Water extraction patterns and water use efficiency of chickpea (*Cicer arietinum* L.) cultivars in Canterbury

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Abstract

The response of two Canadian Kabuli chickpea (*Cicer arietinum* L.) cultivars to four different irrigation treatments was studied on a Wakanui silt loam soil in Canterbury, during 1999/2000. This study aimed to quantify yield potential under irrigation at different crop growth stages. Irrigation applied during or post flowering gave significant seed yield increases and there were indications of greater water use efficiency. In both cultivars, full irrigation (105 and 109 mm) increased seed yield (> 4 t/ha) by 76 – 124 % over the unirrigated chickpeas. Soil water depletion was generally confined to a soil depth of 80 cm. While this indicated the effective rooting depth, most of the water used came from the top 0 – 30 cm of the soil profile. Evapotranspiration (i.e., crop water use) was measured using a neutron moisture meter and water use efficiency (WUE) was examined at crop maturity for all treatments. The pattern of water use is an important parameter determining seed yield in chickpea and there was a significant correlation ($p < 0.001$) between water use and seed yield ($r^2 = 0.73$). There were also highly significant ($p < 0.001$) interactive effects of irrigation, sowing date and cultivar on WUE and the trend was similar to that for seed yield. The estimated WUE ranged from 5.8 to 11.7 kg of seed/ha per mm of water used.

***Additional key words*:** Cicer arietinum, *chickpea, Canterbury, water use efficiency, Kabuli*

Introduction

Indeterminate chickpea (*Cicer arietinum* L.) is an ancient pulse crop that is an important source of food, feed, fodder, breaks in disease/pest cycles and soil N (Singh, 1997; Felton *et al.*, 1998). Variable seed yields are a deterrent to growing chickpea as, in major chickpea growing countries, they are mostly grown on residual soil moisture and often experience water stress during their growth (Thomas and Fukai, 1995; Singh *et al.*, 1997; Siddique and Sykes, 1997). The world average yield of 709 kg/ha (FAO, 1997) results in a shortfall of production to demand and in these situations production can be maximised by using available soil moisture with maximum efficiency.

Generally grain legume crops can extract water from the top 0 - 90 cm of soil. However, most of the water used by a crop comes from the top 0 - 30 cm of the soil profile (Silim *et al.*, 1993; Parihar, 1996). Studies on chickpea water use are location specific and a crop uses between 100 and 450 mm of water to produce grain yields of between 900 and 3,000 kg/ha (Brown *et al.*, 1989; Dalal *et al.*, 1997; Jadhav *et al.*, 1997; Prasad *et al.*, 1999). Within this range there is a close, linear correlation ($r = 0.85$) between the amount of water used and seed yield (Singh and Bhushan, 1979-80). Reported water use efficiencies range from 1.1 to 15.7 kg of seed per ha/mm of water (Horn *et al.*, 1996; Dalal *et al.*, 1997; Prasad *et al.*, 1999). Chickpea seed yield is a product of T x WUE, where T is the amount of water transpired and WUE is the water use efficiency, defined as the quantity of seed produced per unit of water transpired (Dalal *et al.*, 1997; Soltani *et al.*, 1999).

The Canterbury region of New Zealand has a high potential for chickpea production (McKenzie and Hill, 1995; Verghis *et al.*, 1999). Most previous studies of chickpea water use have been undertaken in the Equatorial tropics and the Mediterranean semi-arid regions (Brown *et al.*, 1989; Dalal *et al.*, 1997; Jadhav *et al.*, 1997; Prasad *et al.*, 1999) and this is the first major study conducted in Canterbury (sub-humid temperate environment). The present investigation was therefore carried out to test the effects of different irrigation treatments and sowing date on: 1) The seed yield of two

Canadian Kabuli chickpea cultivars; 2) The water extraction pattern in relation to irrigation/rainfall and 3) Water use efficiency.

Materials and Methods

Experimental site and treatments

The experiment was located at the Henley Research farm of Lincoln University, Canterbury (Lat. 43° 38' S, Long. 172° 30' E) on a Wakanui silt loam soil (Hewitt, 1992). The site was previously in perennial ryegrass (*Lolium perenne*). The soil had an available moisture storage capacity of about 300 mm per 100 cm of soil depth. The Ministry of Agriculture and Forestry (MAF) soil test for 0 – 30 cm soil depth (Table 1) showed moderately high fertility.

The experimental layout was a split-split plot randomised complete block design with four irrigation levels as main plots (Table 2). Sub-plots consisted of two sowing dates (18 October and 22 November 1999). Two high yielding, early flowering and *Aschochyta* blight resistant Canadian Kabuli chickpea cultivars (cv. Sanford and cv. B-90) as sub-sub plots were randomly assigned within each sub-plot. Each sub-plot was 10 m long with 14 rows, which were 15 cm apart. There were three replicates giving a total of 48 plots.

