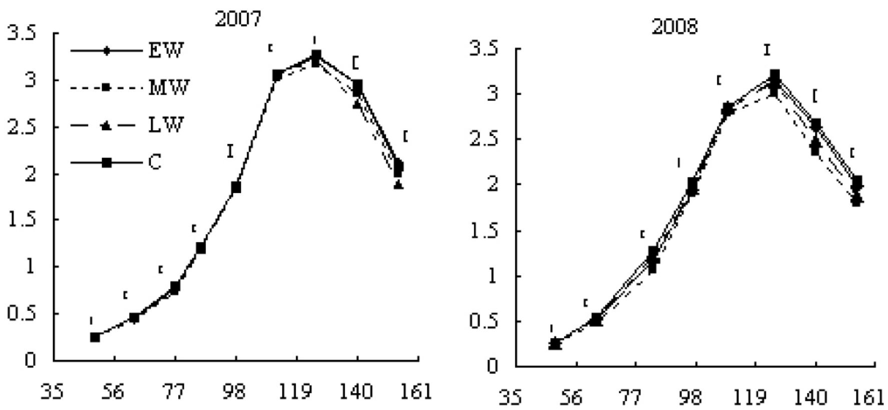

Figure 4. Fruit weight development rate under different treatments in 2007 and 2008 seasons.

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occurred at the late growth stage. When the RDI was severe in 2008 with the MW treatment, the fruit growth rate was reduced (smaller fruits at harvest), which is consistent with previous studies of apples (Ebel *et al.,* 1995).

The RDI during different growth stages had some effect on fruit quality, as shown in Table 3. There was a similar trend for fruit quality under different RDI schedules during 2007 and 2008 seasons. The results from two years of study indicate that water deficit significantly increased dry matter content, soluble sugar and sugar/TA ratio ($P< 0.05$). There was, however, a tendency for a decrease in the titratable acidity (TA) ($P< 0.05$) content and in the fruit fresh weight, resulting in a greater difference in sugar/acid ratio. Accumulation of fruit sugars may help to maintain fruit growth during a water deficit. A mild water deficit later in the season improved fruit quality as measured by higher *TSS* (total soluble solids) content.

Fruit Yield and *WUE*

Table 4 shows the effect of water deficit on fruit yield and quality during 2007 and 2008 seasons. Fruit yield (FY) was not significantly different among the different treatments in the 2007 season. In the 2008 season, however, the yield for MW treatment was lower than that for other treatments, which might have been caused by reduction of precipitation from 80 DAFB to harvest. The *ET* was similar under the control and LW treatments in different growing seasons. The difference in *ET* between the treatments was caused by varying precipitation and distribution of rainwater. The greatest difference in *ET* was seen between the RDI treatment and control, and measured 112.6 mm and 100.0 mm in the 2007 and 2008 seasons, respectively. The smallest difference in *ET* was observed when the RDI treatment was compared to the control, and measured 43.2 mm and 25.5

Table 3. Effect of water deficit during different growth stages on the fruit attributes of 'Yali ' pear.

Year	Stage	Treatment	FW	Dry matter content (%)	Soluble sugar (%)	TA (%)	Sugar/ TA
2007	25 DAFB	EW	3.98ns	18.34a	0.91a	0.32b	2.84a
		MW	3.86ns	17.56b	0.82b	0.38a	2.16c
		LW	4.01ns	17.51b	0.84b	0.37a	2.27b
		C	3.86ns	17.42b	0.85b	0.39a	2.18c
	80 DAFB	EW	33.50ns	18.14b	2.28b	0.23a	9.91d
		MW	33.21ns	18.92a	2.65a	0.18b	14.72a
		LW	33.82ns	17.90b	2.28b	0.22a	10.36c
		C	34.1ns	17.96b	2.32b	0.21a	11.05b
	155 DAFB	EW	215.5ns	12.5b	6.72b	0.13a	51.69c
		MW	208.7ns	13.1ab	6.79ab	0.10ab	47.9d
		LW	207.5ns	13.5a	6.95a	0.10ab	69.5a
		C	216.3ns	12.8b	6.64b	0.12b	55.33b
2008	25 DAFB	EW	3.89ns	18.42a	0.86a	0.30b	2.87a
		MW	3.88ns	17.81ab	0.78b	0.35a	2.23b
		LW	4.01ns	17.63ab	0.76b	0.32ab	2.38c
		C	4.02ns	17.92b	0.75b	0.32ab	2.34d
	80 DAFB	EW	32.62a	17.07b	1.81b	0.21ab	8.62b
		MW	31.13b	17.98a	1.92a	0.20b	9.60a
		LW	32.81a	17.23b	1.78bc	0.23a	7.74d
		C	33.20a	17.03b	1.75c	0.22a	7.95b
	155 DAFB	EW	215.61a	12.61b	6.28d	0.19a	33.05d
		MW	202.50b	12.81ab	6.56b	0.17b	38.59b
		LW	212.52ab	13.30a	6.90a	0.16b	43.13a
		C	220.80a	12.53b	6.38c	0.17b	37.53c

