

IRRIGATION OF CHICKPEA (*CICER ARIETINUM* L.) INCREASES YIELD BUT NOT WATER PRODUCTIVITY

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SUMMARY

The depth to ground water is increasing in several regions of the world due to use of high-yielding, but also high water-requiring crops such as rice (*Oryza sativa*) and wheat (*Triticum aestivum*), in order to maintain food security for an ever increasing world population. There is a need not only to increase the water productivity of food crops, but also to find less water-requiring crops. Irrigated chickpea (*Cicer arietinum* L.), traditionally grown without irrigation, may provide an alternative crop to irrigated wheat in some regions. Two field experiments were conducted to determine the effects of irrigation on chickpea yields, yield components and grain and biomass water productivity (based on irrigation (WP_I) and irrigation + rainfall (WP_{I+R})) grown in a loamy sand soil. In the first year, 75 mm of irrigation at the vegetative stage and at the vegetative plus podding stages resulted in a 59% and a 73% increase in grain yield, respectively, compared to no irrigation, but with little change in WP_{I+R}. Overall yields in the second year were significantly higher due to warmer temperatures and fewer frosts during flowering and podding. Compared to no irrigation, 75 mm of irrigation at flowering or at podding resulted in a 7% and a 27% increase in grain yield, but a decrease in grain and biomass water productivity (WP_{I+R}). Irrigation had a significant effect on the number of pods plant⁻¹ in both the years and on 100-seed weight in the first year. We conclude that application of a single irrigation during podding to chickpea grown in a loamy sand soil will reliably increase yields and may provide a water-saving alternative to wheat in water-scarce environments.

INTRODUCTION

Chickpea (*C. arietinum* L.) is an important grain legume (pulse) crop, which in 2010 was grown globally on 12 million hectares with a total production of 11 million tonnes (FAOSTAT, 2012). India, Pakistan, Turkey, Australia, Myanmar, Ethiopia, Iran and Mexico are the major chickpea-producing countries. South Asia is not only an important producer (8 million tonnes in 2009), but also an important importer (0.7 million tonnes in 2009) of chickpea. It has considerable importance as food, feed and fodder. As a human food, chickpea is used as a green vegetable, as whole grain, split and dehulled to produce a stew (dahl or dal), hummus, and ground to produce flour with many items prepared from the flour.

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Chickpea is primarily a rainfed crop grown on in-season rainfall in Mediterranean climatic regions such as southern Australia, west Asia and southern Europe, and on conserved soil moisture in south Asia and north-eastern Australia. Chickpea suffers from drought and high temperatures during reproductive development resulting in the production of fewer pods and seeds and reduced yields (Behboudian *et al.*, 2001; Fang *et al.*, 2010; Leport *et al.*, 1998, 1999, 2006; Turner, 2003). In the north-western plain zone of India, chickpea was displaced to marginal soils and rainfall zones as the production of irrigated rice and wheat increased to meet the requirements of the Green Revolution. However, yields of rice and wheat are stagnating in many parts of the world (Brisson *et al.*, 2010) including in north-west India and China, as a consequence of climate change, greater use of mildly-saline and deeper groundwater and lack of sufficient fertilizer input (Brisson *et al.*, 2010; Tilman *et al.*, 2011). Moreover, there is over-exploitation of groundwater in many parts of the world (Jägerskog and Jønch Clausen, 2012), with the result groundwater resources are becoming scarcer (Deng *et al.*, 2006; Hira, 2009) and improved water productivity of water resources is required to meet the food requirements and the changing eating habits of the increasing world population.

To overcome the yield reductions from terminal drought, chickpea is grown with supplemental irrigation in some part of the world, particularly in west Asia and northern India (Anonymous, 2003), where it increases chickpea productivity (Erman *et al.*, 2011; Khamssi *et al.*, 2010; Leport *et al.*, 1998, 1999; Yadav *et al.*, 2006). The application of one irrigation (Munirathnam and Sangita, 2009), two irrigations (Abraham *et al.*, 2010; PAU, 2011) or three irrigations (Mansur *et al.*, 2010) has been observed to increase chickpea grain yields substantially. However, the actual number of irrigations required depends upon many factors including the rainfall received, soil texture, weather conditions, and crop duration. Studies with chickpea in Mediterranean-climatic regions have shown that supplemental irrigation can significantly increase yields and water productivity (Oweis *et al.*, 2004; Zhang *et al.*, 2000). In a study in northern Syria, yields increased linearly with the amount of water applied, but water productivity did not always increase, depending on time of planting. Eighty millimetres of supplemental irrigation increased the water productivity of chickpea on an average over 4 years by 11% from 4.2 to 4.7 kg ha⁻¹ mm⁻¹ with a late November sowing and from 4.7 to 5.2 kg ha⁻¹ mm⁻¹ with a late February sowing, but did not increase the water productivity when sown in mid-January (Oweis *et al.*, 2004). Whether supplemental irrigation will increase water productivity where chickpea is grown on conserved soil moisture is unknown.