Irrigation strategy

Chickpea is reputed to be most responsive to irrigation at flowering and pod filling (Saxena, 1987). Therefore, in this study the irrigation treatments were selected to provide a wide range of potential soil moisture deficits during the vegetative, flowering, and pod filling to physiological maturity phases of plant development (Table 2). To accurately apply irrigation water to the experimental plots at different crop growth stages a T-tape irrigation system was used. The T-tape was placed in every second row (45 cm spacing). The amount of water applied was measured with a flow meter (Neptune, type Sz, size 25.4 mm). Irrigation was applied weekly to replace the previous week's water loss according to a soil moisture water balance. During the period for which any treatment was being irrigated it received an amount of water (A) equal to the difference between estimated potential evapotranspiration and rainfall (R) plus irrigation (I) in the previous week, i.e.,

$$A = \sum Ep - (I + R),$$

where Ep is the rate of potential evapotranspiration (mm/day) and was calculated from meteorological data using Penman's method (Penman, 1970).

Husbandry

The seedbed was prepared using standard farm practice. Weed control was achieved with two applications of cyanazine at 1.7 kg a.i./ha applied both pre-sowing (seven days before) and pre-emergence (seven days after). All post-emergence weeding was by hand. The seed was treated with a systemic fungicide Apron C 70 SD (a.i. metalaxyl 350 g/kg and captan 350 g/kg) at the rate of 200 g (dissolved in 500 ml of water) per 100

Table 1. MAF soil quick test for 0 - 30 cm soil depth at Henley Research Field, Lincoln University, Canterbury, October 1999.

pH	Ca*	K	P	Mg	Na	S	TN
5.8	10	8	13	30	8	9	0.27

*Ca, K, P, Mg, Na and S expressed as micrograms/gram soil and total nitrogen (TN) as a percentage.

Table 2. Experimental irrigation treatments.

	Sowing date	
Irrigation treatments[1]	18 October 1999	22 November 1999
1 Nil	No irrigation	No irrigation
2 Full[2] (emergence to maturity)	105 mm	109 mm
3 Full (flower to pod)	61 mm	58 mm
4 Full (pod to maturity)	51 mm	58 mm

[1] Applied via a T-tape irrigation system.
[2] Full irrigation was applied to replace water lost through evapotranspiration.

kg seed. Seed, which had a germination of ≥90 %, was sown with a tractor driven cone seeder to give a population of approximately 50 plants/m^2.

Water use

Volumetric soil moisture content was measured weekly using the Time Domain Reflectometry (TDR) Trase system 1 Model 6050X1 for the top 0 - 30 cm of the soil profile. Moisture in the rest of the soil profile was measured with a neutron probe (NMM) model 3300 at 10 cm intervals in a 110 cm access tube centred in each plot. Water use (Wu) was assumed to be equivalent to the evapotranspiration (Et) between sowing and physiological maturity which was calculated using the soil water balance approach, i.e.,

$$Et = (P + I) - \Delta SWC - Ro - D,$$

where Et = evapotranspiration, P = rainfall (mm), I = irrigation (mm), –SWC = change in soil water content from time 1 to time 2 at 0 - 110 cm depth, Ro = runoff (mm), D = drainage (mm).

In this experiment Ro was assumed to be zero, as the experimental site was level, and irrigation was applied (T-tape) at a rate which was well below the infiltration capacity of the soil. Drainage was also assumed to be zero below 110 cm soil depth, as the volumetric water content of the soil did not exceed field capacity at any time.

Water-use efficiency [kg of seed/ha per mm of water use (Et)] of chickpea was calculated as the final seed yield of the treatment divided by the total quantity of water used over that period.

Water extraction patterns

Effective rooting depth (ERD) was derived from the neutron probe data. On a given date, ERD was defined as the depth at which soil water content was not significantly different from the measurement made on the previous date, during a period of transpiration and in the absence of water supply (Silim and Saxena, 1993). Total soil water content was calculated by summing the water content of each layer of the soil profile. The top soil layer was 30 cm while all other layers were 10 cm thick. Water extraction patterns of all treatments were checked to assess the maximum depth from which water was extracted. Cumulative water use per soil layer was calculated by partitioning the drainage to the next soil layer. Regressions of the cumulative water use over time for each soil layer were taken. The mean slopes of the regressions of each treatment (equivalent to water use per day) were then analysed by ANOVA, and the LSD at the 5 % level of significance was calculated for each slice down to 110 cm.

Sampling

Final seed yield was measured from a 2.0 m^2 harvest area taken from the central four rows of each sub-plot when the crop reached physiological maturity (i.e., when 50 % of plants had one brown pod). Samples were air dried to about 13 % seed moisture or when seeds did not bend when bitten. Dried samples were machine threshed (using a Kurtpelz stationary thresher) and the straw and seed separated. The seeds were then passed through a sieve to eliminate all seed of less than 2 mm in diameter.