Table 4: Effect of RDI treatments on fruit yield and quality.

Treatment	Irrigation (mm)	Precipitation (mm)	*SWC* (mm)	*ET* (mm)	Yield (kg ha^{-1})	*TSS* (%)	*WUE* (kg m^{-3})
2007							
EW	225	323.3	-3.47c	544.8d	48155ns	11.3b	8.84a
MW	225	308.7	29.13b	562.8c	47862ns	11.8b	8.52b
LW	225	331.9	57.17a	614.2b	47700ns	12.2a	7.79c
Control	300	373.9	-16.47d	657.4a	48245ns	11.4b	7.33d
2008							
EW	225	403.8	-40.0b	588.8c	60111 a	11.0b	10.21a
MW	225	261	70.0a	556.0d	57945 b	11.5a	10.43a
LW	225	429.1	-23.6b	630.5b	59379 ab	11.4a	9.42b
Control	300	451.2	-95.2c	656.0a	60699 a	10.7b	9.25b

mm in 2007 and 2008 seasons, respectively, indicating that RDI can save water. Soil water depletion (SWD) was significantly different due to different precipitation and irrigation patterns. The *SWD* in control treatment was less than that in any of the other treatments because of irrigation.

The *FY* ranged from 47,700 kg ha^{-1} to 60,699 kg ha^{-1}. The *FY* was the highest in control treatment whereas the lowest *FY* was recorded in MW treatment and corresponded to the smallest amount of precipitation. The *FY* in 2008 was higher than in 2007, which might have also been caused by differences in precipitation. There was a 77.3 mm difference across the entire growing season. The precipitation differences between 2007 and 2008 for the four consecutive growing seasons were 3.2 mm, -125.0 mm, 24.6 mm and 19.9 mm. There were no significant differences in the *FY* under different treatments in the 2007 season, while *FY* under the MW treatment was significantly different in 2008. The results indicate that 'Yali' pear fruit growth was not sensitive to water stress from pullulation to DAFB 80. This might have been due to the deep roots this cultivar possesses, which can use more of the deep soil water.

Table 4 shows the *WUE* for different treatments during the 2007 and 2008 seasons. The *WUE* ranged from 7.33 to 8.52 kg m^{-3} and 9.25 to 10.43 kg m^{-3} in the 2007 and 2008 seasons, respectively. The trend was similar among the treatments for the two seasons but there were significant differences at $P= 0.05$. The *WUE* of the most irrigated treatment (control) was the lowest; the *WUE* of the EW and MW treatments were the highest.

DISCUSSION AND CONCLUSIONS

The schedule of withholding irrigation has significant impacts on *LRWC*, shoot growth, fruit yield, fruit quality and *WUE* of pear. Regulated deficit irrigation had a significant influence on the soil water balance, which resulted in the difference in water consumption, *LRWC* and shoot growth. Chalmers *et al.* (1986) observed a significant increase in RDI fruit growth after resuming full irrigation. In the Asian pear, an osmotic adjustment of the fruit was able to contribute to this kind of recovery (Behboudian *et al.,* 1994). Nevertheless, even though RDI fruits seemed to adjust osmotic at the end of the deficit period, no clear enhancement in fruit growth was observed during stage III . The yield and weight of the fruit were significantly reduced during the second year of continual research with the same MW treatment (i.e., the MW fruit size at harvest was smaller than the control). There is an apparent contradiction between these results and those of studies that report a recovery of fruit growth. Previous studies on the growth of peaches, pears and other fruits that were subject to early RDI suggested that many plants have compensatory mechanisms that become activated when the water deficit is removed. Water deficit has an ultimate effect on the growth of fruits and is related to the degree of soil water stress during the slow growth of the fruits. The distribution of precipitation also plays an important role in the soil water and plants interaction which will affect the plant growth and production. Meantime, the different species or varieties of fruit trees also have the various responses to the water stress. Therefore, there would be a slight difference for the results under various growth variables such as precipitation, soil, fruit trees and so on. At different stages, the same irrigation volume can have significantly different impacts on the growth of fruit trees, water consumption, fruit quality and *WUE*.

