

## Full Length Research Paper

# Water use efficiency of controlled alternate irrigation on wheat/faba bean intercropping

Yang Caihong<sup>1</sup>, Chai Qiang<sup>2\*</sup>, Li Guang<sup>1</sup>, Feng Fuxue<sup>3</sup> and Wang Li<sup>1</sup><sup>1</sup>College of Forestry, Gansu Agricultural University, Lanzhou 730070, China.<sup>2</sup>College of Agronomy/Gansu Provincial Key Lab of Aridland Crop Science, Gansu Agricultural University, Lanzhou 730070, China.<sup>3</sup>School of Engineering, Gansu Agricultural University, Lanzhou 730070, China.

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Water supply is limited worldwide and there is a need for saving of water in irrigation. In this study, two irrigation methods, that is, conventional irrigation (CI), alternate irrigation (AI, alternate watering on both sides of the row), and three planting patterns, that is, sole wheat, sole faba bean and wheat/faba bean intercropping were applied on root box experiment. Results showed that the yields of intercropping with AI generally increased compared with sole cropping. Sole faba bean and wheat/faba bean intercropping with AI significantly increased the root-shoot ratio compared to all the other treatments.  $P_n$  in AI was not reduced significantly when compared to that of CI at the same planting pattern. However,  $T_r$  and  $G_s$  in AI was significantly lower than that of CI for sole wheat, sole faba bean and wheat/faba bean intercropping. Maximum biomass accumulation was obtained in the CI treatment, but severe water deficit led to a less reduction in the AI treatment, such reduction was much smaller under AI and therefore the higher water use efficiency was obtained. In conclusion, AI is an effective and water-saving irrigation method in wheat and faba bean production especially in intercropping system, and may have the potential to be used in the field.

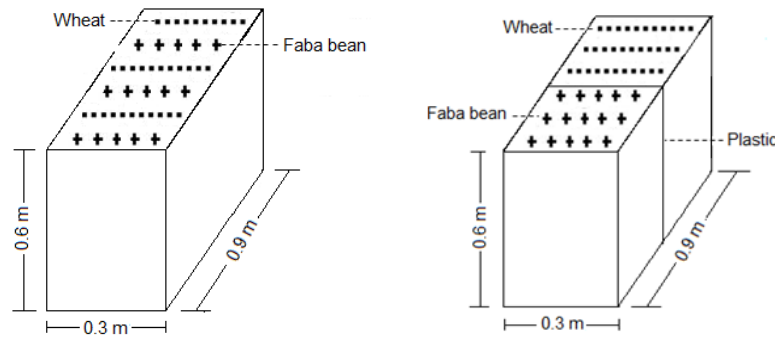
**Key words:** Yield, irrigation, water use efficiency, wheat (*Triticum aestivum*), Faba bean (*Vicia faba*).

## INTRODUCTION

Intercropping, the agricultural practice of cultivating two or more crops in the same area at the same time, is an intensive management for crop production which aims to match efficiently crop demands to the available growth resources and labor. It is relatively common in tropical and temperate areas, because of the effective utilization of water (Xu et al., 2008), nutrients (Xia et al., 2013; Zhang and Li, 2003) and solar energy (Yang et al., 2014). The

majority of intercropping systems involve legume/cereal combinations, interspecific facilitation occurs when one plant species enhances the growth of another plant species and has been observed mainly in legume/cereal systems (Li et al., 1999, 2001), and most of the research that has been conducted on intercropping has therefore focused on the legume-cereal intercropping, a productive and sustainable system (Ghosh et al., 2009; Lithourgidis

\*Corresponding author. E-mail: Chaiq@gsau.edu.cn. Tel: +086-931-7608083. Fax: +086-931-7631200.



**Figure 1.** A schematic diagram of root box for wheat and faba bean controlled alternate irrigation.

et al., 2011; Tosti et al., 2010). In China, half of the total grain yields was produced with intercropping (Zhang and Li, 2003), wheat/faba bean intercropping system in particular was one of major planting pattern in northwestern regions. In general, intercropping has been shown to be more productive than sole cropping. However, combinations of certain crops result in increased competition among the components. This results in reduced yields, which may make some crop species unsuitable for intercropping. Increased competition especially for water may be ultimately leading to changes in crop productivity levels.