Water use, production and water-use efficiency were analysed using ANOVA (Genstat 5 Committee of the Statistics Department, Rothamsted Experimental Station, Hertfordshire, UK) and the LSD ($P = 0.05$) was calculated to show differences between means. Standard errors of the mean (SEM), coefficient of variation (CV as a %) and correlation coefficient (r^2) were also calculated.

Results

Climate

All climate data were from the Broadfield Meteorological station, Lincoln University, situated about 1.0 km from the experimental site. The maximum and minimum temperatures were similar to the long-term averages (Fig. 1). However, the mean monthly maximum temperatures during December and January were 18.9 and 19.5 °C respectively compared to the 55-year mean values of 21.3 and 22.6 °C. Total rainfall from October 1999 to April 2000 was 353 mm, about 90 % of the long-term average of 385 mm. Overall, rainfall during the growing season (sowing to physiological maturity) was approximately 260 mm. Solar radiation from December to March was about 10 % higher than the long term mean. In January the Penman evapotranspiration (EPT) was about 25 % lower than normal.

Seed yield

Seed yield ranged from 2.5 to 5.1 t/ha. Seed yield was not affected by sowing date, but cv. Sanford outyielded cv. B-90 by an average 5 %. Irrigation increased seed yield and there was a significant ($p < 0.01$) three-way interaction between irrigation, sowing date and cultivar (Fig. 2a). Full irrigation nearly always gave the highest yield (Fig. 2a), but the size of the effect depended upon sowing date and cultivar. Generally cv. Sanford responded more to irrigation than cv. B-90. However, in the unirrigated plots cv. B-90 (2.7 t/ha) outyielded cv. Sanford (1.8 t/ha) in the October sowing while in the November sowing, cv. Sanford (3.1 t/ha) outyielded cv. B-90 (2.3 t/ha).

Full irrigation from emergence to maturity and flowering to pod initiation gave significantly higher seed yields than nil and late irrigation at podset to maturity (p - m) (Table 3). There was a significant seed yield difference among irrigation treatments ($p < 0.001$) and between cultivars ($p < 0.05$). Full irrigation (105 mm) from emergence to flowering gave the highest seed yield of 4.9 t/ha compared with no irrigation (2.4 t/ha) or late irrigation (3.6 t/ha).

Water use and water-use efficiency

Total crop water use varied from 342 mm to 466 mm, and was significantly affected by both irrigation and sowing date ($p < 0.001$, Table 3). The evapotranspiration from emergence to maturity was significantly higher (17 – 36 %, $p < 0.001$) for the fully irrigated treatments than in the nil and late irrigated crops. October sown chickpea used 420 mm of water, which was only 9 % more than the November sown crop.

