Water use efficiency of chickpea (*Cicer arietinum* L.) cultivars in Canterbury: effect of irrigation and sowing date

M.R. Anwar, B.A. McKenzie and G.D. Hill

Plant Sciences Group, Soil, Plant & Ecological Sciences Division, PO Box 84, Lincoln University, Canterbury

Abstract

The relationship between chickpea (*Cicer arietinum* L.) yield and water use was investigated on a Wakanui silt loam soil in Canterbury, New Zealand. Eight irrigation treatments were applied to three Canadian Kabuli chickpea cultivars sown in November and December 1998. Irrigation of 197 mm from emergence to flowering gave a higher seed yield (4.9 t/ha) than no irrigation (2.8 t/ha). Chickpea water use was 426 mm in the fully irrigated treatment but only 175 mm in non-irrigated plants. In November but not December sown chickpeas, there was a significant positive relationship between water use, total dry matter (TDM) production and seed yield. TDM and seed yield showed a linear reduction to maximum potential soil moisture deficit (D_{max}). The critical maximum potential soil moisture deficit (cD_{max}) for this type of soil was approximately 150 and 90 mm for the November and December sowings respectively.

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

Introduction

Crops like chickpea (*Cicer arietinum* L.), cowpea (*Vigna unguiculata* L.), grasspea (*Lathyrus sativus* L.), lentil (*Lens culinaris* Medik.), black gram (*Vigna mungo* L.) and mung bean (*Vigna radiata* L.) are important food grain legumes in South and Southeast Asia, the Mediterranean, semi-arid and savanna regions. They are mostly grown on residual soil moisture and often experience water stress during their growth (Lawn and Ahn, 1985; Smithson *et al.*, 1985; Steele *et al.*, 1985; Thomas and Fukai, 1995; Kharag *et al.*, 1997; Siddique and Sykes, 1997). In these situations production can be maximized by using available soil water with maximum efficiency.

In New Zealand, the Canterbury region exhibits a high potential for chickpea production. McKenzie and Hill (1995) and Verghis (1996) have shown that under experimental conditions chickpeas can yield 4.3 t/ha of seed. Chickpea has not traditionally been cultivated in New Zealand and the entire local demand is met by imports (NZHSC, 1988). However, some Canterbury farmers (McFarlane, A.; Sellwood, A.G.; Clarke, P. pers. comm.) are willing to cultivate chickpeas on a commercial basis provided production technology is available.

To achieve maximum growth and yield in chickpea requires an understanding of the detailed pattern of water use in relation to crop phenology and assimilate partitioning into the seeds. However, the amount of water needed for maximum chickpea yield in Canterbury, where annual precipitation averages only 600 mm, is not known. Studies on chickpea water use are location specific and rare (Nagarajrao *et al.*, 1980). From the limited available information chickpea uses 100 - 450 mm of water to produce seed yields of between 900-3000 kg/ha. Reported water-use efficiencies range from 5.2 to 35.2 kg/ha/mm for dry matter (DM) yield, and from 1.1 to 15.7 kg/ha/mm for seed yield (Keatinge and Cooper, 1984; Siddique and Sedgeley, 1986; Horn *et al.*, 1996; Dalal *et al.*, 1997).

In New Zealand there has been no quantitative research on chickpea water use-efficiency. The maximum potential soil moisture deficit (D_{max}) during the growing season has been correlated with yield in several other legumes in Canterbury (Husain, 1984 for field bean; Jamieson *et al.*, 1984 for pea; McKenzie, 1987 for lentil). However, no information is available on the response of chickpea to water deficit in Canterbury. The objectives of this research were to :

1. determine how sowing date and irrigation can affect chickpea water use-efficiency
2. determine the effects of water deficit on chickpea growth and yield.

Materials and Methods

Site, treatments and sowing

The experiment was located at Lincoln University (Canterbury, New Zealand) (Lat. 43° 38' S, Long. 172° 30' E) on a Wakanui silt loam soil (Hewitt, 1992) of pH 6.3. Total N in the top 20 cm was 0.06% and the soil fertility was moderately high (Table 1). The total water holding capacity for the top 100 cm of the soil was about 300 mm. Total rainfall during the growing season was 177 mm and the average temperature was 15.7 °C.