In the present study the effect of irrigation application to chickpea at the vegetative stage, flowering, podding or at a combination of different stages on its growth, yield and water productivity were conducted over two growing seasons in northern India. The hypotheses tested were (i) that supplemental irrigation would increase the yield and water productivity of the chickpea crop, and (ii) that supplemental irrigation during reproductive development would increase yields and water productivity to a greater extent than supplemental irrigation during vegetative growth.

Table 1. Mean soil properties in the surface 0.15 m at the experimental site.

Parameter	Value	Method used
pH (1:2 Soil: water suspension)	8.2	Beckman's glass electrode pH meter (Jackson, 1967)
Sand	81%	International pipette method (Piper, 1966)
Silt	6%	
Clay	13%	
Texture	Loamy sand	
Organic carbon	0.28%	Walkley and Black's rapid titration method (Jackson, 1967)
Available P	29 kg ha ⁻¹	Extractable method (Olsen <i>et al.</i> , 1954)
Available K	170 kg ha ⁻¹	1N ammonium acetate extractable method (Jackson, 1967)

MATERIALS AND METHODS

Site characterization

Field experiments were conducted during the winter season of 2007–08 and 2008–09 at the experimental farm of the Punjab Agricultural University, Ludhiana ($30^{\circ} 56' N$, $72^{\circ} 52' E$, altitude 247 m), India. The soil at the experimental site was loamy sand, low in available nitrogen, but with a medium level of available phosphorus and potash. It had a water-holding capacity of 350 mm over the upper 1.8 m. Major properties of the experimental soil are presented in Table 1. Meteorological data were recorded at the Meteorological Observatory of the Punjab Agricultural University, Ludhiana, which is situated about 4 km from the experimental site.

Treatments and experimental design

In 2007–08, three treatments (i) no irrigation, (ii) irrigation at the late vegetative/early flowering stage (72 days after sowing, DAS), and (iii) irrigation at both the late vegetative/early flowering (72 DAS) and podding (118 DAS) stages, were imposed in a randomized block design with three replications. In 2008–09, the three treatments were (i) no irrigation, (ii) irrigation at flowering (108 DAS), and (iii) irrigation at podding (123 DAS), in a randomized complete block design with three replications. Each plot was 10 m × 3.3 m and the plots were separated with 0.70 m wide buffers to avoid movement of irrigation water from one plot to another. At each irrigation event 75 mm of water was applied as flood irrigation. In common with farmer practice, all treatments received a pre-sowing irrigation of 100 mm in both years of study.

Crop husbandry and observations recorded

After harvesting the preceding rice crop in October, the pre-sowing irrigation was applied and when the soil moisture level was suitable the seedbed was prepared by disk plough, followed by one cultivation and then levelled. Chickpea (*C. arietinum* L. cultivar PBG 1) was sown on 18 November 2007 and 13 November 2008 in rows 30 cm apart using a seed rate of 45 kg ha⁻¹. Before sowing, 15.5 kg N and 40 kg P₂O₅ ha⁻¹ was applied as diammonium phosphate (18% N and 46% P₂O₅). Weeds were controlled by hand weeding at 30 and 60 days after sowing (DAS). Two sprays of Thiodan 35

EC (endosulphhan) @ 2.5 L ha⁻¹ were applied at 120 and 134 DAS to control pod borer (*Helicoverpa armigera* Hub.). The crop was harvested on 20 April 2008 (154 DAS) and 25 April 2009 (163 DAS). At maturity, data on plant height, number of primary branches, number of secondary branches and number of pods were recorded on five randomly selected plants. Seeds of 10 randomly-chosen pods were used to record number of seeds pod⁻¹. Biological yield (aboveground total dry matter of the crop at the time of harvest) and grain yield were recorded on a whole plot basis and converted into kg ha⁻¹. Harvest index – the ratio of grain yield to aboveground dry matter – was calculated by multiplying grain yield by 100 and dividing by the biological yield. Data on 100-seed weight were also recorded by weighing 100 randomly-selected seeds after threshing.