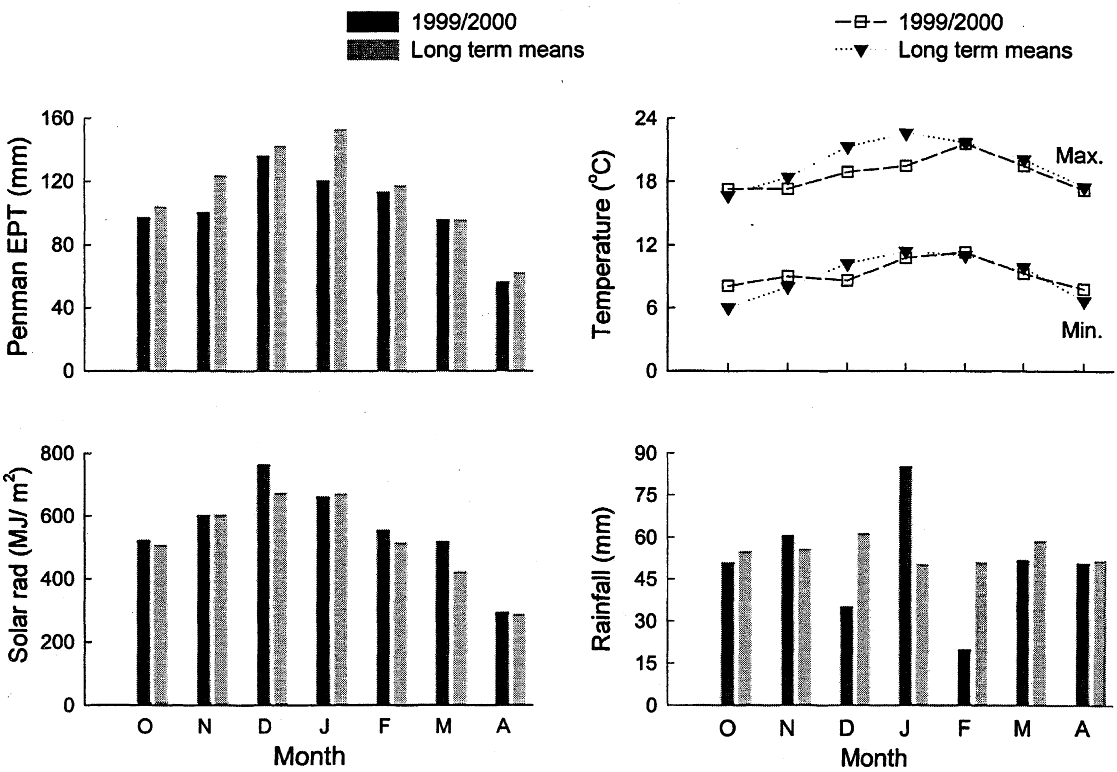

Figure 1. Weather data during the 1999/2000 growing season and long term means for Lincoln University, Canterbury. Long term means for rainfall and temperature (1944-99) and solar radiation and penman potential evapotranspiration (ETP)(1975-99).

There was also a sowing date by cultivar interaction ($p < 0.01$) for pre- and post-anthesis water use (Table 4) and a significant irrigation by sowing date interaction for post-anthesis water use (Fig. 3). Irrigated crops (full irrigation from emergence to maturity [Full(e - m)] sown in October generally used more water (295 mm) post-anthesis than the same crops sown in November (258 mm). For all treatments both October and November sown chickpea showed a highly significant linear relationship between seed yield and total water use ($r^2 = 0.73$; $p < 0.001$) (Fig. 4).

The mean water-use efficiency (WUE) for all treatments was 9.9 kg seed/ha per mm of water use (Table 3). There was a highly significant ($p < 0.001$) interaction among irrigation, sowing date and cultivar for WUE and the trend was similar to that for seed yield (Fig. 2b). At both sowing dates, both cultivars made more efficient use of the supplied water [Full(e - m) and rainfall] in the production of grain, reflecting greater WUE. The relationship between WUE and irrigation supply (Fig. 2b) showed that per unit of water supplied, WUE was similar in both cultivars, though the rate was greater in cv. Sanford than in cv. B-90. From fully irrigated [Full(e - m)] plots cv. Sanford had the greatest WUE (11.7 kg of seed/ha per mm of water use) and least in the nil irrigated plots (5.8 kg of seed/ha per mm of water use). However, in the November sowing cv. Sanford had a higher WUE in the nil irrigated plots than cv. B-90.

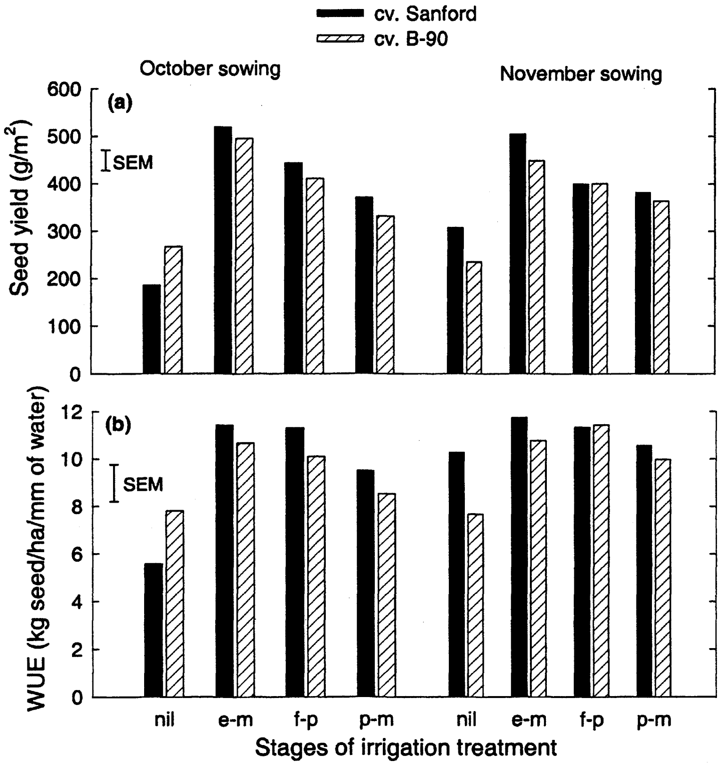

Figure 2. The three way interaction of irrigation, sowing date and cultivar for (a) seed yield and (b) water use efficiency of Kabuli chickpeas in Canterbury, 1999/2000. Nil: no irrigation, e-m: emergence to maturity, f-p: flower to pod and p-m: pod to maturity.

