EFFECT OF ALTERNATE PARTIAL ROOT-ZONE IRRIGATION AND INFILTRATING IRRIGATION ON PHOTOSYNTHETIC CHARACTERISTICS AND YIELD OF JUJUBE TREES
/
渗灌和分根交替灌溉对枣树光合特性及产量的影响

Prof. Ph.D. Stud. Agr. Feng Y. [1,2], **Prof. Ph.D. Sci. Zhou J.** [1*], **As. Ms. Agr. Wang Z.** [2], **As. Ph.D. Agr. Zhang W.** [3], **Ph.D. Agr. Yu.D.** [4]
[1] School of Resources and Environment, Northwest A&F University / China; [2] Institute of Fertilizer and Agricultural Water Conservation, Xinjiang Academy of Agricultural Sciences / China; [3] College of Grassland and Environmental Sciences, Xinjiang Agricultural University / China; [4] Department of Earth & Environmental Studies, Montclair State University / USA
Tel: +8618999973689; E-mail: fengyaozu@sina.com

Abstract: *At present, irrigation in Ziziphus Jujuba orchards around Tarim basin in Xinjiang Province, China, is mainly surface irrigation. Due to outdated irrigation technology and low irrigation efficiency, the fruit yields are low, which seriously affects sound development of local special forest fruit industry in Xinjiang. Infiltrating irrigation technology has favorable water-saving effects and studying its impact on the physiological and yield variation of Jujube trees would therefore greatly assist the development of the Jujube industry in Xinjiang China. Several ten-year-old Jujube trees were selected in Akesu area of Xinjiang to investigate the effects of different water-saving irrigation methods on their physiology and yield. Diurnal variation of photosynthetic capacity in Jujube leaves during florescence, young fruit and fruit expanding stages and Jujube yield were measured under 6000 m^3/ha of alternate partial root-zone irrigation and conventional infiltrating irrigation. The results indicated that: (1) the diurnal variation of net photosynthetic rate in Jujube leaves presented a bimodal curve with a midday depression phenomenon. The diurnal variation of transpiration rate appeared to single peak type. The diurnal variation of water use efficiency was a single-valley curve. The stomatal conductance varied during the growth season; (2) under conventional irrigation, the net photosynthesis rate, stomatal conductance and transpiration rate increased with increased irrigation volume; and (3) with the same irrigation volume, the root-divided alternative irrigation, compared with conventional irrigation, reduced leaf transpiration rate and increased leaf net photosynthesis rate and water use efficiency, resulting in an increase of Jujube yield by 11% per hectare. The study showed that root-divided alternative irrigation could save water consumption and increase Jujube yield*

Keywords: *jujube; root irrigation; root-divided alternative irrigation; photosynthesis*

摘要： *目前，新疆环塔里木盆地枣园多采用地面灌溉方式，灌溉技术落后、效率低，导致枣树产量低，严重阻碍了新疆特色林果业健康发展。渗灌技术具有良好的节水效果，因此研究渗灌对枣树生理及产量变化影响，对发展新疆特色枣业具有科学指导意义。本研究以阿克苏地区实验林场九队10年树龄的灰枣为研究对象，利用Li-6400便携式光合仪，在6000m^3·hm^{-2}分根交替灌溉和不同灌溉量的渗灌条件下测定花期、幼果期和膨大期枣树叶片光合日变化，及其测定枣树产量。结果表明：（1）枣树叶片净光合速率日变化为双峰曲线，具有光合“午休”现象；蒸腾速率日变化曲线呈单峰型；水分利用效率日变化则呈单谷型；气孔导度随生育期的推进变化趋势不同。（2）常规渗灌条件下，随着灌溉量增加叶片净光合速率、气孔导度、蒸腾速率呈上升趋势。（3）同一灌溉量,与常规渗灌相比，分根交替灌溉能降低叶片蒸腾速率，提高叶片净光合速率、水分利用效率和枣树产量，且亩产量提高11%。初步证明，分根交替灌溉能够起到节水增产作用，为节约水资源，提高枣产量，促进特色枣产业的持续发展提供决策依据。*

关键词: *灰枣；渗灌；分根交替灌溉；光合特性*

INTRODUCTION

Jujube is the key industry of Xinjiang China, especially for the area around Tarim basin in South Xinjiang China. The region around Tarim basin has advantages in land, light and heat resources, but inadequate water is a major constraint affecting rapid development of the Jujube industry. Most irrigation system in orchards around Tarim basin use surface irrigation. As a result of outdated irrigation technology, extensive irrigation management, poor controllability of irrigating water quotas and low irrigation efficiency, The Chinese data are low and of inferior quality and low benefit fruit, which seriously affects sound development of this fruit industry. Therefore, study of the impact of different irrigation modes and volumes on the water utilization and yield of Jujube tree is necessary.

引言

枣产业是新疆，特别南疆环塔里木盆地的重点产业，南疆环塔里木盆地具有得天独厚的土地和光热资源，但水资源不足是该区枣产业快速发展的主要制约因素之一。目前，南疆环塔里木盆地的大部分果园现大多采用地面灌溉，灌溉技术落后，灌溉管理粗放，灌水定额可控性差，灌溉效率低、导致果品产量少，品质差、效益低，严重阻碍了林果产业的健康发展。因此，研究不同灌溉方式和灌溉量对枣树水分利用与产量的影响具有重要的科学价值。

Photosynthesis has a close contact with the physiological and ecological indexes of plants, and it is the key factor affecting their yield and quality [10-12, 17]. Study of the diurnal variation of photosynthesis characteristics of potted mango seedlings under different soil water contents allowed determining the optimal soil water content range [16]. Study of photosynthetic function of apple leaves under different irrigation modes by Ma et al [8] showed that alternate half root-zone irrigation was optimal. Chai et al [1] determined the diurnal variation of photosynthesis characteristics of fragrant pear during different growing periods. However, there are few reports concerning photosynthesis characteristics of Jujube trees under different moisture regulation. This study analyzed the diurnal variation of photosynthesis of Jujube leaves and yield during different growth periods under conditions of regular infiltrating irrigation and alternate partial root-zone irrigation (APRI). The results will provide a scientific foundation for saving water resources, increasing Jujube yield and accelerating the sustainable development of the Jujube industry.

光合作用与植物生理生态指标有着密切的关系，是影响植物产量和品质关键因素[10-12, 17]。姚全胜通过对不同土壤水分含量条件下杧果盆栽幼苗光合特性日变化规律的研究，确定最佳杧果盆栽的土壤含水量范围[16]；马怀宇通过对不同灌水方式下苹果叶片光合功能的研究，结果表明[8]，半根交替灌水为最佳灌溉方式；柴仲平[1]通过对梨树（香梨）不同生长期光合日变化研究，确定了梨树光合特性变化规律，但对水分调控下枣树光合特性研究鲜见报道。本研究在常规渗灌与分根交替灌溉条件下，结合当地环境因子变化特征，分析枣树不同生育期枣树叶片光合日变化规律和枣树产量变化规律，为节约水资源，提高枣产量，促进特色枣产业的持续发展提供决策依据。

MATERIALS AND METHODS

Study area

The study area located in Team 9 of Experimental Forest Farm, Akesu Prefecture, Xinjiang, China (80°20'E, 41°10'N; 1200 m). The area has a temperate continental climate, with long sunshine duration and large day–night temperature differences. The annual sunshine duration is 2800–3831 h. The total radiation amount is 6000 MJ/hm^2 and it is one of the areas with the most solar radiation in China. The annual frost-free season is 183–227 d, the annual average temperature is 9.9–11.5°C, and annual precipitation is 42.4–94 mm. Ten-year-old Jujube trees were selected in the study area, with planting interval of 2 m × 4 m. The surface soil texture is sandy, and the profile soil texture is sand over clay. The chemical characteristics of the soil profile are shown in Table 1.