Drought is one of the most important environmental factors limiting growth and yield of crops (Chaves et al., 2003). In the traditional agricultural irrigation, yield increase was mainly attained from the amounts of water used in irrigation satisfying the biological characteristics of water demand (Deng et al., 2002). Enhancing water use efficiency, both under rain-fed and irrigated agriculture is a high priority for agricultural improvement in developing countries (Canone et al., 2015; Melkonyan, 2015; Ronaldo et al., 2015). Thus, new irrigation strategies must be established to use the limited water resource more efficiently. In recent years, the concept of alternate partial root-zone irrigation (APRI) or partial root-zone drying (PRD) has been raised and attracted considerable interest (Kang et al., 1997; Davies et al., 2000; Kang and Zhang, 2004).

This technique was derived from earlier split-root studies (Blackman and Davies, 1985) and requires that approximately half of the root system be always exposed to drying soil while the remaining half is irrigated as in full irrigation. The wetted and dried sides of the root system were alternated in a frequency according to crops growing stages and soil water balance. This could result in the concentration increasing of abscisic acid (ABA) in the xylem flow from roots to leaves, triggering the closure of stomata (Tardieu et al., 1993; Zhang and Davies, 1990), and decreasing the transpiration of crops. Water management under PRD irrigation focuses on efficient use of limited soil water and increasing crop water-use

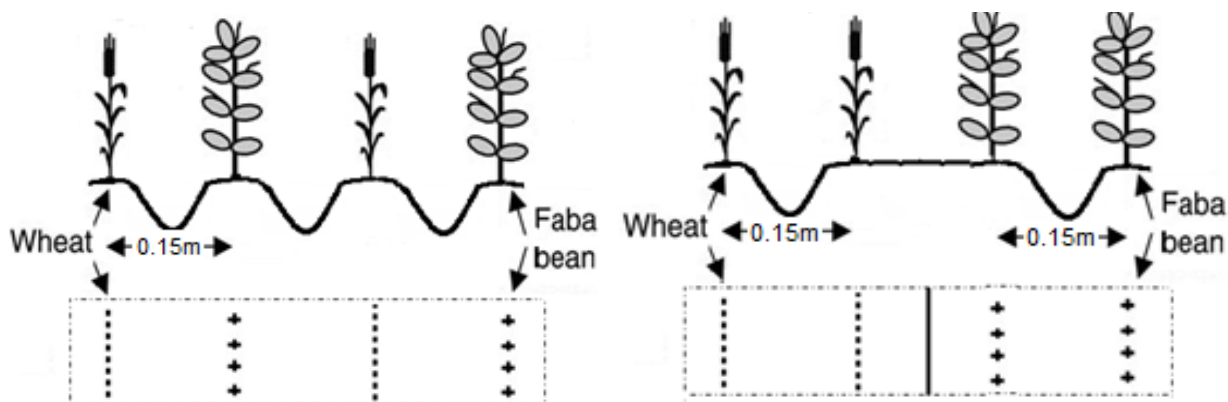
efficiency. Root growth is critical for crops to use soil water and obtain high yield under water deficit conditions (Robertson et al., 1993). The effect of this irrigation mode on increasing WUE and maintaining yield has been extensively verified (Davies and Hartung, 2004), it is hypothesized that these same benefits may be obtained in wheat/faba bean intercropping. However, the effects of enhanced WUE on wheat/faba bean intercropping have not been investigated.

In wheat/faba bean intercropping system, the conventional irrigation scheme was often designed only according to the water demand of a main crop in deficient growth stage, it often caused the mismatching of water supply and demand for the other crop. For the sake of solving the problem, the authors explored a new irrigation method that based on limited water supply but could meet the water demand on both wheat and faba bean, might be an effective way to decrease the irrigation quota and increase the WUE of wheat/faba bean intercropping system. The experiment was designed to test the effect of controlled alternated irrigation on the yield, root-shoot ratio, physiological response and WUE of wheat/faba bean intercropping. The objective of the study was to compare AI with different planting pattern on wheat and faba bean plants in terms of plant root and shoot growth, shoot physiology and WUE.