Water extraction and daily water use

Figure 5 shows the water extraction patterns during the period from emergence to harvest maturity. In both the October and November sowing the initial water content (MAX) was about 29 and 24 mm respectively, per 10 cm soil slice to 30 cm soil depth. It was then about 32 to 35 mm per 10 cm slice down to a depth of 110 cm. The final water contents were highly variable among treatments and at different depths. In the October sowing the minimum or final soil water content (MIN) in the top 0 - 30 cm of the soil profile was 7 mm per 10 cm slice down to 30 cm soil depth at 90 % physiological

Table 3. The effectof irrigation, sowing date and cultivar on seed yield (SY), water use (Wu) and water-use efficiency (WUE) of Kabuli chickpeas in Canterbury, 1999/2000.

Factors	Pre–anthesis Wu (mm)	Post–anthesis Wu (mm)	Total Wu (mm)	SY (g/m^2)	WUE (kg/ha/mm of water)
Irrigation (IR)[A]					
Nil	137	206	342	249.0	7.8
Full (e-m)	190	277	466	492.0	11.2
Full (f-p)	144	256	400	413.7	11.0
Full (p-m)	138	263	400	361.8	9.6
Mean	152	250	402	379.1	9.9
SEM	6.3	4.51	4.2	7.11	0.20
Significance	p<0.01	p<0.001	p<0.001	p<0.001	p<0.001
Sowing date(SD)					
18 October	166	254	420	378.1	9.4
22 November	138	247	385	380.2	10.5
SEM	3.9	3.4	3.2	12.21	0.28
Significance	p<0.001	ns	p<0.001	ns	p<0.05
Cultivar (Cv)					
Sanford	151	250	401	389.2	10.2
B-90	154	249	403	369.1	9.6
SEM	2.5	1.7	2.2	5.46	0.15
Significance	ns	ns	ns	p<0.05	p=0.01
CV(%)	8.0	3.4	2.7	7.1	7.2
Significant interactions	SD x Cv p<0.01	IR x SD p<0.05 SD x Cv p<0.01	Nil	SD x Cv p=0.05 IR x SD x Cv p<0.01	IR x SD x Cv p<0.001

[A]Irrigation: full = full irrigation to replace that lost from evapotranspiration; e - m = emergence to maturity; f - p = flower to pod; p - m= pod to maturity, ns = non significant

Table 4. The sowing date by cultivar interaction for pre and post-anthesis water use (Wu) of Kabuli chickpeas in Canterbury, 1999/2000.

	Pre-anthesis Wu (mm)		Post-anthesis Wu (mm)	
Sowing date	Sanford	B-90	B-90	Sanford
18 Oct.	160	173	249	380
22 Nov.	142	134	250	398
SEM	4.6		3.8	
CV (%)	8.0		3.4	

maturity and 15 mm per 10 cm slice down to 70 cm. Because of rainfall in the week after 90% physiological maturity (132 days after emergence) the soil water content in the top 0 - 30 cm was 16 mm per 10 cm slice. In the November sowing MIN in the top 0 - 30 cm soil profile was 6.5 mm per 10 cm slice and soil water depletion below 30 cm depth was similar to the October sowing. Rapid depletion of soil water in the 0 - 30 cm soil profile indicated the presence of more roots [maximum effective rooting depth (Max_{roots})]. The inroads into soil water reserve and the generally even depletion down to 80 cm suggested the estimated effective rooting depth (ERD).

The daily water use of chickpea crops at different soil depths (Fig. 6) indicated that there were significant differences between the rate of water use down to 40 cm soil depth. From the fully irrigated (105 mm) plots, the October sown chickpea used 0.88 mm of water per day in the 0 - 30 cm of the soil profile. The water use then declined to 0.66 mm of water per day in the nil irrigation plots. Daily water use declined from 0.82 mm of water per day in the November sown fully irrigated (109 mm) chickpeas to 0.53 mm of water per day in the no irrigation treatment. At 40 cm depth, the October sown chickpea irrigated at flower to podset (61 mm) had the highest rate of water extraction at 0.27 mm of water per day. Below 80 cm soil depth there was little water use in any of the treatments.

Discussion

Seed yield

In Canterbury, where the rainfall during the growing season was approximately 260 mm, Kabuli chickpea seed yield was affected by the interaction of irrigation, sowing date and cultivar. Under full irrigation (105 and 109 mm) seed yield of both cultivars and from both sowing dates, ranged from 4.4 to 5.1 t/ha. This nearly doubled seed yield relative to the non-irrigated control. This result supports the recent finding of Malhotra *et al.* (1997) that in Syria irrigation increased chickpea seed yield by 44 %. The indeterminate growth habit of the chickpea took full advantage of favourable soil moisture conditions through prolonged flowering and podding,

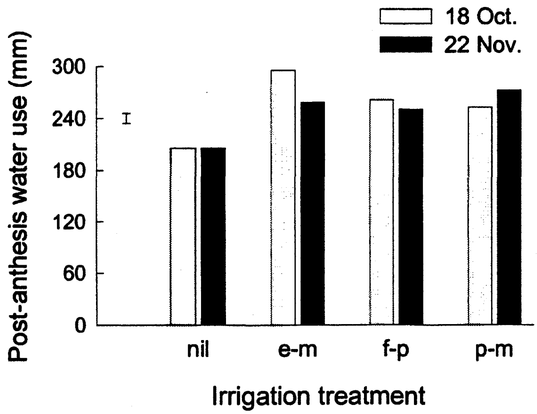

Figure 3. The irrigation by sowing date interaction for post-anthesis water use of Kabuli chickpeas in Canterbury, 1999/2000. Nil: no irrigation, e-m: emergence to maturity, f-p: flower to pod and p-m: pod to maturity.