材料与方法

试验地概况

试验地位于新疆阿克苏地区实验林场九队(80°20′E、41°10′N)，海拔 1200m。属温带大陆性气候，光照时间长，昼夜温差大，年日照时数为 2800-3831.35h,总辐射量 6000MJ·hm^{-2}，是全国太阳辐射量最多地区之一，全年无霜期为 183-227d，年平均气温为 9.9℃-11.5℃，年降水量 42.4-94mm。试验地枣树品种为 10 年树龄灰枣，枣树种植模式为 2m×4m，试验区土壤质地为沙土，质地构型为下粘上沙，土壤剖面肥力特征见表 1。

Table 1

Soil profile characteristics and nutrients of Jujube in the study area

Depth [cm]	Texture	Saturated moisture content [%]	Unit weight [g/cm^3]	Available nitrogen [mg/kg]	Phosphorus concentration [mg/kg]	Available kalium [mg/kg]	Organic content [%]	Salinity [g/kg]	pH
0–20	Sandy soil	28.18	1.46	6.15	14.20	35.52	0.52	1.85	7.64
20–40	Sand	27.34	1.49	2.46	16.54	31.48	0.28	1.23	7.42
40–60	Clay	31.76	1.48	9.83	9.47	73.34	0.72	1.45	7.44
60–80	Clay	31.83	1.50	2.46	3.78	21.31	0.13	1.34	7.73

Material of infiltrating irrigation tube

The infiltrating irrigation tube was constructed of special rolled steel, with a pipe diameter of 32 mm, an aperture of 2 mm and a pitch of holes of 1.0 m (fig.1).

渗灌管材料

渗灌管材选用特制 Cr12 钢材，管径 32mm，孔径：2mm；孔距 1.0m（图 1）。

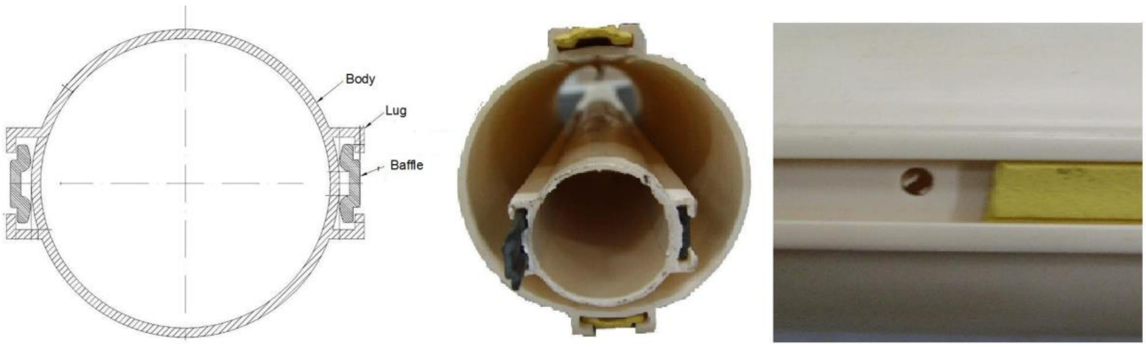


Fig.1 - Section of infiltrating irrigation tube

Experimental design

Two irrigation modes including regular infiltrating irrigation and Alternate Partial Root-zone Irrigation (APRI) were adopted. The regular infiltrating irrigation used three irrigation quotas: 3000 m3/hm2, 6000 m3/hm2 and 9000 m^3/hm^2 abbreviated as W1, W2 and W3, respectively. The laying method was two rows of infiltrating irrigation tubes placed under one row of fruit trees. The distance between the infiltrating irrigation tubes and trees was 70 cm, and placement depth was 25 cm.

The APRI used only one irrigation quota of 6000 m^3/hm^2. The laying method was three rows-6 tubes. From east to west, tube no.. 1, 4 and 5 were water supply system 1, while tube no. 2, 3 and 6 were system 2, and these two systems supplied irrigation alternately. The water volume was controlled by water meter and the total fertilizer amount was 1995 kg/hm² (Table 2), with each treatment having three replications.

试验设计

试验采用常规渗灌和分根交替灌溉两种灌溉方式，常规渗灌设置 3 个灌溉总额：3000 m^3/hm^2、6000 m^3/hm^2 和 9000 m^3/hm^2，分别记为 W1，W2，W3，铺设方式一行果树下铺设两行渗灌管，渗灌管距树 70cm，埋深 25cm；分根交替灌溉（APRI）设置一个灌水总额 6000 m^3/hm^2，铺设方式为 3 行 6 管，自东向西 1、4、5 管为一号供水系统，2、3、6 管为二号供水系统，一、二号供水系统交替灌溉；水量由水表控制，施肥总量为 1995kg/hm²，每个处理 3 次重复，具体施肥见表 2。

Table 2

Fertilizer design

Total fertilizing amount		**1995[kg/hm²]**				
Fertilizer variety		Fertilizing amount	Base fertilizer amount	Additional fertilizer before flowering		Additional fertilizer after flowering
N	[kg/hm²]	997.5	72	587.1		334.5
P_2O_5		726	276	162		270
K_2O		262.5	37.5	37.5		187.5
Growth period		Budding period	Full-blossom period	Fruitlet period	Expanding period	Mature period
Additional fertilizer 11 times		1	4	3	2	1

Determination and control of soil moisture

A TRIME instrument was used to measure moisture before and after irrigation during the growth period, while a SM100 Soil Moisture Timing Collector was also used to measure before and after rainfall. Five points were fixed in two sides by taking the pipeline as the center, i.e., the horizontal perpendicular distances between the pipeline and the five points were respectively 0, ±35, ±70, ±105, and ±140 cm. In addition, six points were fixed in the vertical direction of the ground to monitor soil moisture variation (of vertical depths of 0, 20, 40, 60, 80 and 120 cm) giving a monitoring depth of 0–120 cm, Then, soil was extracted using a soil auger, dried and measured by TRIME instrument and SM100 Soil Moisture Timing Collector.

The following formula is used for calculating the irrigation period.

土壤水分测定及控制

采用随机取样的方法，生育期内灌前灌后水分监测采用 trime 仪观测、sm100 土壤水分定时采集器，降雨前后加测。以管道为中心两边分别定 5 个点，即在垂直管道距离为 0cm、±35cm、±70cm、±105cm，±140cm，5 个点，垂直地面 6 个深度，即垂直地面向下 0cm、20cm、40cm、60cm、80cm、120cm、6 个深度监测土壤含水变化，监测深度 0-120cm。土钻取土、烘干对 trime 仪和 sm100 进行校核。

灌水周期:

$$T = m / ET_a \quad (1)$$

Where, T is irrigation period (d), m is irrigation quota (m^3/hm^2) and ET_a is daily water consumption (m^3/hm^2). The detailed moisture adjustment program is shown in Table 3.