Water productivity

Water productivity (based on irrigation (WP_I) and irrigation + rainfall (WP_{I+R})) for grain yield and biomass was computed as:

$$\text{Grain WP}_I (\text{kg m}^{-3}) = \text{Grain yield} (\text{kg ha}^{-1}) / \text{Total irrigation amount} (\text{m}^3)$$

$$\text{Biomass WP}_I (\text{kg m}^{-3}) = \text{Biomass} (\text{kg ha}^{-1}) / \text{Total irrigation amount} (\text{m}^3)$$

$$\begin{aligned} \text{Grain WP}_{I+R} (\text{kg m}^{-3}) &= \text{Grain yield} (\text{kg ha}^{-1}) / \text{Irrigation water applied} \\ &\quad + \text{Rainfall} (\text{m}^3) \end{aligned}$$

$$\text{Biomass WP}_{I+R} (\text{kg m}^{-3}) = \text{Biomass} (\text{kg ha}^{-1}) / \text{Irrigation water applied} + \text{Rainfall} (\text{m}^3)$$

Statistical analysis

All data were subjected to analysis of variance as one-way ANOVA (Cochran and Cox (1959) using CPCS-1 software (Cheema and Singh, 1991). Wherever the '*F*' ratio was significant, the least significant difference (LSD) values were calculated at 5% level of significance for comparing the treatment means.

RESULTS

Weather

Figure 1 shows the mean weekly rainfall and maximum and minimum temperatures over the cropping season for the two years of the study. During 2007–08 and 2008–09, 88.7 mm and 81.2 mm rainfall was received during the crop season. The temperatures, especially the minimum temperatures, were lower in 2007–08 than in 2008–09. Furthermore, in 2007–08 there were 19 nights (on 31 December and 18 throughout January) when frost occurred (the temperature decreased below 0 °C), and only two nights in 2008–09 when the temperatures were this low.

Crop growth, yield attributes and yield

The yield of the unirrigated chickpeas in 2008–09 was more than double the yield in 2007–08. This was presumably the result of the colder temperatures and