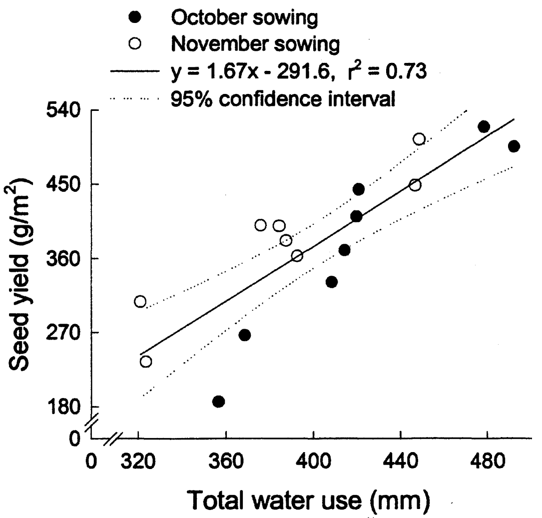

Figure 4. The relationship between seed yield and water use of Kabuli chickpeas in Canterbury, 1999/2000. Y = seed yield (g/m^2) and X = total evapotranspiration (mm) ($r^2 = 0.73$, $p < 0.001$).

which eventually increased seed yield. Provision of irrigation at any growth stage increased yield (Table 3), but the highest yields for both cultivars and sowing date were achieved when drought stress was eliminated by irrigating throughout the growing season (Fig. 2). These yields were significantly ($p < 0.01$) higher than those achieved in the other irrigation treatments. In the October sowing cv. Sanford was more susceptible than cv. B-90 to drought, producing an unirrigated yield of only 1.9 t/ha.

The more than 100 % increase in Kabuli chickpea seed yield, which resulted from full irrigation (emergence to maturity), is similar to the response to irrigation in Canterbury for other grain legumes (White *et al.,* 1982; Husain *et al.*, 1990; Dapaah *et al.*, 2000). Overseas, there are many reports of chickpea yield as a function of sowing date and cultivar. Irrigation has consistently been shown to increase seed yield (Saxena *et al.*, 1990; Singh and Virmani, 1996; Horn *et al.*, 1996; Malhotra *et al.*, 1997; Prasad *et al.*, 1999).