## MATERIALS AND METHODS

### Plant material and experimental conditions

The experiment was carried out under glasshouse conditions at the plant growth unit, Gansu Agricultural University, Lanzhou (Latitude 36°03'N, longitude 103°49'E), China. It was conducted from January to July 2008. The wheat were sown on 25 March and harvested on 15 July, while the faba bean were sown on 28 March and harvested on 22 July. Wheat and faba bean plants were grown in root box (900 mm in length, 300 mm in width and 600 mm in height), three strips comprising 3 rows of wheat and 3 rows of faba bean constituted a root box, the inside of the root box was evenly separated into two containers (sole cropping) with plastic sheets such that water and nutrients exchange among the containers was prevented (Figure 1).



**Figure 2.** Layout of wheat/faba bean intercropping and sole cropping for controlled alternate irrigation in root box experiment.

The row spacing of wheat and faba bean were all 150 mm. Each root box consisted of 3 rows with 45 plants for wheat and 3 rows with 9 plants for faba bean (Figure 2). Root boxes were filled with heavy loam soil with a bulk density of  $1.17 \text{ g dried weight cm}^{-3}$  and field capacity of  $24.3\%$  (g water  $\text{g}^{-1}$  wet weight). Soil was sieved by 2 mm mesh and mixed with NPK-complete fertilizer to keep soil structure, nutrition and soil microorganism homogeneous at the beginning. In addition, a PVC tube (2 cm in diameter) with holes was installed in each root box to supply irrigation water to prevent surface soil hardening from the irrigation and reduce evaporation.

### Treatments and experimental design

Experimental design was a split-plot with three replicates in which the main plot treatments were alternate irrigation (AI) and conventional irrigation (CI). CI which every row was irrigated during each watering, and AI which one of the two neighboring furrows was alternately irrigated during consecutive watering. Each root box was considered as a block to randomly allocate the above six treatments in a randomized complete block design (RCBD) with nine replications. Sub-plot treatments consisted of sole wheat seeds (*Triticum aestivum* L., Yongliang No. 4), sole faba bean (*Vicia faba* L. cv., Lincan No. 5) and wheat/faba bean intercropping.

At the age of 3 weeks, plants were chosen for uniformity and relatively even root distribution among the root boxes and subjected to controlled soil water content. Before the soil water was controlled, soil water regimes in all root boxes were kept the well-watered (60% of their field capacity). Irrigation was strictly controlled when soil water content reduced to or near to the lower limit of soil water content (55% of their field capacity). The amount of water used for each plant was recorded. The root box size was such that interval of 5 days was enough to keep the soil water content above the designed levels. Crop water consumption (evapotranspiration) and the amount of irrigation were calculated from the root box water balance.

### Measurements

At the end of the experiment, wheat and faba bean were harvested for their root dry mass, shoot dry mass, and the final grain yields for each individual plant were also recorded. Land equivalent ratio (LER) was used to evaluate the success of intercropping, the total LER is defined as the total land area required under monoculture to give the yields obtained in the intercropping mixture. It is expressed as:

$$LER = \frac{Y_{WI}}{Y_{WM}} + \frac{Y_{FI}}{Y_{FM}} \quad (1)$$

Where  $Y_{WM}$  and  $Y_{FI}$  are grain yields of wheat in monoculture and intercropping ( $\text{kg}\cdot\text{ha}^{-1}$ ), respectively;  $Y_{MM}$  and  $Y_{FM}$  are grain yields of maize in monoculture and intercropping, respectively ( $\text{kg}\cdot\text{ha}^{-1}$ ). WUE was calculated for each plant as the harvest yield divided by the total amount of water actually irrigated.

During the soil drying period, the photosynthetic rates, transpiration rates and stomatal conductance of all plants were measured at critical growth stage using a photosynthesis analysis system (CI-301PS, CID, USA). These measurements were made on fully expanded leaves facing the sun at about 9:00 to 11:00 h.