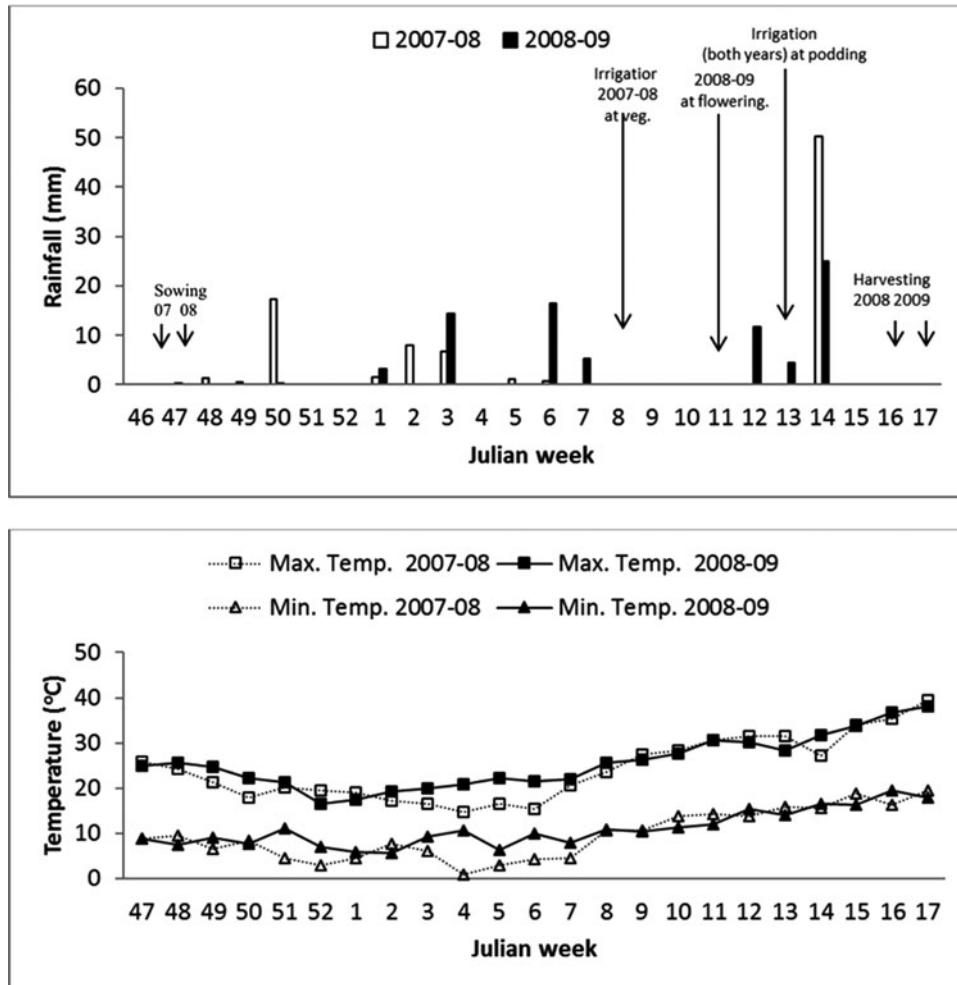


Figure 1. Weekly rainfall (a) and mean weekly maximum and minimum temperatures (b) during the cropping seasons of 2007–08 and 2008–09.

greater frequency of frosts in 2007–08 than in 2008–09. In 2007–08, irrigation at the vegetative stage significantly ($p = 0.01$) increased the aboveground biomass and grain yield by 59% and 36%, respectively, as compared to no irrigation (Figure 2). The additional irrigation at podding increased the aboveground biomass ($p = 0.01$) by a further 26%, but failed to increase the grain yield further. In 2008–09, irrigation at podding increased the aboveground biomass ($p = 0.05$) and grain yield ($p = 0.05$) as compared to the unirrigated control by about 30%, but irrigation at flowering did not significantly increase the biomass and only increased yields by 7%. So a single irrigation of 75 mm had a much greater effect on aboveground biomass and yield in 2007–08 than 2008–09. The single irrigation at the vegetative stage increased