式中：T-灌水周期（天）； m-灌水定额 m^3/hm^2；ET_a-日耗水量 m^3/hm^2，具体水分调控方案见表 3 。

Table 3

The root penetration irrigation systems in Jujube orchard

Irrigation quota: 3000、6000、9,000 [m^3/hm^2]						
	Total	**Budding period**	**Full-blossom period**	**Fruitlet period**	**Expanding period**	**Mature period**
Irrigation quota	100%	5%	35%	30%	25%	5%
Irrigation frequency	26	3	6	7	6	4
Irrigation period	6.2 days	8 days	6 days	5 days	6 days	8 days

Determination of photosynthetic rate and physiological index

The Li-6400 Portable Photosynthesis Meter equipped with red and blue light (6400-02B) was used to determine the following indices of environmental factors during the flowering period (30 May 2012), the fruit period (25 June) and the expanding period (25 July), including photosynthetic active radiation (PAR) and atmospheric CO_2 concentration (Ca). The following photosynthetic physiological indices were also been determined: net photosynthetic rate (Pn), stomatal conductance (Gs) and evaporation rate (Evap). Three plants were selected in each treatment with relatively consistent growth and two healthy leaves from the middle and upper parts of young shoots were measured on cloudless days. The average value of three reading values of each leaf was regarded as the measured value. The period of time was 09:00–21:00, with one measurement every 2 h. The limiting value of water use efficiency (WUE) was calculated using the obtained parameters, using the formula: WUE= Pn/Evap

Determination of meteorological factors

A Vantage Pro2 wired automatic meteorological station was used to measure precipitation (P), solar radiation (Rs), air temperature (Ta), relative humidity (RH) and wind speed (Ws).

Yield determination

During the harvest time of Jujube, five plants were randomly selected in each treatment respectively, and the statistic was made by taking the plot as a unit. The quantity and weight of fruit, average weight of single fruit and total yield in each treatment were recorded to calculate the yield per hectare in accordance with single-plant yield and planting density.

Data processing

Excel 2010 and SPSS 18.0 were used for data processing and statistical analysis.

RESULTS AND ANALYSIS

Environmental factor analysis of Jujube orchard

Under natural conditions, variation in Rs, PAR, Ca, Ta, RH and other environmental factors all affected the photosynthesis characteristics of Jujube leaves. Rs and

光合速率及生理指标测定

于花期（2012 年 5 月 30 日）、幼果期（6 月 25 日）、膨大期（7 月 25 日），采用 Li-6400 便携式光合仪，配备红蓝光源（6400-02B），测定环境因子指标：光合有效辐射（*RAR*）和大气 CO_2 浓度（*Ca*），光合生理指标：净光合速率（*Pn*）、气孔导度（*Gs*）、和蒸腾速率（*Evap*）。每处理选取生长较为一致的植株 3 株，选光照较好的新梢中上部健康叶 2 片并标记，每叶片以 3 次读数的平均值作为测定值，时间为 09:00-21:00,每隔两个小时测定一次。根据所获取的参数计算水分利用效率 *WUE*，公式为 *WUE=Pn/Evap*。

气象因子测定

采用 Vantage Pro2 有线自动气象站测定降雨量（precipitation, P）和太阳辐射（solarradiation，Rs）, 气温（airtemperature，Ta）, 相对湿度（relative humidity, RH）和风速（wind speed，Ws）.

产量测定

在红枣收获期，每个处理随机选取 5 株进行单采单收，以小区为单位进行统计。采收时，记载各处理的果实数目、果实重量，平均单果重及总产量，根据单株产量和栽植密度计算出每亩产量。

数据处理

本文采用 Excel 2010 与 SPSS 18.0 进行数据处理与统计分析。

结果与分析

枣园环境因子分析

自然条件下，太阳辐射、光合有效辐射、大气 CO_2 浓度、大气温度以及大气相对湿度等环境因子的变化都会给果

PAR among measured external environmental indices increased gradually with time from 9:00, reached peaks around 15:00 and then dropped gradually (Table 4). Rs and PAR in different growth periods increased gradually from 30 May, reached peaks on 25 June and dropped on 25 July. Ta presented a variation trend of initial increase followed by a decrease, with peak values all at 17:00. Diurnal variation amplitudes of Ta on 30 May, 25 June and 25 July were 20.6°C, 17.2°C and 19.8°C, respectively. That of the earlier growth period was higher than the latter, mainly because Ta at 9:00 was low in the earlier growth period.

This showed that large day–night temperature differences, strong Rs and low RH are typical climatic features of this desert-oasis zone. However, great variation in temperature and RH could improve the yield and quality of fruit trees as it increased the carbon assimilation capacity of plants in daytime and decreased the consumption of dry matter by plant respiration at night.

树叶片的光合特性带来影响。由表 4 可知，在测定的外界环境指标中，太阳辐射和光合有效辐射从 9:00 开始随时间的推移逐渐升高，15:00 左右达到峰值，之后逐渐降低；不同生育期太阳辐射和光合有效辐射从 5 月 30 日开始逐渐增高，6 月 25 达到最高值，7 月 25 日有所下降。大气温度呈呈现先升高后降低的变化趋势，均在 17：00 温度达到最高值，5 月 30 日、6 月 25 日和 7 月 25 日的气温日变幅为 20.6℃、17.2℃、19.8℃，生育初期的日气温变幅高于后期，主要是因为生育初期 9:00 的大气温度偏低的。

可见，昼夜温差大，太阳辐射强，空气湿度低等气候特征为荒漠绿洲区的典型气候特征，而温湿度变化大的特点，可以提高植物白天的碳同化能力并且降低夜间的植物呼吸作用对干物质的消耗，从而提高果树果实的产量及品质。

Table 4

Daily changes of environmental factors in different growth periods

Date	Indices	Determined time						
		9:00	11:00	13:00	15:00	17:00	19:00	21:00
30 May	Solar radiation [W/m^2]	92	275	603	764	631	443	188
	Air temperature [^{o}C]	11.7	20.1	26.2	32	32.3	30.1	29.3
	Relative humidity [%]	73	43	31	13	15	16	21
	Photosynthetic active radiation [μmol/(m^2·s)]	597.33	1,490.00	1,640.00	1,928.00	1,640.00	751.50	429.33
	Atmospheric CO_2 concentration[μmol/mol]	404.67	393.30	396.83	397.00	398.70	401.57	404.43
25 June	Solar radiation [W/m^2]	127	261	774	854	653	456	283
	Air temperature [^{o}C]	18.1	25.8	28.6	34.5	35.3	34.1	30.8
	Relative humidity [%]	51	38	33	18	21	23	22
	Photosynthetic active radiation [μmol/(m^2·s)]	1,397.67	1,940.00	2,123.67	2,400.00	1,998.00	1,840.00	1,674.00
	Atmospheric CO_2 concentration [μmol/mol]	409.57	402.83	383.33	387.60	392.43	388.57	395.60
25 July	Solar radiation[W/m^2]	104	191	687	807	660	456	169
	Air temperature [℃]	16.6	24.4	29.3	36.4	37.6	36.4	33.1
	Relative humidity [%]	75	58	40	20	27	28	35
	Photosynthetic active radiation [μmol/(m^2·s)]	673.67	1,515.33	2,050.33	2,155.00	1,600.67	1,531.00	1,274.00
	Atmospheric CO_2 concentration(μmol/mol)	437.53	367.10	361.77	379.60	384.90	388.57	395.60

Note: The former three items were from the observed results of the meteorological station (observation once every 15 min), while the latter two were from the measured results of the photosynthesis meter.