This study indicated that RDI has the potential for use in the cultivation of 'Yali' pear trees. One of the most important factors in pear orchard management is growth control. Water deficit treatments restricted the shoot growth and decreased the need for summer pruning. There was no significant difference in the fresh weight and yield. The MW treatment slightly reduced fresh weight of the fruit in 2007, but there were no differences at the time of harvest, indicating that the 'Yali' pear has some compensatory growth after experiencing water deficit. The fruit yield was not sensitive to water stress during the MW treatment. Water stress at this stage can significantly improve the *WUE*. There was also a significant difference in fruit quality under different irrigation treatments. During water stress, the fruit soluble solid content, reducing sugar and sugar acid ratio were higher than in the control, which is consistent with previous studies. Water stress was able to improve fruit quality by more than 50% when compared to the well-irrigated treatment. Withholding of late-season irrigation improved fruit characteristics by increasing the *TSS* and soluble sugars without reducing fruit yield. Late-season withholding effectively reduced water consumption during this stage. Moderate water stress in the latter period promoted maturation of fruits, which was positively correlated with fruit soluble solids and sugar content.

Our results indicated that RDI is a beneficial agricultural practice for the production of pear fruit. RDI can guarantee fruit yield and quality when it is adopted in the period from pullulation to 25 DAFB and at one month before harvest. This test was carried out with the crown of the fruit trees under a plastic cover to prevent rainfall infiltration during the regulated deficit irrigation periods.

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اثرات کم آبیاری منظم بر خصوصیات رویشی و تولیدی گلابی کولتیوار "یالی"

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چکیده

به‌منظور بررسی اثر RDI بر رشد، عملکرد و کیفیت گلابی‌های "یالی" آزمون‌های میدانی بر روی گروه‌های C(شاهد کاملاً آبیاری شده)، EW (عدم آبیاری ابتدایی، تنش آبی از جوانه‌زنی تا ۲۵ روز پس از شکوفه‌دهی (DAFB))، MW (عدم آبیاری در اواسط رشد، تنش آبی از DAFB۲۵ تا ۸۰ DAFB) و LW (عدم آبیاری پایانی، تنش آبی از DAFB۱۲۰ تا ۱۵۰ DAFB) در منطقه هاندان در شمال چین طی فصول رویشی ۲۰۰۷ و ۲۰۰۸ انجام شدند. نتایج نشان دادند که مقدار نسبی آب برگ‌ها (RWC) بر اثر تنش آبی به‌طور قابل‌توجهی کاهش یافت. تنش آبی رشد شاخه‌ها را بین ۹/۶ تا ۱۸/۸ ٪ کاهش داده و نیاز به هرس تابستانی را اندکی کاهش بخشید. بین تیمارهای LW ،EW و C، از نظر میانگین وزن میوه تازه و عملکرد در هنگام برداشت تفاوت معنی‌داری مشاهده نشد. مصرف آب در حین RDI به شکل قابل ملاحظه ای کمتر از تیمار C بود. عدم آبیاری درLW نه تنها موجب افزایش میزان کل مواد جامد محلول (TSS)، قندهای محلول و وزن خشک میوه شد بلکه کارایی مصرف آب (WUE) را نیز افزایش داد. می‌توان از عدم آبیاری در LW و EW در تولید گلابی به منظور صرفه جویی در مصرف آب بدون ایجاد اثرات نامطلوب بر کیفیت میوه استفاده کرد. اگر از RDI یک ماه قبل از برداشت و یا از زمان جوانه‌زنی تا ۲۵ DAFB استفاده شود، این روش می‌تواند برای تولید گلابی مفید باشد.

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