### Data analysis

Root, shoot growth and physiological data were analyzed with standard split-plot analysis of variance (ANOVA) techniques, with irrigation method as the main factor and planting pattern as the sub factor. The least significant difference (LSD) test was used to compare significant differences between treatment means. The level of significance was set at 5%.

## RESULTS

### Yield response

Intercropping of wheat and faba bean showed some advantage in terms of grain yields, and LER based on grain yield at maturity were greater than 1.0 whether AI or CI (Table 1). The effect of irrigation method on total yield of sole faba bean was not significant ( $p>0.05$ ), and the response of intercropped faba bean with AI was also not significant. However, the yields of intercropping with alternate irrigation generally increased compared with sole cropping. The yield of intercropped wheat was 62.75% of sole wheat, and intercropped faba bean was 52.77% of sole faba bean in AI.

Analysis of variance showed that planting pattern has significant effect on grain harvest index. The harvest

**Table 1.** Yield of wheat/faba bean intercropping subjected to controlled soil drying.

Treatment		Yield(g)		Harvest index		LER
		Wheat	Faba bean	Wheat	Faba bean	
A	S	4.59	16.44	0.3600	0.4214	1.16
	I	5.76	17.35	0.3942	0.4459	
C	S	5.17	16.51	0.3799	0.4159	1.11
	I	5.81	17.97	0.3905	0.4368	
<b>Significance test (P values)</b>						
Irrigation method		NS	NS	NS	NS	
Planting pattern		**	*	*	*	
I×P		NS	NS	*	*	

Note: A-alternate irrigation, C-conventional irrigation, S-sole cropping, I-intercropping, I×P-Interaction effects between irrigation method and planting pattern; NS refers to no significant difference between treatments at 0.05 levels, \*Significant difference between treatments at 0.05 levels, \*\*Significant difference between treatments at 0.01 levels; The same as follows.

**Table 2.** Dried root mass and root-shoot ratio of wheat and faba bean plants subjected to controlled soil drying.

Treatment		Wheat			Faba bean		
		Shoot dry weight (g·plant <sup>-1</sup> )	Root dry weight (g·plant <sup>-1</sup> )	R/S ratio	Shoot dry weight (g·plant <sup>-1</sup> )	Root dry weight (g·plant <sup>-1</sup> )	R/S ratio
A	S	12.75	2.10	0.165	13.99	3.23	0.231
	I	14.61	2.54	0.174	14.15	3.13	0.221
C	S	13.61	1.65	0.121	13.66	2.70	0.198
	I	14.88	2.26	0.152	15.58	2.91	0.187
<b>Significance test (P values)</b>							
Irrigation method		NS	NS	*	NS	*	NS
Planting pattern		**	*	NS	*	NS	*
I×P		NS	NS	*	*	*	**

index of intercropped wheat and faba bean was increased by 2.27 and 5.42% than corresponding sole cropping. No significant difference in harvest index was observed between AI and CI.

### Root and shoot response

Table 2 shows root establishment in the soil as a function of the different planting pattern and irrigation ways of controlled soil drying. The shoot and root dry weight of intercropped wheat was significantly increased by the root intermingling compared with sole cropping with either CI or AI. However, this did not result in significant differences in the root-shoot ratio under different planting pattern.

Generally, shoot dry weight is not significantly different between the two irrigation methods. AI slightly influences the above ground growth of wheat and faba bean plant,

root dry weight in AI was more than that of CI, and the difference between AI and CI was significant for sole faba bean and wheat/faba bean intercropping. Soil drying inhibited root growth, but in this experiment, the root-shoot ratio was increased, suggesting that shoot growth is more sensitively inhibited than roots. It is indicated that AI in sole faba bean and wheat/faba bean intercropping significantly increased the root-shoot ratio compared to other treatments.