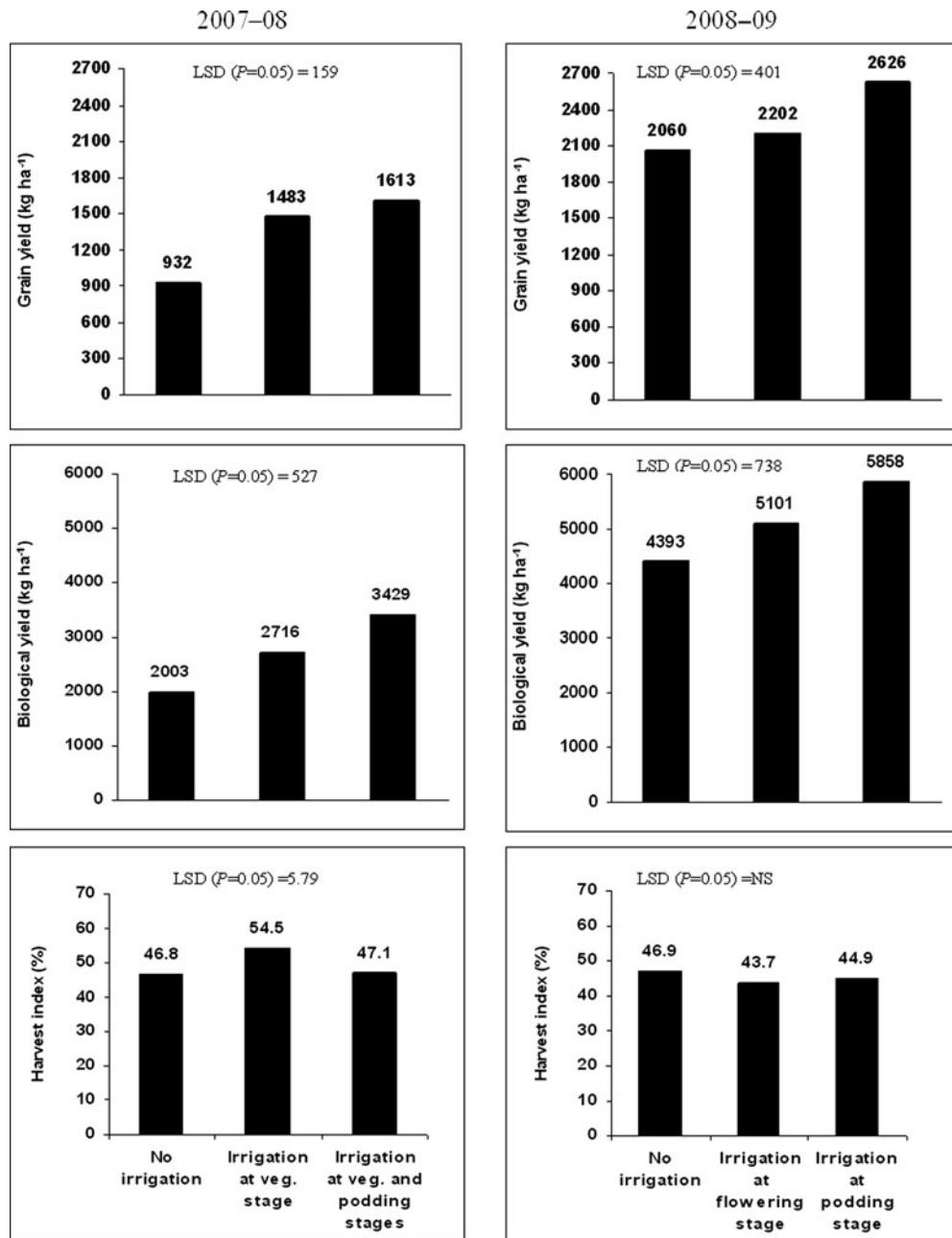


Figure 2. Effect of three irrigation treatments on grain yield, biological yield (aboveground biomass) and harvest index of chickpeas in the growing seasons of 2007–08 and 2008–09. The mean values for each treatment ($n = 3$) are given along with the least significant difference ($\alpha = 0.05$) where statistically significant.

($p = 0.05$) the harvest index from 47 to 54% in 2007–08, but the harvest indices did not differ in 2008–09.

The greater biomass in 2008–09 arose from a greater number of secondary, but not primary branches and was expressed as greater height than in 2007–08 (Figure 3). However, the application of irrigation did not influence plant height, primary branches plant⁻¹ or secondary branches plant⁻¹ in either year of study (Figure 3). The greater grain yield in 2008–09 was associated with a higher number of pods plant⁻¹, but not a higher number of seeds pod⁻¹ or a difference in seed size (100-seed weight) compared with 2007–08 (Figure 4). The number of seeds pod⁻¹ was unaffected by irrigation, number of pods plant⁻¹ was increased by the double irrigation in 2007–08 ($p = 0.05$) and by irrigation at flowering or podding in 2008–09 ($p = 0.05$) (Figure 4). The 100-seed weight increased significantly ($p = 0.01$) only in 2007–08 with irrigation in the vegetative/early flowering phase and was further increased by the additional irrigation at the podding stage (Figure 4).

Water productivity

The higher grain yield in 2008–09 compared with 2007–08 resulted in quite higher grain and biomass water productivity (WP_I as well as WP_{I+R}) than in 2007–08 (Table 2). Irrigation in 2007–08 had little effect on grain and biomass water productivity (WP_I as well as WP_{I+R}) and actually reduced it in 2008–09. In 2007–08, the application of a total of 150 mm in the vegetative and podding stages reduced the grain and biomass water productivity (WP_I as well as WP_{I+R}) as compared with 75 mm irrigation water applied at vegetative stage only. In 2008–09, a single irrigation at podding provided the most efficient use of water and greatest boost to yield, resulting in higher grain and biomass water productivity (WP_I as well as WP_{I+R}).