The experimental layout was a split-split plot randomized complete block design with eight irrigation levels as main plots (Table 2). Sub-plots consisted of two sowing dates (3 November and 7 December 1998). Three Canadian Kabuli chickpea cultivars (Sanford, Dwelley and B-90) as sub-sub plots were randomly assigned within each sub-plot. Each sub-plot was 10 m long with 14 rows each 15 cm apart. There were two replicates giving a total of 96 plots.

Irrigation strategy

To accurately apply irrigation water to experimental plots at different stages of crop growth, T-tape irrigation was used (Table 2). 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 deficit 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).

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 at 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 kg seed. Seeds which had a germination of ≥ 90% were sown with a tractor driven cone seeder to give a population of approximately 45 plants/m^2.

Measurements and calculations

Soil moisture content was measured weekly using the Time Domain Reflectometry Trase system 1 Model 6050X1 for the top 0-30 cm. Moisture in the remaining soil depth was measured with a Troxler 4300 Neutron probe at 10 cm intervals to a depth of 80 cm in all 96 plots. 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 method,

i.e., $WU = Et = (P + I) - \Delta SWC - Ro - D$

where P = rainfall (mm), I = irrigation (mm), ΔSWC = change in soil water content from time 1 to time 2 at 0-80 cm depth, Ro = runoff (mm) and D = drainage (mm).

In the 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, as the volumetric water content of the soil did not exceed the field capacity at any time.

Water-use efficiency [WUE = kg DM/ha per mm of water (ET) and kg seed/ha per mm of water (ET)] of chickpea was calculated as the total dry matter

Table 1. Soil fertility status (0-20 cm) of Iverson Field, Lincoln University, Canterbury, determined by AgResearch Quick Tests (Cornforth and Sinclair, 1984).

pH	Ca	K	P	Mg	Na	S	BDY
6.3	10	13	18	22	8	3	0.91

Table 2. Experimental irrigation treatments (mm).

	Sowing date (1998)	
Irrigation treatments[1]	3 Nov	7 Dec
1 Nil	-	-
2 Full[2] (emergence to maturity)	231	218
3 Full (emergence to flower)	197	163
4 Half (emergence to flower)	99	82
5 Full (flower to pod)	99	68
6 Half (flower to pod)	41	43
7 Full (pod to maturity)	27	75
8 Half (pod to maturity)	14	48

[1] Applied via a T-tape irrigation system
[2] Full irrigation was applied to replace water lost through evapotranspiration and half was full x 0.5

production (TDM) and seed yield of the treatment divided by the quantity of water used over that period.

The maximum potential soil moisture deficit (D_{max}) was calculated from standard meteorological data, as described by Jamieson *et al.* (1995). This method estimates the difference between the theoretical crop demand for water (potential evapotranspiration) and the supply of water (rainfall and irrigation).

Total dry matter production and seed yield for each plot were determined from a randomly placed 2 m^2 quadrat when the crop in each plot reached physiological maturity (i.e., when 50% of plants had one brown pod). Samples were air dried to about 13% seed moisture. Dried samples were machine threshed to separate the straw and seed. The seeds were sieved to eliminate all seeds <2 mm in diameter.

Water use, production, water-use efficiency and maximum potential soil moisture deficit measurements were analyzed using ANOVA. The lsd ($P = 0.05$) was calculated to show differences between means.

All climate data were recorded at the Broadfield meteorological station, Lincoln, Canterbury, which was situated about two km from the experimental site.

Results

The 1998 - 99 (November-April) growing season at Lincoln was dry, with a total rainfall of only 177 mm; this was approximately 50% of the long term average of 329 mm. Penman evapotranspiration (PEt) was 650 mm. Overall, the mean temperature (15.7 °C) and the potential soil moisture deficit at 473 mm were close to long term averages.