### Physiological responses

For monitoring change of photosynthesis rate ( $P_n$ ), transpiration rate ( $T_r$ ) and stomatal conductance ( $G_s$ ) of the leaves, sunny and cloudless days were chosen with a portable photosynthesis system (CI-301PS, CID, USA) at about 9:00 to 11:00 h on May 14, May 29 and June 10,

**Table 3.** Photosynthesis rate, transpiration rate and stomatal conductance of wheat and faba bean subjected to controlled soil drying.

Date (month/day)	Treatments		$P_n$		$T_r$		$G_s$	
			Wheat	Faba bean	Wheat	Faba bean	Wheat	Faba bean
5/14	A	S	6.86	8.54	2.85	1.55	0.85	10.54
		I	7.58	8.24	3.25	1.68	0.91	11.03
	C	S	6.85	9.23	3.23	1.69	1.11	10.56
		I	6.83	8.21	3.26	1.87	0.75	12.56
5/29	A	S	8.51	10.21	5.14	2.11	2.31	11.56
		I	8.98	11.12	5.58	2.33	1.84	13.23
	C	S	8.57	15.54	4.95	2.56	1.85	13.56
		I	9.5	14.25	4.86	2.45	1.92	11.65
6/10	A	S	9.87	16.12	7.56	2.89	2.61	16.25
		I	9.55	15.56	7.23	2.87	2.53	16.56
	C	S	9.52	17.13	7.14	2.98	2.44	16.29
		I	10.24	15.56	6.88	2.87	2.68	17.11
<b>Significance test (<math>P</math> values)</b>								
Irrigation method			NS	NS	*	*	*	*
Planting pattern			*	*	NS	*	**	*
I×P			NS	NS	*	*	*	*

$P_n$ -Photosynthesis rate ( $\mu\text{mol}/\text{m}^2\text{s}^{-1}$ ),  $T_r$ -Transpiration rate ( $\text{mol}/\text{m}^2\text{s}^{-1}$ ),  $G_s$ -Stomatal Conductance ( $\text{mol}/\text{m}^2\text{s}^{-1}$ ). The data were measured at 9:00 to 11:00 h for each time in sunny and cloudless days. The dates of the measurements were in the middle of two irrigations. Each value is a mean of three replicates.

2008 (Table 3). Four youngest mature leaves that were fully exposed to sun were chosen for such measurement of each treatment.  $P_n$  in AI was not reduced significantly when compared to that of CI at the same planting pattern. However,  $T_r$  in AI in three measurements for sole wheat and sole faba bean was also significantly lower than those of CI. It should also be noted that  $G_s$  in AI in three measurements showed the similar changes as  $T_r$

for sole wheat, sole faba bean and wheat/faba bean intercropping. AI did not lead to a leaf water deficit that might have contributed to growth and stomatal regulation. When compared to CI, AI did not significantly inhibit leaf photosynthesis, but did significantly restrict stomatal opening, especially for sole faba bean and wheat/faba bean intercropping. As a result, WUE in AI was significantly higher than that of CI in the respective

measurements at the same planting pattern.

#### Water use efficiency (WUE)

WUE calculated as the yield or biomass production per unit amount of water consumption was substantially improved in these treatments. Improved irrigation methods (AI) can significantly

**Table 4.** Total water consumption, biomass and water use efficiency (WUE) of wheat and faba bean plants subjected to controlled soil drying.

Treatment	Dry biomass (g)	Water consumption (kg)	WUE <sub>y</sub> (g/kg)	WUE <sub>b</sub> (g/kg)
A Sole wheat	12.23	17.48	0.263	0.700
A Sole faba bean	14.55	19.53	0.842	0.745
A Intercropping	15.09	16.36	0.706	0.922
C Sole wheat	12.44	26.76	0.193	0.465
C Sole faba bean	10.94	27.84	0.593	0.393
C Intercropping	15.74	27.26	0.436	0.577
<b>Significance test (P values)</b>				
Irrigation method	*	**	*	*
Planting pattern	**	NS	*	NS
I×P	NS	*	NS	NS

improve wheat/faba bean intercropping water use efficiency (Table 4). Compared to CI, AI increased WUE<sub>y</sub> and WUE<sub>b</sub> by 35.94, 41.94, 61.90% and 50.53%, 89.58%, 59.71% for sole wheat, sole faba bean, wheat/faba bean intercropping, respectively; However, wheat/faba bean intercropping significantly improved WUE<sub>b</sub> than corresponding sole wheat and sole faba bean. As the root growth data in Table 1 have suggested, such drying and rewetting methods with a moderate root-shoot ratio were possibly too aggressive in terms of water saving.