Diurnal variation of photosynthesis under infiltrating irrigation

1) Diurnal variation of net photosynthetic rate

The diurnal variation of Pn of jujube leaves at different growth periods presented an ‘M’ shape (Fig. 2), with the peak value usually at 11:00 and 17:00; and it always showed a ‘noon break’ appearance during 14:00–16:00, especially under W1 treatment. Under regular infiltrating irrigation, the Pn of Jujube leaves showed a steady increasing trend with increased irrigation volume. For the daily average Pn on 30 May (Table 5), that of W1 significantly decreased by 23% compared with that of W3 ($P < 0.05$). Meanwhile, the difference in Pn between W2 and APRI was not significant, and the Pn of APRI

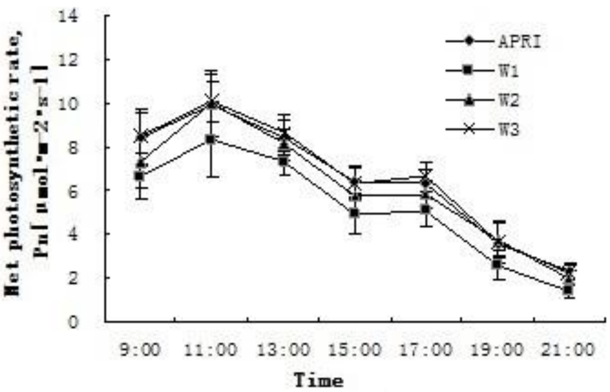
渗灌条件下光合特性日变化规律

1)净光合速率(Pn)的日变化规律

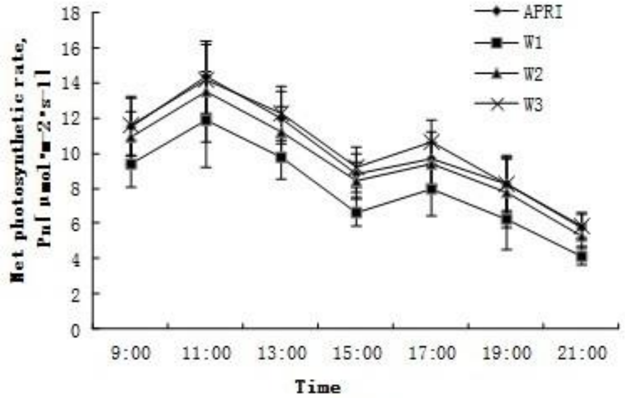
由图 2 可知，不同生育期枣树叶片净光合速率日变化呈“M”型，峰值基本都出现在 11:00 和 17:00，14:00-16:00 均出现“午休”现象，W1 处理下“午休”现象最明显。常规渗灌下随着灌溉量的增加，叶片的光合速率呈明显的稳定上升的趋势。5 月 30 日的日平均光合速率（表 5）W1 与 W3 相比降低 23%，差异显著（P<0.05），W2 和 APRI 净光合速率差异不显著；APRI 和 W2 相比略有上升。6 月

increased slightly compared with that of W2. On 25 June, the Pn of W1 significantly decreased by 21.2% compared with that of W3 ($P < 0.05$). On 25 July, the Pn of W1 and W2 decreased by 33% and 13%, respectively, compared with that of W3 ($P < 0.05$). The Pn of APRI increased by 14% compared with that of W2 ($P < 0.05$). Thus APRI significantly increased the Pn of Jujube leaves under the same irrigation volume compared to regular infiltrating irrigation.

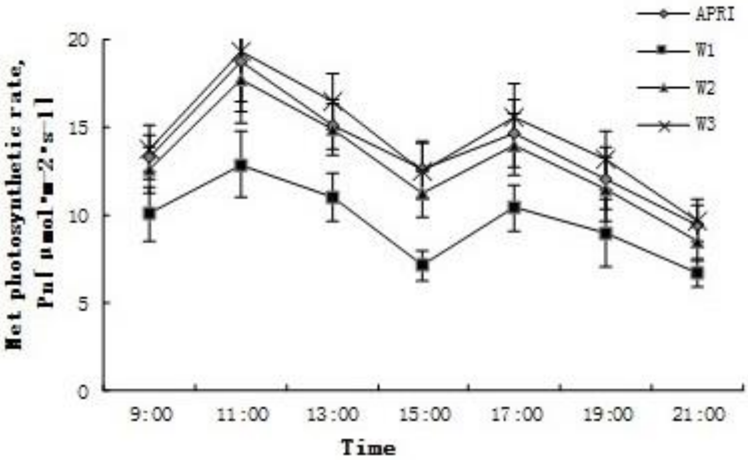
25 日 W1 与 W3 相比降低了 21.2%，差异显著（P<0.05）。7 月 25 日 W1、W2 与 W3 相比分别降低了 33%和 13%，差异显著（P<0.05）；APRI 与 W2 相比上升了 14%，差异显著（P<0.05），表明同一灌溉量，APRI 能够显著提高枣树叶片净光合速率。



May 30th



June 25th



July 25th

Fig.2 - Diurnal variation of net photosynthetic rate of jujube leaves under infiltrating irrigation

Table 5

Daily average values of all photosynthetic indexes under infiltrating irrigation conditions

Date	Treatment	Net photosynthetic rate [μmol/·m$^{2\cdot}$s]	Evaporation rate [mmol/·m$^{2\cdot}$s]	Water use efficiency [μmol/mmol]	Stomatal conductance [mol/m$^{2\cdot}$s]
30 May	APRI	6.48±0.52^{a}	1.86±0.24^{ab}	3.46±0.39^{a}	71.52±19^{ab}
	W1	5.19±0.47^{b}	1.69±0.21^{b}	3.00±0.40^{b}	45.52±16^{b}
	W2	6.45±0.54^{a}	2.04±0.22^{a}	3.13±0.47^{b}	79.05±19^{a}
	W3	6.59±0.53^{a}	2.15±0.26^{a}	3.04±0.36^{b}	84.67±20^{a}
25 June	APRI	9.97±1.0^{a}	3.64±0.32^{a}	2.85±0.18^{a}	150.5714±39^{a}
	W1	7.87±0.95^{b}	3.37±0.37^{b}	2.45±0.22^{b}	114.4286±38^{b}
	W2	9.23±0.97^{a}	3.84±0.39^{a}	2.55±0.19^{b}	162.714±38^{a}
	W3	10.13±1.00^{a}	4.19±0.40^{a}	2.50±0.17^{b}	168±40^{a}
25 July	APRI	14.33±1.20^{a}	3.24±0.73^{b}	5.25±0.82^{a}	172.08±52^{a}
	W1	9.60±0.82^{c}	2.82±0.56^{c}	4.40±0.88^{b}	123.57±37^{b}
	W2	12.54±1.09^{b}	3.43±0.64^{ab}	4.68±0.90^{b}	198.22±48^{a}
	W3	14.36±1.16^{a}	3.86±0.75^{a}	4.50±0.78^{ab}	205.18±53^{a}