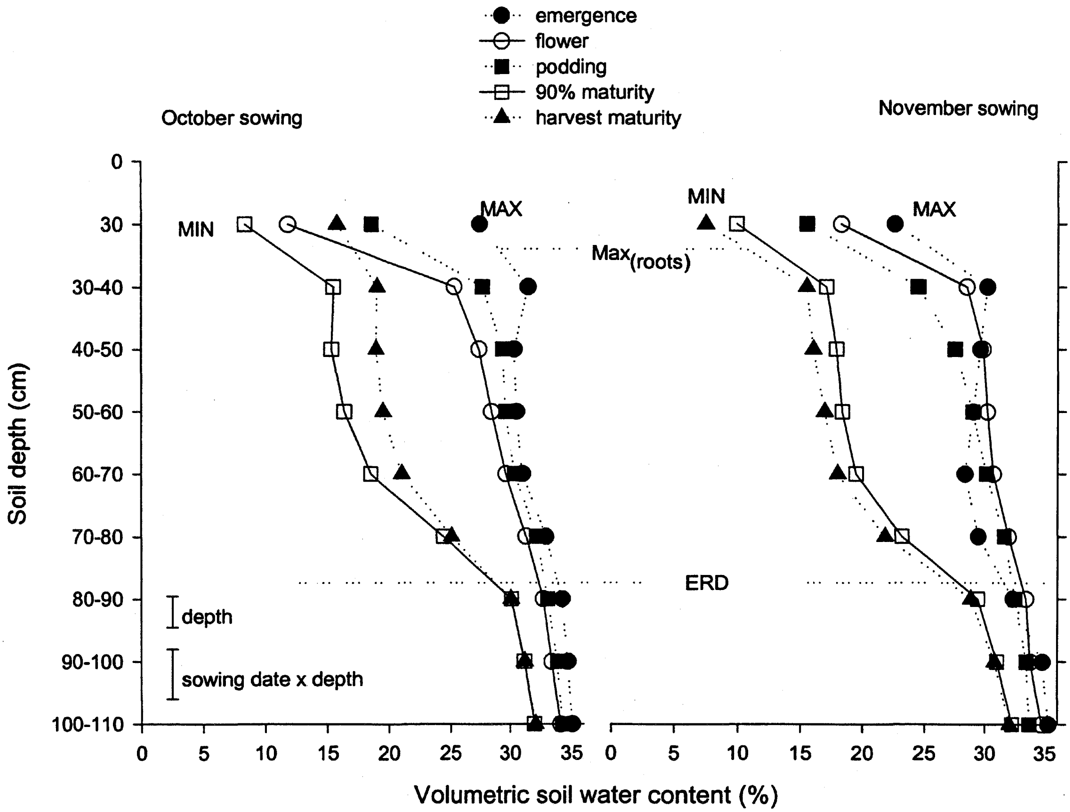

Figure 5. Variation with depth of volumetric soil water content under Kabuli Chickpeas in Canterbury, 1999/2000. Horizontal dotted lines show the estimated effective rooting depth (ERD) and maximal ERD value (MAX[roots]), MIN: minimal soil water content measured at each depth in the week before harvest, MAX: maximum soil water content near field capacity (day of emergence). Each data point is the mean of three replicates. Bars indicate LSD. (p <0.05).

Further, Kabuli chickpea seed yield was also related to water use in a similar way to that for lentils in Canterbury (McKenzie and Hill, 1990). Chickpea seed yield potential depends on inherent plant characters such as reproductive characteristics, biomass production and partitioning. The realisation of that potential depends on the interaction of these characters with environmental factors such as water supply (Singh, 1991; Singh and Virmani, 1996). The results of this experiment suggest that in Canterbury, the seed yield of Kabuli chickpea can be increased by irrigating at any stage of crop development, provided that the water is needed as determined by the potential soil moisture deficit.

Water use

There was a highly significant interaction ($p < 0.001$) between moisture supply, date of sowing and cultivars for water use efficiency (Table 3 and Fig. 2) but no

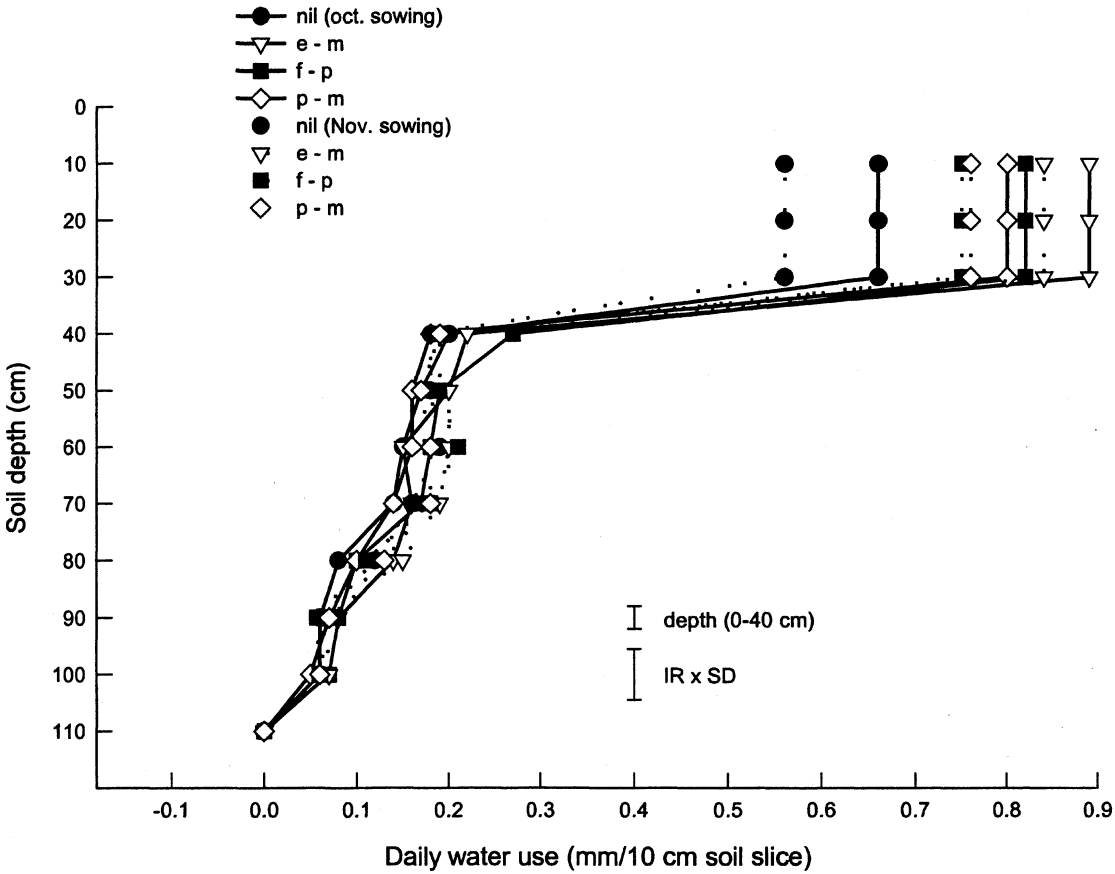

Figure 6. Daily water use at each depth of Kabuli chickpea under four irrigation treatments (nil: no irrigation, e-m: emergence to maturity, f-p: flower to pod and p-m: pod to maturity) in Canterbury, 1999/2000. Solid lines are for October sowing and dotted lines for November. Bars indicate LSD ($p < 0.05$) for main effect of irrigation (IR) and sowing date (SD).