DISCUSSION

Plant growth, yield attributes and grain yield

Adequate soil moisture is a requirement for obtaining an optimum plant stand, good growth and consequent high productivity of chickpea (Singh *et al.*, 2011). Optimum moisture at podding is known to increase the transfer of assimilates to reproductive organs, thereby reducing flower and pod abortion and increasing yield (Leport *et al.*, 1999, 2006). In the present study, on a coarse-textured soil, one or two irrigations at different stages improved chickpea grain yield substantially (Figure 2) in both the years of study primarily due to an increase in the number of pods plant⁻¹ (Figure 3), as shown previously (Ahlawat *et al.*, 2005; Shamsi *et al.*, 2010). This is in line with Turner *et al.* (2006) who reported that water shortage, as the plant enters its reproductive phase, induces the end of reproductive development and ultimately yield is reduced. Irrigation during pod development delays the cessation of flowering and pod development leading to an increase in the number of pods per plant and yield (Leport *et al.*, 1998, 1999, 2006).

The study has also highlighted the large differences in yield from year to year at the same site with and without irrigation. We suggest that this was largely the result

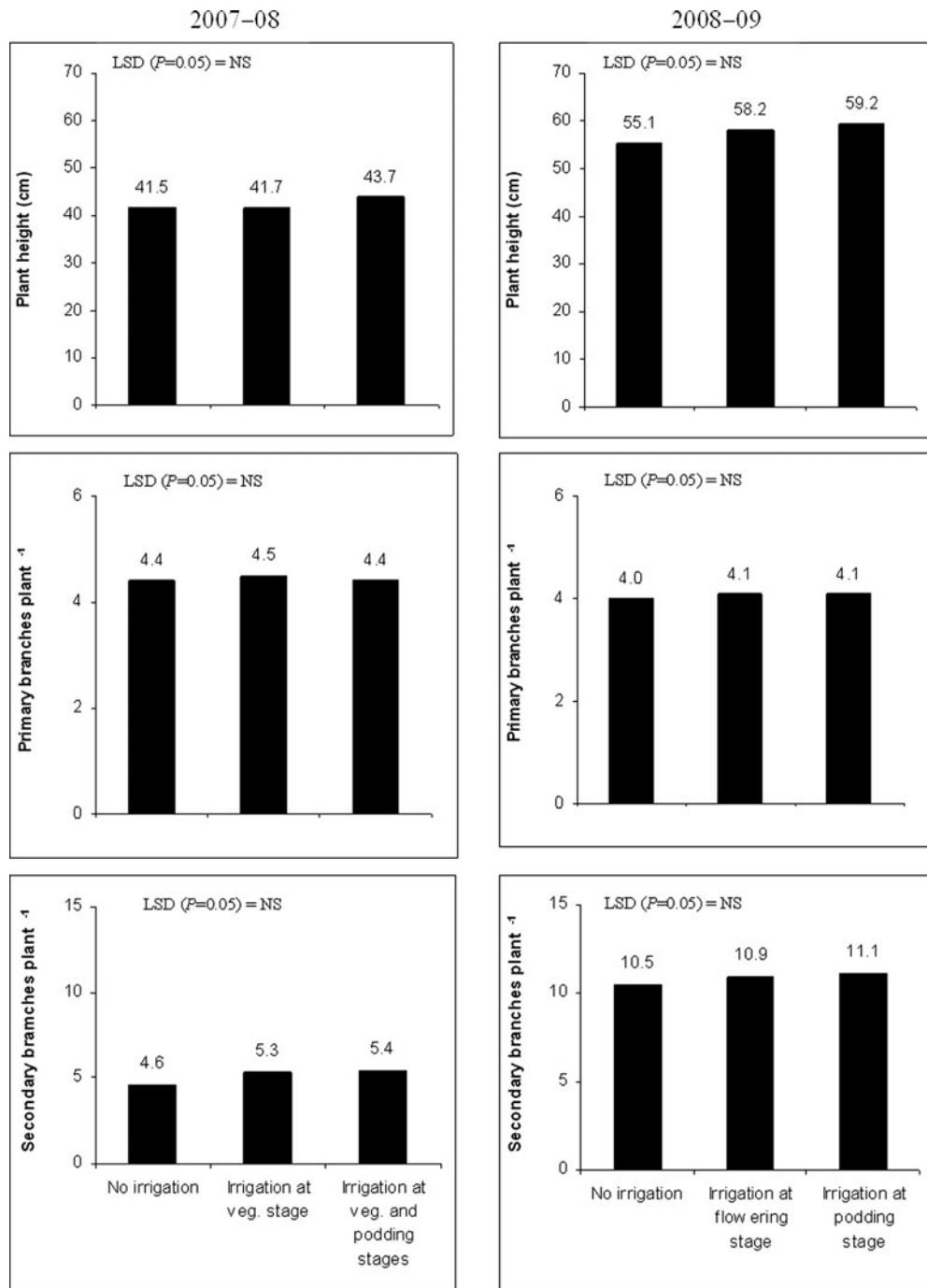


Figure 3. Effect of three irrigation treatments on plant height, the number of primary branches and secondary branches in chickpea in the growing seasons of 2007–08 and 2008–09. The mean values for each treatment ($n = 3$) are given along with the least significant difference ($P = 0.05$) where statistically significant.