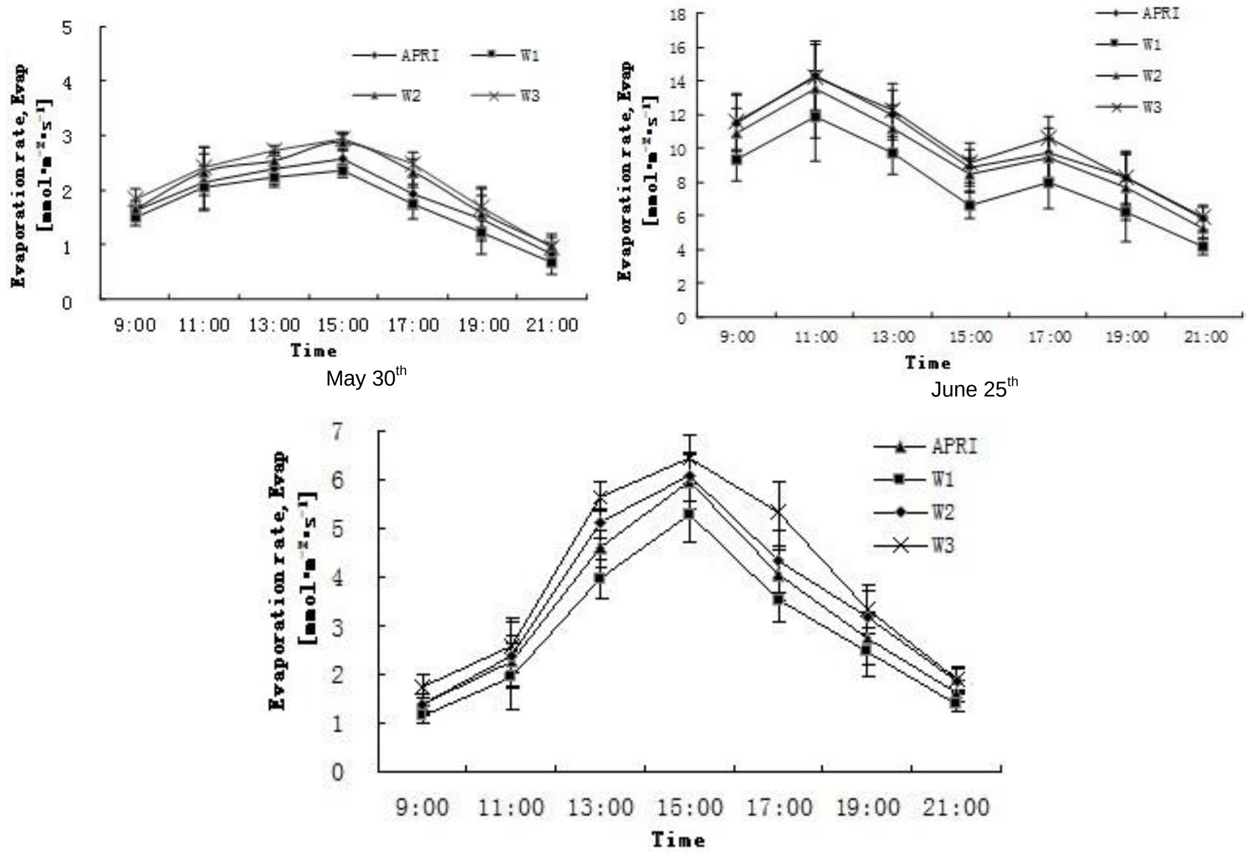
Notes: Different letters (i.e. a, b and c) indicate significant difference at $P < 0.05$.

2) *Diurnal variation of evaporation rate*

Evaporation is an important physiological index reflecting the water status of plants. The ability of plants to adapt to arid environments is strong when Evap is low[2]. The diurnal variation curves of Evap were uniformly of unimodal type under different treatments during main growth periods, with the peak values always during 14:00–16:00 (Fig.3). Under regular infiltrating irrigation, the Evap increased gradually with increased irrigation volume. The daily average Evap (Table 5) of W1 were all significantly different ($P < 0.05$) on 30 May, 25 June and 25 July compared with those of W3, while the corresponding values of APRI decreased by 9%, 6% and 7% compared with those of W2. Thus APRI decreased the Evap of jujube leaves under the same irrigation level compared to regular infiltrating irrigation.

2) 蒸腾速率(Evap)的日变化规律

蒸腾速率是反映植物水分状况的重要生理指标，蒸腾速率越低则代表植物适应干旱环境的能力越强[2]，由图 3 可知，主要生育期不同处理下蒸腾速率日变化曲线趋势相同呈单峰型，峰值均出现在 14:00-16:00 之间。常规渗灌下随着灌溉量的增加，蒸腾速率逐渐升高。5 月 30 日、6 月 25 日和 7 月 25 日 W1 的日平均蒸腾速率（表 5）与 W3 相比均较表现为差异显著（$P<0.05$）；APRI 与 W2 相比分别下降了 9%、6%和 7%，表明同一灌溉水平 APRI 降低了叶片蒸腾速率。



May 30th
June 25th
July 25th

Fig. 3 - Diurnal variation of evaporation rate of jujube leaves under infiltrating irrigation conditions

3) *Diurnal variation of water use efficiency*

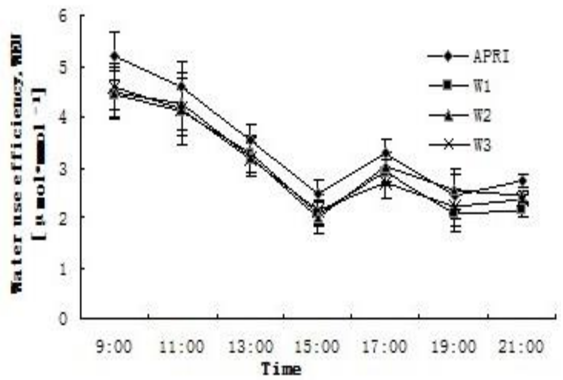
The WUE reflects the short-term or instantaneous behavior of plant leaves to water conditions. To some extent, it reflects the water consumption of plants and their adaptability to an arid environment[9].The diurnal variation curves of WUE of Jujube leaves presented a single-valley shape during main growth periods (Fig. 4). WUE reached a maximum at 9:00. The main reasons for this phenomenon include that the Pn of leaves increased with increased PAR (external environmental factor) by this time, the stomatal aperture of leaves was larger, the RH of air was still high and the Evap had not reached a maximum. WUE of plants was high, and dropped to a minimum at 15:00. The daily average WUE of leaves of W2 and APRI on 30 May increased by 3% and 14%

3) 水分利用率(WEU)的日变化规律

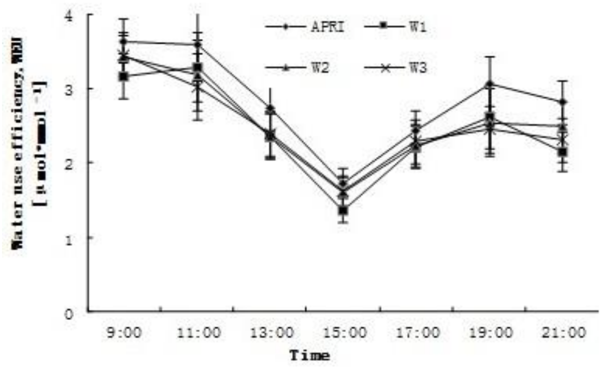
水分利用率是反映植物叶片对水分条件的短期或瞬间反应行为在一定程度上反映植物的耗水性和对干旱的适应性[9]。由图 4 可看出，枣树主要生育期内叶片的水分利用效率日变化曲线呈单谷型，9:00 时水分利用率达到最大，主要是因为此时叶片的净光合速率会随着外部环境因子光合有效辐射的上升而增加，且此时的叶片气孔开度较大，空气的相对湿度还较高，蒸腾速率还未达到最大，所以植物的水分利用效率高。15:00 是水分利用率降到最低值。5 月 30 日 W2 和 APRI 处理下叶片水分利用率日均值比 W3 分别提高了 3%和 14%， 6 月 25 日 W2 和 APRI 处理下叶片水分利用率日均值

compared with that of W3, they thereafter increased by 2% and 14% on 25 June, and by 2% and 15% on 25 July. The results implied that slight moisture loss could improve the WUE of leaves. The daily average WUE of leaves of APRI on 30 May, 25 June and 25 July increased by 11%, 12% and 13%, respectively, compared with those of W2. Thus APRI significantly increased the WUE of Jujube leaves under the same irrigation level.