significant interaction effects for total water use. Pre-, post-anthesis and total water use depended on the irrigation regime. In both sowings, under full irrigation [emergence to physiological maturity, (Full(e-m)], water use was 466 mm, slightly higher than the 426 mm used by fully irrigated chickpea in the previous season (Anwar *et al.*, 1999). In Canterbury a fully irrigated lentil crop used 332 mm (McKenzie and Hill, 1990). In India, Prasad *et al.* (1999) also made similar observations in chickpea. Irrigation increased soil moisture content, which in turn probably improved the leaf water potential, stomatal opening and leaf area index and these components caused higher transpiration. Similar results have been reported by Rajagopal *et al.* (1989) and Nandan and Prasad (1998). A strong relationship between seed yield and total water use was observed in this study ($r^2 = 0.73$, $p < 0.001$), demonstrating large seed yields are produced when more water is used after flowering begins.

The estimates of water use efficiency (WUE) for Kabuli chickpea in this study (5.6 to 11.7 kg of seed/ha per mm of water use) were comparable to those reported for chickpeas grown overseas (Herridge *et al.*, 1995; Dalal *et al.*, 1997; Prasad *et al.*, 1999). In general, WUE was higher in cv. Sanford than cv. B-90 due to the higher seed yield, but full irrigation [Full(e-m)] increased WUE in both cultivars and for both sowing dates (Fig. 2). Similar observations were also reported by Rao *et al.* (2000) in cluster bean (*Cyamopsis tetragonoloba*) and in field beans (*Vicia baba*) by Knott (1999). There was a significant linear relationship ($r^2 = 0.74$, $p < 0.01$) between total rainfall (received before and during the crop season) and grain WUE in chickpeas grown in Australia (Dalal *et al.*, 1997). Seed yield is also associated with seed water use efficiency (Dahan and Shibles, 1995). Thus, under favourable soil moisture and environmental conditions during the growing season in Canterbury, these Canadian Kabuli chickpeas used more water after flowering commenced and partitioned more dry matter into seeds.

Water extraction patterns

The differences in the pattern of variation in the volumetric soil water content with time depended on rainfall and irrigation. In general, the surface horizons lost water more or less exponentially and the slope become more gradual with depth (Fig. 5). At some depths the initial gradual loss of water at a particular time (date) was followed by an accelerated rate of water loss. Dardanelli *et al.* (1997) has suggested that the depth of soil to which accelerated rate of soil drying was observed can be considered as the "effective rooting depth". This study has enabled the definition of the effective rooting depth (ERD) for Kabuli chickpea in Canterbury, which was approximately 0 – 80 cm, as soil water depletion was generally confined to the top 80 cm of soil. The pattern of water extraction was similar to that observed by Thomas and Fukai (1995) in Australia. Due to favourable rainfall (Fig. 1) and irrigation during the growing season there was a higher root proliferation, mostly in the upper layer (0 – 30 cm). Thus, more water was used by the plants from the upper layer indicating that a majority of the roots were in this soil layer (Max_{roots}) (Fig. 5). The daily water use of the two cultivars ranged from 0.55 to 0.88 mm/10 cm soil layer per day from 0 – 30 cm in the soil profile (Fig. 6). This result corroborates the findings of Nagarajrao *et al.* (1980), Nayar and Singh (1985), Brown *et al.* (1989) and Parihar (1996).

Conclusions

Kabuli chickpea cultivars have the potential to produce seed yields of more than 4 t/ha and irrigation (105 and 109 mm) increased the seed yield by 2.4 t/ha (98 %) over no irrigation. There was a highly significant linear relationship between water use and seed yield ($r^2 = 0.73$, $p < 0.001$). The irrigation, sowing date and cultivar interaction had a significant effect on water use efficiency, which ranged from 5.6 to 11.7 kg of seed/ha per mm of water use. There were indications of greater efficiency of water use from irrigation.

This study has shown that in Canterbury these Canadian Kabuli chickpea cultivars are capable of drawing water from depths greater than 60 cm. However, most of the water use (0.55 to 0.88 mm/10 cm layer of soil per day) came from the top 0 – 30 cm, where most of the active roots were concentrated (maximum effective rooting depth).

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