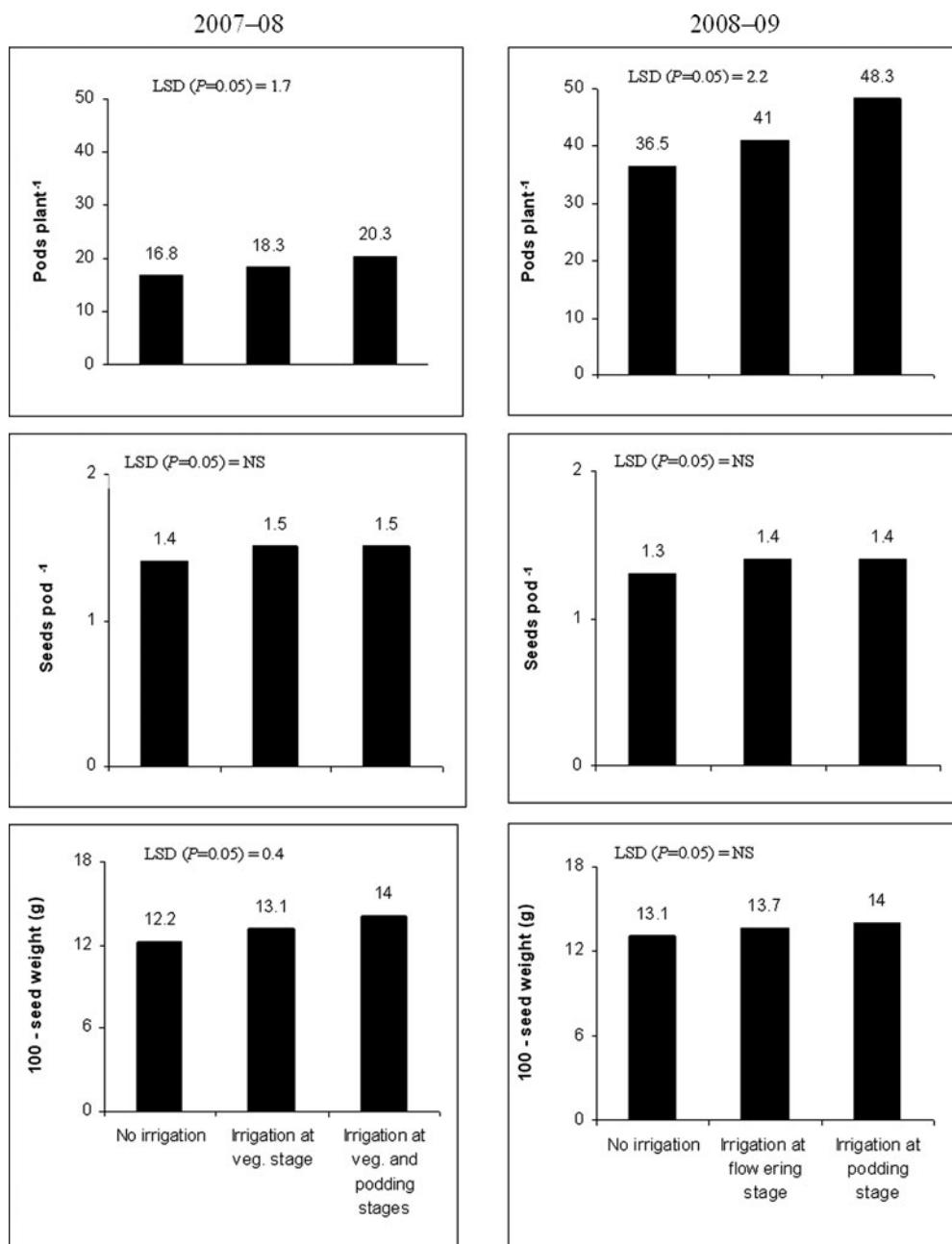


Figure 4. Effect of three irrigation treatments on the number of pods per plant, the number of seeds per pod and the 100-seed weight of chickpeas in the growing seasons of 2007–08 and 2008–09. The mean values for each treatment ($n = 3$) are given along with the least significant difference ($\alpha = 0.05$) where statistically significant.