Total dry matter

Full irrigation from emergence to maturity [Full (e - m)] and emergence to flowering [Full (e - f)] gave significantly higher TDM production than nil and late irrigation at podset to maturity (p - m) (Table 3). Total dry matter at harvest ranged from 532 to 1,168 kg/ha. Late irrigation at flowering to podset (f - p) and podset to maturity (p - m) had no effect on TDM production. There was no significant difference in TDM production among cultivars, but there was a significant difference between sowing dates ($p < 0.05$). The TDM yield declined from a mean of 826 kg/ha in the November sown crop to 771 kg/ha for the December sowing.

Significant irrigation level by sowing date interactions occurred for the full (e - m), full (e - f), nil and late (p - m) irrigation (Table 4); the response of TDM production to irrigation depended on sowing date. At two irrigation levels (nil and half (f - p)) November sown plants produced more TDM than the December sown plants. At the other irrigation levels there was no difference between sowing dates. The cultivar by irrigation interaction showed that at full irrigation cv. Sanford produced the highest yield (1,135 kg/ha). At all other irrigation levels there was no difference among cultivars.

Seed yield

Seed yield ranged from 2.8 to 4.9 t/ha. Irrigation increased seed yield by 74 - 90% and trends were similar to those for TDM yield. There was a significant seed yield difference between sowing dates ($p < 0.001$) and among cultivars ($p < 0.05$) (Table 3). Full irrigation (197 mm) from emergence to flowering gave the highest seed yield of 4.9 t/ha compared with no irrigation (2.8 t/ha) or late irrigation (2.6 t/ha). Seed yield was doubled in November sown chickpeas (4.6 t/ha) and cv. Sanford produced 14 and 16% more seed yield than cv. Dwelley and cv. B-90 respectively.

Significant irrigation by sowing date and sowing date by cultivar interactions indicated that the response to irrigation depended on the sowing date (Table 4, 5). Generally irrigated crops sown in November yielded over 100% more seed than the same crops sown in December. However, with late irrigation or no irrigation, the yield advantage of the early sowing was less at about 34%.

Across all irrigation treatments, seed yield from the November sowing was positively correlated with TDM production ($r^2 = 0.72$, $p < 0.01$). However, in the December sowing there was a no relationship between TDM and seed yield ($r^2 = 0.26$, $p = 0.19$).

Water use and water-use efficiency

Total crop water use varied from 175 mm to 426 mm (Table 3), and was significantly affected by both irrigation and sowing date. There was also an irrigation by sowing date interaction (Table 6). The evapotranspiration from emergence to maturity was significantly higher ($p < 0.001$) for the fully irrigated treatments and was about 90% greater than in the nil and late irrigated crops. Chickpea used only 227 and 209 mm of water respectively when irrigation was applied late (pod fill to physiological maturity). November sown chickpea used 286 mm of water, which was only 6% more than the December sown crop.

For all treatments both November and December sown chickpea showed a highly significant linear relationship between TDM production and water use (Et) with an r^2 of 0.84 and 0.92 respectively (Fig. 1). The November and December sown chickpea crop produced 23.0 and 32.7 kg DM/ha respectively for each mm of water used. In the November sowing, chickpea seed

Table 3. The effects of irrigation, sowing date and cultivar on total dry matter at final harvest (TDM), seed yield (SY), water use (Wu) and water-use efficiency of chickpeas in Canterbury, New Zealand, 1998/99.