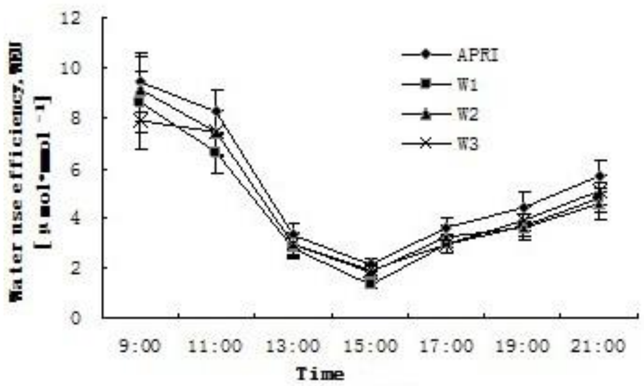
比 W3 分别提高了 2%和 14%。7 月 25 日 W2 和 APRI 处理下叶片水分利用率日均值比 W3 分别提高了 2%和 15%，说明轻度的水分亏损会提高叶片水分利用率。5 月 30 日、6 月 25 日和 7 月 25 日 APRI 处理下的叶片水分利用率日均值比 W2 分别提高 11%、12%和 13%，表明同一灌溉水平 APRI 能够显著提高叶片水分利用率。



May 30th



June 25th



July 25th

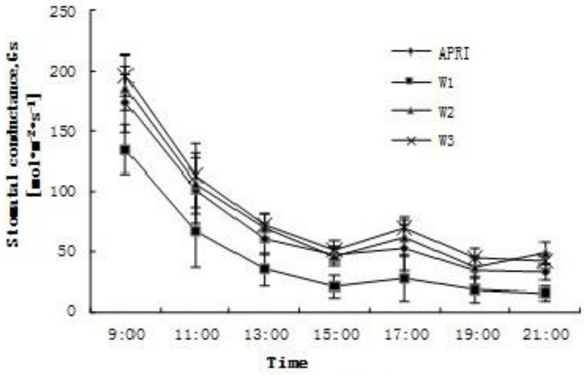
Fig. 4 - Diurnal variation of water use efficiency of Jujube leaves under infiltrating irrigation conditions

4) Diurnal variation of stomatal conductance

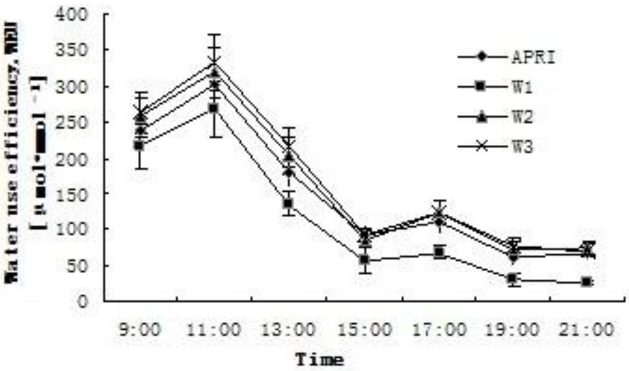
The Gs of leaves reached a maximum on 9:00 on May 30 (Fig.5) and then declined gradually and remained stable after 15:00. The main reason for the aforesaid phenomenon is that PAR was relatively low in the morning and the air RH was high, which led to high stomatal apertures, and then Gs decreased gradually with increasing PAR and decreasing RH. The daily average value of Gs of W1 was notably lower than those of other treatments ($P < 0.05$). The variation trends of Gs and Pn of Jujube leaves were similar, both with a bimodal pattern on 25 June, and peak values always at 11:00 and 17:00. The Gs of treatments all showed a trend of initially high followed by low values. The daily average value of Gs of W1 decreased by 31% compared with that of W3 ($P < 0.05$). The diurnal variation curve of Gs of Jujube leaves showed a bimodal pattern on 25 July, and peak values occurred at 13:00 and 17:00 with the former higher than the latter. The daily average values of Gs of W1 and APRI decreased by 39% and 16%, respectively, compared with those of W3. The daily average values of Gs of APRI on 30 May, 25 June and 25 July decreased by 9%, 7% and 12%, respectively, compared with those of W2 ($P < 0.05$).

4) 气孔导度（Gs）的日变化规律

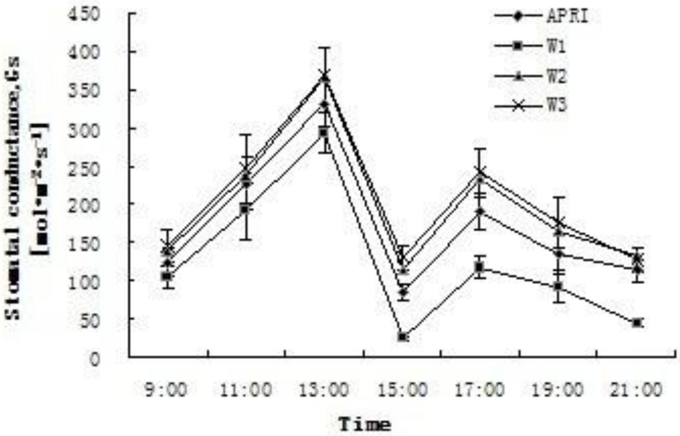
由图 5 可知，5 月 30 日叶片气孔导度在 9:00 达到最大，随后逐渐降低，15:00 后趋于平缓，主要原因是早上太阳光合有效辐射较低，空气湿度较高，导致气孔高度开放，随后随着光合有效辐射升高和空气湿度降低气孔导度逐渐降低；W1 处理下气孔导度日均值显著低于其他处理（$P<0.05$）。6 月 25 日叶片气孔导度变化趋势与净光合速率一致，呈双峰型，峰值出现在 11:00 和 17:00 点，不同处理气孔导度均呈现前高后低的趋势， W1 的叶片气孔导度日均值比 W3 下降了 31%，差异显著（$P<0.05$）；7 月 25 枣树叶片的气孔导度日变化曲线呈双峰型。气孔导度峰值出现在 13:00 和 17:00。第一次峰值明显高于第二次，与 W3 气孔导度日均值相比 W1 和 APRI 分别下降了 39%和 16%，5 月 30 日、6 月 25 日和 7 月 25 日 APRI 处理下的叶片气孔导度日均值比 W2 分别降低了 9%、7%和 12%，差异不显著（$P<0.05$）。



May 30th



June 25th



July 25th

Fig.5 - Diurnal variation rule of stomatal conductance

Influence of infiltrating irrigation and APRI on yield of Jujube

The weight of fresh fruit, weight of dry fruit, fruit setting quantity, fruit width and yield per hectare all increased gradually with increased irrigation volume under regular infiltrating irrigation (Table6). APRI increased weight of fresh fruit, weight of dry fruit, fruit setting quantity and fruit width of Jujube under the same irrigation level compared to regular infiltrating irrigation. The yield per hectare of APRI increased by 11% compared with that of W2, showing that APRI could save water and increase yield.

渗灌和 APRI 对枣树果实产量影响

由表 6 可知，常规渗灌条件下随着灌溉量的增加枣树的鲜果重、坐果数、干果重、果径和亩产量均逐渐增加，同一灌溉水平，APRI 有利于提高枣树的鲜果重、坐果数、干果重和果径，与 W2 亩产量相比, APRI 的亩产量提高了 11%，表明 APRI 能够达到节水增产的作用。

Table 6

Yield analysis of Jujube

Treatment	Irrigation quota [m^3/hm^2]	Weight of fresh fruit [g]	Weight of dry fruit [g]	Fruit setting quantity [Thousand piece]	Fruit width [cm^2]	Yield [kg/hm^2]
APRI	6000	5.19	3.17	212.22	3.60	16426 a
W1	3000	4.15	2.67	201.65	3.40	12147 b
W2	6000	4.70	3.15	207.40	3.50	14703 b
W3	9000	5.25	3.14	216.29	3.80	17100 a

DISCUSSIONS AND CONCLUSIONS

For Jujube trees in the area around Tarim basin in South Xinjiang of China, the daily average values of Pn

结论与讨论

南疆环塔里木盆地生长后期净光合速率日均值高于果实生长前期，本文中7月25 日和6月25日的净光合速率明显

in the later growth period were higher than that of earlier periods. The Pn values of this study on 25 June and 25 July were higher than that on 30 May. This phenomenon was possibly due to the peak values of PAR on 30 May, 25 June and 25 July, which were 1928, 2400 and 2155 W/m^2, respectively. Moreover, Ta difference might also cause different photosynthetic rates. Excessive Ta can decrease the photosynthetic rate of plant leaves [6-7, 14] and generate the photosynthetic 'noon break' phenomenon. Low temperature at night can also improve Pn during the day, as research results of McDonald and Paulsen [9] showed that the Pn of pea and other plants under a diurnal temperature of 30/25°C was lower than that of 30/15°C. The decrease of RH and Ta could reduce respiration and consumption by weakening the dark respiration rate. Thus, the fruit setting rate and yield could be improved.