Table 2. Effect of irrigation scheduling on grain and biomass water productivity (WP_I and WP_{I+R}) in chickpea.

Year	Treatment	Grain yield (kg ha ⁻¹)	Biomass yield (kg ha ⁻¹)	Irrigation water (mm)	Rainfall (mm)	Grain WP _I (kg m ⁻³)	Biomass WP _I (kg m ⁻³)	Grain WP _{I+R} (kg m ⁻³)	Biomass WP _{I+R} (kg m ⁻³)
2007–08	No irrigation	932	2003	0	88.7	—	—	1.05	2.26
	Irrigation at vegetative stage	1483	2716	75	88.7	1.98	3.62	0.91	1.66
	Irrigations at vegetative + podding stages	1613	3429	150	88.7	1.08	2.29	0.68	1.44
2008–09	No irrigation	2060	4393	0	81.2	—	—	2.54	5.41
	Irrigation at flowering stage	2202	5101	75	81.2	2.94	6.80	1.41	3.27
	Irrigation at podding stage	2626	5858	75	81.2	3.50	7.81	1.68	3.75

of the reduction in the number of frosts and warmer temperatures in 2008–09 than 2007–08. Cool temperatures below 12 °C are known to increase flower abortion and decrease yields (Crosier *et al.*, 2003). The single irrigation in 2007–08 was applied when the cool temperatures and frosts were likely affecting flower and pod abortion (Crosier *et al.*, 2003) and suggest that the irrigation may have alleviated the effects of the cool temperatures and frosts by the release of latent heat (Mavi, 1996).

Water productivity

In the favourable growing season of 2008–09, grain and biomass water productivity (WP_I as well as WP_{I+R}) was higher in all treatments than in 2007–08, indicating that the cool temperatures in the vegetative phase in 2007–08 had a much greater effect on yields and that irrigation could not completely alleviate the poor growing conditions. Chickpea genotypes may vary in water use (Zaman-Allah *et al.*, 2011a, 2011b) and, therefore, screening the genotypes for potential utilization under limited moisture conditions may help in improving chickpea yields (Yadav *et al.*, 2006). However, this study has highlighted that other factors, such as cool temperatures, can markedly affect the water productivity and that these and other factors (Gan *et al.*, 2010; Pramanik *et al.*, 2009) may override any cultivar differences.

There are challenges of considering water productivity as a sole indicator, as no-irrigation treatments (with low yield) exhibited higher WP while high yielding treatments showed lower WP. Thus WP should be interpreted carefully, considering other yield parameters. Further, linear yield increase does not necessarily mean higher WP.

Crop diversification with chickpea and optimum irrigation scheduling – a necessity for sustainable agriculture

In northern Indian states such as Punjab, Haryana and Uttar Pradesh, and in parts of northern China, the ground water level is decreasing at an alarming rate (Deng *et al.*, 2006; Hira, 2009). To sustain agriculture in these regions, irrigation water needs to be used judiciously. Chickpea requires little irrigation compared to other crops grown during the same season such as wheat and winter maize (*Zea mays*). For example, chickpea requires only one irrigation, whereas wheat and winter maize require four and six irrigations, respectively (PAU, 2011), though the number of irrigations may vary with rainfall. In the present study, one irrigation applied at podding increased grain yield by 27% in 2008–09 and the additional irrigation at podding increased grain yield by 9% in 2007–08. Thus, one irrigation during podding can increase chickpea grain yields substantially, with consequently higher net returns. Surprisingly in 2007–08, a single irrigation in the late vegetative phase increased yields by 59%, but this appears to be a result of the cool temperatures during early flowering increasing flower abortion and irrigation helping to counteract this increase in abortion. Thus the timing of the single irrigation may depend on the weather conditions at the site and in the particular season. Diversifying the cropping system with chickpea – a lesser water requiring crop – and timely irrigation during podding (or the early flowering

if temperatures are low and frosts frequent) can help save underground water for the long-term sustainability of agriculture.

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