Factors	TDM (g/m^2)	SY (g/m^2)	Water use (mm)	Water-use efficiency: Dry matter (kg/ha/mm of water)	Water-use efficiency: Seed (kg/ha/mm of water)
Irrigation (IR)*					
Nil	577	279.0	175	33.1	15.9
Full (e-m)	1130	411.0	426	26.6	9.6
Full (e-f)	1168	486.6	389	30.2	12.2
Half (e-f)	938	466.8	306	30.6	15.2
Full (f-p)	734	337.0	264	27.8	12.4
Half (f-p)	751	287.9	228	32.5	12.2
Full (p-m)	560	251.8	227	24.9	11.1
Half (p-m)	532	264.9	209	25.3	13.0
Mean	799	348.1	279	28.9	12.7
SEM	67.9	27.22	9.2	2.21	1.2
Significance	p<0.01	p<0.01	p<0.001	ns	ns
Sowing date (SD)					
November	826	463.3	286	29.5	16.5
December	771	233.0	270	28.3	9.1
SEM	14.0	15.67	4.6	0.44	0.59
Significance	p<0.05	p<0.001	p<0.05	ns	p<0.001
Cultivar (Cv)					
Sanford	827	381.6	277	29.6	14.2
Dwelley	776	334.1	278	28.4	12.3
B-90	794	328.7	279	28.6	11.8
SEM	20.7	14.43	2.1	0.85	0.53
Significance	ns	p<0.05	ns	ns	p<0.01
CV (%)	14.7	23.5	4.2	16.7	23.6
Sig. interactions	IR x SD* IR x Cv*	IR x SD* SD x Cv*	IR x SD*	IR x SD**	SD x Cv**

*Irrigation: full = full irrigation to replace that lost from evapotranspiration; half = irrigated with half the amount of full; e-m = emergence to maturity; e-f = emergence to flower; f-p= flower to pod; p-m= pod to maturity.

yield was linearly correlated with water use ($r^2 = 0.75$, $p < 0.01$) but seed yield from December sown chickpea showed a poor correlation with water use (Fig. 2).

Mean water-use efficiency (WUE) for all treatments was 28.9 kg DM/ha per mm of water and 12.7 kg seed/ha per mm of water (Table 3). Irrigation did not significantly affect WUE. For TDM production, WUE depended on the interaction between irrigation levels and sowing date (Table 6). WUE was generally higher in the December sown plots, which received adequate irrigation. In plots, which received late, or no irrigation the November sowing generally had the highest WUE. There were also highly significant effects of both sowing date and cultivar and their interaction on the WUE for seed (kg seed/ha per mm of water) (Table 5). The November sowing produced 16.5 kg seed/ha per mm of water. This was 80% higher than the December sown chickpea crop. In the December sowing cv. Sanford had the highest WUE (11.5 kg seed/ha per mm of water) which was 27% and 71% higher than in cv. Dwelley and cv. B-90.

Table 4. The irrigation by sowing date interaction for total dry matter at final harvest (TDM), seed yield and cultivar of chickpeas in Canterbury, 1998/99.

	Sowing dates 1998/99						
	TDM (g/m^2)		Seed yield (g/m^2)		Cultivar interaction for TDM(g/m^2)		
Irrigation *	November	December	November	December	Sanford	Dwelley	B-90
nil	652	503	323.0	235.1	628	587	517
full (e-m)	1126	1135	609.7	212.3	1332	1020	1039
full (e-f)	1216	1120	644.5	328.6	1100	1166	1238
half (e-f)	929	947	673.3	260.3	951	886	977
full (f-p)	746	722	491.5	182.5	763	748	691
half (f-p)	919	583	380.1	195.8	829	699	725
full (p-m)	522	599	258.1	245.5	550	514	617
half (p-m)	502	562	326.1	203.7	462	589	546
SEM	73.5		41.51			83.1	
CV(%)	14.7		23.5			14.7	

*Irrigation: full = full irrigation to replace that lost from evapotranspiration; half = irrigated with half the amount of full; e-m = emergence to maturity; e-f = emergence to flower; f-p = flower to pod; p - m= pod to maturity.

Table 5. The sowing date by cultivar interaction for seed yield and water-use efficiency (WUE) of chickpeas in Canterbury, 1998/99.

	Seed yield (g/m^2)		WUE (seed kg/ha/mm of water)	
Cultivar	Nov.	Dec.	Nov.	Dec.
Sanford	473.2	290.0	16.9	11.47
Dwelley	434.4	233.8	15.5	9.0
B-90	482.3	175.2	16.9	6.7
SEM	22.87		0.86	
CV(%)	23.5		23.6	

Table 6. The irrigation by sowing date interaction for water use (E_t) and water-use efficiency (WUE) of chickpeas in Canterbury, 1998/99.