Different irrigation treatments had a significant impact on Pn of Jujube trees, which rose with increased irrigation volume. Under the same meteorological conditions, the lack of soil moisture could result in decreases of Gs and Evap. Thus, the Pn of leaves and the WUE could also be reduced [4-5,18-19]. This study showed that the WUE of leaves decreased under W1 irrigation treatment. During each growth period, the Pn, Gs and Evap for the W2 treatment were lower than those for W3, but the difference was not significant. However, the WUE for W2 was higher than that for W3 treatment, showing the decrease of irrigation volume to some extent did not decrease the Pn, Gs and Evap, but improved the WUE and enabled the Jujube trees to possess certain drought resistant ability [15, 3] .

Under the same irrigation level, the Pn of APRI on 30 May and 25 June increased slightly compared with that of W2, while the Pn and WUE under APRI treatment on 25 July were apparently higher than those of W2, and the Pn and WUE under APRI and W2 treatments were 14.33, 12.54, 5.25 and 4.50 μmol·mmol^{-1}, respectively. The main reason for this phenomenon was the abundant secondary roots produced by jujube under alternate stress of the APRI treatment, and then the absorbing ability of root systems for water and fertilizer was enhanced, and so WUE improved and Pn also increased, the yield therefore also increased. The Evap under APRI treatment in each growth period was higher than that of W2, but the Gs was lower. This was mainly because some roots were in an area of dry soil under APRI, and so the Jujube roots likely formed plenty of abscisic acid due to water stress, which was transferred to leaves to reduce stomatal apertures and water consumption by evaporation. Some roots were in area with irrigated soil, so as to meet the normal physiological activities.

APRI improved the fruit setting rate and yield of Jujube trees under the same irrigation level as regular infiltrating irrigation. The fruit setting rates and yields of APRI and W2 treatments were 212220 and 207400, and 16426 and 147036 kg/hm^2, respectively. Pn increased when Jujube trees suffered alternate stress under the APRI treatment, and so the fruit setting rate and total yield improved.

Under the same irrigation level, the APRI reduced Evap and Gs, and improved Pn, WUE and yield per hectare and significantly (P < 0.05) improved the yield by 11% compared with regular infiltrating irrigation. The

高于5月30日。造成这一现象的原因可能是由于5月30日、6月25日和7月25 日、的光合有效辐射的峰值分别为1928、2400和2155W/m^2，但空气温度的差异则导致其光合速率的不同，过高的空气温度会导致植物叶片光合速率的降低，且会产生"光合午休"现象[6-7, 14]。夜间的低温也会提高白天的光合速率，McDonald 等的研究结果表明豌豆等作物昼夜温度为30/25℃时的光合速率会低于30/15℃时的光合速率[9]。大气相对湿度 和空气温度的降低则导致暗呼吸速率的减弱，从而降低呼吸消耗，提升坐果率和产量。

不同灌水处理对枣树的净光合速率有着显著的影响，随着灌水量的增加枣树叶片净光合速率呈上升趋势。在同样的气象条件下，土壤水分的亏缺会导致气孔导度和蒸腾速率的降低，从而降低净光合速率[4-5,18-19]，并降低叶片水分利用效率，本文在W1灌溉处理下叶片水分利用效率下降，与该文章结论相一致。不同时期W2处理下的净光合速率、气孔导度和蒸腾速率低于W3处理差异不显著，但W2处理下的水分利用效率高于W3处理，表明一定程度上降低灌水量并不会显著降低净光合速率、气孔导度和蒸腾速率，但会提高水分利用效率，具有一定的抗旱能力[15, 3]。

同一灌溉水平，5 月 30 日和 6 月 25 日 APRI 的净光合速率高于 W2，但不显著；7 月 25 日 APRI 处理下的净光合速率和水分利用效率显著高于 W2，APRI 和 W2 处理下的净光合速率和水分利用效率分别为 14.33μmol·m^{-2}·s^{-1}、12.54μmol·m^{-2}·s^{-1} 和 5.25μmol·mmol^{-1}、4.50 μmol·mmol^{-1}，造成这一现象的原因可能是因为 APRI 使枣树根部受到交替胁迫后次生根大量增加，根系吸水吸肥能力增加，水分利用效率明显提高，净光合速率也随之增加，最终产量也得到提升。各时期 APRI 处理下的蒸腾速率高于 W2，气孔导度低于 W2，但差异不显著，主要是因为 APRI 使部分根系处于土壤干燥的区域，枣树受到水分胁迫，根部形成大量脱落酸，传送到叶片，气孔开度减少，降低蒸腾耗水量；还有部分根系处于灌水的区域中，以满足正常的生理活动。

本文中，同一灌溉水平，APRI 能够提高枣树坐果率和枣树产量。APRI 和 W2 处理下的坐果率高和产量分别为 212220 个、207400 个和 16426kg/hm^2、147036 kg/hm^2，APRI 处理下果树受到一定交替胁迫能够提高净光合速率进而提高坐果率，产量得到提升。

在同一灌溉水平下，分根交替灌溉降低枣树叶片蒸腾速率、气孔导度；提高枣树叶片的净光合速率、水分利用率，最终提高枣树达11%，与常规渗灌相比达到显著水平

yield per hectare of Jujube showed no difference (P < 0.05) under the APRI compared with W3. The APRI improved Pn and yield on the basis of water saving. This study demonstrated an effective irrigation mode for development of the jujube industry in Xinjiang, and provided a decision basis for saving water resources, increasing Jujube yield and accelerating the sustainable development of this industry.

ACKNOWLEGEMENT

The study was supported by the Program for International S&T Cooperation Projects (2010DFA92720-11), National Sci-tech Support Program (2009BADA4B03), Xinjiang Water Conservancy Sci-tech Special Project (2013T04), (2013T05) and (2014T16).

REFERENCES

[1]. Chai Z P, Wang X M, Chen B L, et al.(2013) – *Research on Diurnal Variations of Photosynthetic Characteristics Pyrusbretschneideri Under Different Growth Stages.* Northern Horticulture, vol.6, pp.1-5;
[2]. Chai Z P, Wang X M, Sun X, et al.(2011) – *Influence of Different Application Ways of Biogas Waste Fertilizer on Photosynthetic Characteristics and Yield of Zizyphus jujube.* Acta Agriculturae Boreali-occidentalis Sinica, vol.20, no.2, pp.170-173;
[3]. Fang Q X, Chen Y H, Li Q Q, et al. (2006) – *Effects of soil moisture on radiation utilization during late growth stages and water use efficiency of winter wheat.* Acta Agronomica Sinica, vol.32, no.6, pp. 861-866;
[4]. Guo C F, Sun Y, Zhang M Q.(2008) – *Effect of soil water stress on photosynthetic light response curve of teaplant.* Chinese Journal of Eco-Agriculture, vol.16, no.6, pp.1413-1418;
[5]. Jiao J Y, Yin C Y, Chen K. (2011) – *Effects of soil water and nitrogen supply on the photosynthetic characteristics of Jatropha curcas seedlings.* Acta Phytoecologica Sinica, vol.35, no.1, pp.91-99;
[6]. Li T L, Yan A D, Luo X L, et al.(2010) – *Temperature modified model for single-leaf net photosynthetic rate of greenhouse tomato.* Transactions of the Chinese Society of Agricultural Engineering, vol.26, no.9, pp. 274-279;
[7]. Li T L, Li M. (2009) – *Effect of short-term daytime sub-high temperature stress on photosynthesis of tomato leaves.* Transactions of the Chinese Society of Agricultural Engineering, vol.25, no.9, pp.220-225;
[8]. Ma H Y, Lü D G, Liu G C, et al. (2012) – *Effects of different irrigation modes on the photosynthetic function and antioxidant enzyme activities of 'Hanfu' apple leaves.* Chinese Journal of Ecology, vol.31,no.10,pp.2534- 2540;
[9]. McDonald G K, Paulsen G M. (1997) – *High temperature effects on photosynthesis and water relations of grain legumes.*Plant Soil. Vol.196,no.1, pp.47-58;
[10]. Ou L J, Hu A S, Li B H, et al. (2012) – *Photosynthesis and physiological characteristics of rice with floating culture method.* Transactions of the Chinese Society of Agricultural Engineering, vol.28, no.12, pp.127-133;