## DISCUSSION

Previous studies have shown the yield advantage in legume/non-legume intercropping systems. The results were reported for mixed cultures of wheat and faba bean (Agegnehu et al., 2008; Tosti and Guiducci, 2010; Barker and Dennett, 2013), wheat and field bean (Haymes and Lee, 1999), barley and faba bean (Agegnehu et al., 2006), maize and faba bean (Li et al., 1999; Mei et al., 2012) and wheat and lentil (Akter et al., 2004). In this experiment, there was also an advantage in wheat/faba bean intercropping over monoculture as the LER was above 1.0 under different irrigation method. The total yield of wheat/faba bean intercropping was also significantly higher than sole wheat and sole faba bean respectively.

A number of experiments have reported that alternate irrigation (AI) maintain a reasonable crop yield and save irrigation water (Kang et al., 2002b; Liang et al., 2013; Tang et al., 2005; Ye et al., 2013; Zegbe et al., 2004). It has been proved to be an effective irrigation way for many crops and in many areas (Kang and Zhang, 2004). In our study, AI method on wheat/faba bean intercropping could improve WUE without a significant decrease of photosynthetic rate and biomass, which is in agreement with some earlier research on AI (Du et al., 2013).

Generally, aboveground and belowground architecture

of plants usually influences plant's relative competitive ability (Akanvou et al., 2001; Dingkuhn et al., 1999). The response of different cropping system to irrigation method, however, was not identical with intercropping being more sensitive than sole cropping. The soil drying signal from the partially irrigated root system could account for the reduced vegetative growth observed in the AI treatments plants. This study has shown that green gram for AI invested proportionally more of its photosynthetic resources into yield and biomass production per unit of water transpired, whereas faba bean invested more heavily in root production. Research on redundancy growth and its application in field management showed that appropriate reduction of redundancy growth might result in increased yield (Han et al., 2005).

This experiment of alternate irrigation on wheat/faba bean intercropping glasshouse conditions has also indicated that AI has the good control of the excessive vegetative growth. The ground part growth of intercropped wheat and faba bean with alternate irrigation was much shorter than that of monoculture with conventional irrigation. However, average grain yield per plant in wheat and faba bean plant with alternate irrigation didn't see significant difference.

Furthermore, different irrigation method led to a substantial difference in the root growth pattern and root interactions of component crops in intercropping. The low competitive capacity of legume compared to cereal was ascribed to its small root system and resulting low competitive ability. It is therefore possible that, during a typical drying cycle (about 5 to 7 days), part of the root system near the soil surface comes in contact with dry soil, while other roots continue to extract water from deep and wetter soil layers. Extraction of soil water from deeper layers has been observed in some PRD and surface irrigation studies (Kriedemann and Goodwin, 2003; Canone et al., 2015). These led to a higher faba bean WUE in sole faba bean and wheat/faba bean intercropping

with alternate irrigation.

## Conclusion

The authors' results have shown that controlled alternate irrigation is better than conventional irrigation. AI showed good physiological responses in  $P_n$ ,  $T_r$ , Gs,  $WUE_y$  and  $WUE_b$ , which may provide a useful approach to apply the theory of root-to-shoot long distance signaling process in wheat and faba bean production in areas where irrigation is essential. The extra benefit for sole faba bean and wheat/faba bean intercropping with AI was that the root-shoot ratio was enhanced if compared with CI at the same planting pattern. Furthermore, increasing yield,  $WUE_y$  and  $WUE_b$  of AI on wheat/faba bean intercropping was also significantly proved in this experiment. It has been suggested that AI had great potential in efficient water use and more data is needed to build in field experiment in arid areas where irrigation is essential and evaporation demand is high.

## Conflict of Interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

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