（P<0.05），与W3相比，分根交替灌溉条件下红枣亩产量未表现出差异（P<0.05），表明分根交替灌溉能够达到节水提高净光合速率和产量作用；为新疆枣产业的发展提供有效的灌溉方式，为节约水资源，提高枣产量，促进特色枣产业的持续发展提供科学依据。

致谢

国家国际科技合作项目（2010DFA92720-11），国家科技支撑项目（2009BADA4B03），新疆水利科技专项（2013T04），（2013T05）和（2014T16）。

参考文献

[1]. 柴仲平, 王雪梅, 陈波浪, 等. (2013) – *香梨不同生长期光合特性日变化研究.* 北方园艺, 第 6 卷, 1-5;
[2]. 柴仲平, 王雪梅, 孙霞, 等. (2011) – *沼肥不同施用方式对枣树光合特性与产量的影响.* 西北农业学报, 第 20 卷, 第 2 期, 170-173;
[3]. 房全孝, 陈雨海, 李全起, 等. (2006) – *土壤水分对冬小麦生长后期光能利用及水分利用效率的影响.* 作物学报,第 32 卷, 第 6 期, 861-866.
[4]. 郭春芳, 孙云, 张木清. (2008) – *土壤水分胁迫对茶树光合作用-光响应特性的影响.* 中国生态农业学报, 第 16 卷, 第 6 期, 1413-1418;
[5]. 焦娟玉, 尹春英, 陈珂. (2011) – *土壤水、氮供应对麻疯树幼苗光合特性的影响.* 植物生态学报, 第 35 卷, 第 1 期, 91-99;
[6]. 李天来, 颜阿丹, 罗新兰, 等. (2010) – *日光温室番茄单叶净光合速率模型的温度修正.* 农业工程学报, 第 26 卷, 第 9 期, 274-279;
[7]. 李天来, 李淼. (2009) – *短期昼间亚高温胁迫对番茄光合作用的影响.* 农业工程学报, 第 25 卷, 第 9 期, 220-225;
[8]. 马怀宇, 吕德国, 刘国成, 等. (2012) – *不同灌水方式对'寒富'苹果叶片光合功能和抗氧化酶活性的影响.* 生态学杂志, 第 31 卷, 第 10 期, 2534-2540;
[9]. McDonald G K, Paulsen G M. (1997) –*高温对谷物豆科植物的光合作用和水分关系的影响.* 植物与土壤, 第 196 卷, 第 1 期, 47-58;
[10]. 欧立军, 胡爱生, 李必湖, 等. (2012) – *水上浮床种植水稻的光合特性及生理特点.* 农业工程学报, 第 28 卷, 第 12 期, 127-133;

[11]. Papastylianou I. (1995) – *Yield components in relation to grain yield losses of barley fertilized with nitrogen*. European Journal of Agronomy, vol.4, no.1, pp. 55－63;
[12]. Wei L, Xiong Y C, Bao L M,et al.(2011) – *Photosyn - thetic characterization and yield of summer corn during grain filling stage under different planting pattern and population densities.* Acta Ecologica Sinica, vol.31, no.9, pp.2524- 2531;
[13]. Wei R F, Zhuang F, Fan Y Y, et al. (2012) – *Effect of Soil Water Content on Photosynthetic Characteristics and Transpiration Water Consumption of Jujube.* Journal of Irrigation and Drainage, vol.31, no.2, pp.107-111;
[14]. Wolleweber B, Porter J R, Schellberg J.(2003) – *Lack of interaction between extreme high-temperature events at vegetative and reproductive stages in wheat.* Journal of Agronomy and Crop Science, vol.189, no.3, pp.142-150;
[15]. Xu J Z, Peng S Z, Wei Z, et al. (2012) – *Character-istics of rice leaf photosyntetic light response Curve with different water and nitrogen regulation.* Transactions of the Chinese Society of Agricultural Engineering, vol.28, no.2, pp.72-76;
[16]. Yao Q s, Lei X T, Wang Y C, et al.(2006) – *Effects of different water moisture on photosynthesis, transpiration and stoma conductance of potted mango seedlings.* Journal of Fruit Science, vol.23, no.2, pp.223-226;
[17]. Zhu R, Yao Li X, Ma W Y, et al. (2010) – *Status and Prospect of Zizyphus jujube Producing in Sinkiang*. Hei long jiang Agricultural Sciences, vol.6, pp.158-163;
[18]. Zhu Y Y, He K Q, Tang D F, et al.(2007) – *Response to light of ulmus pumila in different soil Moisture.* Research of Soil and Water Conservation, vol.14, no.2, pp. 92-94;
[19]. Zhu J J, Kang H Z, Li Z H, et al. (2005) – *Impact of water stress on survival and photosynthesis of Mongolian pine seedlings on sandy land.* Acta Ecologica Sinica, vol.25,no.10, pp.2527-2533.

[11]. Papastylianou I. (1995) – *施氮条件下产量组分与产量损失之间的关系.* 欧洲农学杂志, 第 4 卷, 第 1 期, 55-63;
[12]. 卫丽, 熊友才, Bao luo Ma, 等. (2011) – *不同群体结构夏玉米灌浆期光合特征和产量变化.* 生态学报, 第 31 卷, 第 9 期, 2524- 2531;
[13]. 魏瑞锋, 庄飞, 范阳阳, 等. (2012) – *土壤水分对枣树光合特性及耗水量的影响.* 灌溉排水学报, 第 31 卷, 第 2 期, 107-111;
[14]. Wolleweber B, Porter J R, Schellberg J. (2003) – *小麦营养生长和生殖阶段期间极端高温事件影响无较强的的持续性.* 农作物科学, 第 189 卷, 第 3 期, 142-150;
[15]. 徐俊增, 彭世彰, 魏征, 等. (2012) – *不同供氮水平及水分调控条件下水稻光合作用光响应特征.* 农业工程学报, 第 28 卷, 第 2 期, 72-76;
[16]. 姚全胜, 雷新涛, 王一承, 等. (2006) – *不同土壤水分含量对杧果盆栽幼苗光合作用、蒸腾和气孔导度的影响.* 果树学报, 第 23 卷, 第 2 期, 223-226;
[17]. 朱锐, 姚立新, 马雯彦, 等. (2010) – *新疆枣树生产的现状与展望.* 黑龙江农业科学, 第 6 卷, 158-163;
[18]. 朱艳艳, 贺康宁, 唐道锋, 等. (2007) – *不同土壤水分条件下白榆的光响应研究.* 水土保持研究, 第 14 卷, 第 2 期, 92－94;
[19]. 朱教君, 康宏樟, 李智辉, 等. (2005) – *水分胁迫对不同年龄沙地樟子松幼苗存活与光合特性影响.* 生态学报, 第 25 卷, 第 10 期, 2527-2533.