	Sowing dates 1998/99			
	Water use (mm)		WUE (dry matter kg/ha/mm of water)	
Irrigation*	Nov.	Dec.	Nov.	Dec.
nil	169	181	38.3	27.9
full (e-m)	449	402	25.0	28.3
full (e-f)	429	349	28.3	32.1
half (e-f)	312	300	29.6	31.7
full (f-p)	283	246	26.5	29.2
half (f-p)	252	205	36.5	28.6
full (p-m)	198	255	26.3	23.6
half (p-m)	197	222	25.5	25.2
SEM	13.0		2.38	
CV(%)	4.2		16.7	

*Irrigation: full = full irrigation to replace that lost from evapotranspiration; half = irrigated with half the amount of full; e-m = emergence to maturity; e-f = emergence to flower; f-p= flower to pod; p-m= pod to maturity

Maximum potential soil moisture deficit

The maximum potential soil moisture deficit (D_{max}) for the non-irrigated plots increased steadily throughout the experiment, reaching 358 mm for the November sowing, which was 35% more than the December sowing. In fully irrigated plots the D_{max} increased linearly from 60 days after sowing (DAS) and maintained a maximum of 142.0 and 62.2 mm for the November and December sowings respectively. In both sowings late irrigation treatments attained similar D_{max} (257 to 340 mm for November and 207 to 228 mm for the December sowing).

Both the November and December sowings showed a highly significant relationship when the TDM relative to the fully irrigated crops was plotted against D_{max} (r^2 = 0.79, $p < 0.01$; r^2 = 0.85, p = 0.001 for November and December sowing respectively) (Fig. 3). This indicated

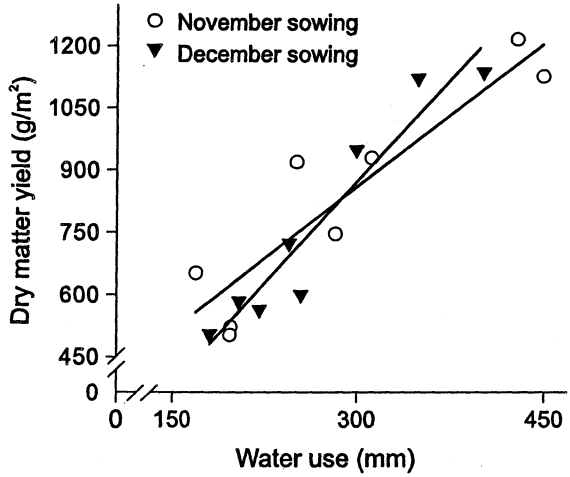

Figure 1. The relationship between chickpea dry matter production and water use in Canterbury, 1998/99.
$y_{November} = 167.1 + 2.30x$ (r^2=0.84)
$y_{December} = 112.1 + 3.27x$ (r^2=0.92)

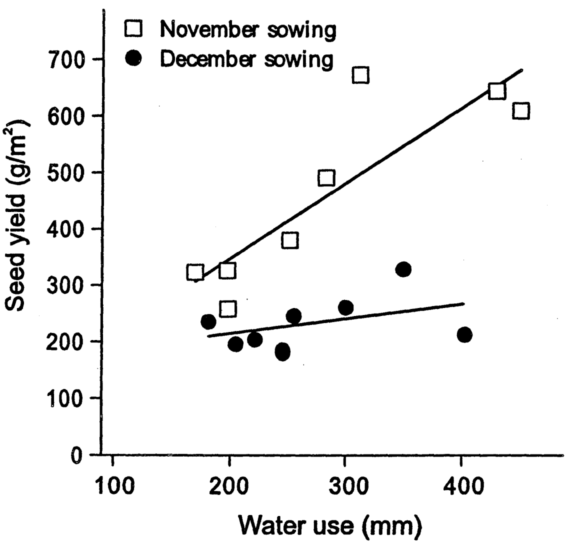

Figure 2. The relationship between chickpea seed yield and water use in Canterbury, 1998/99.
y (November) = 80.4 + 1.34x (r^2=0.75)

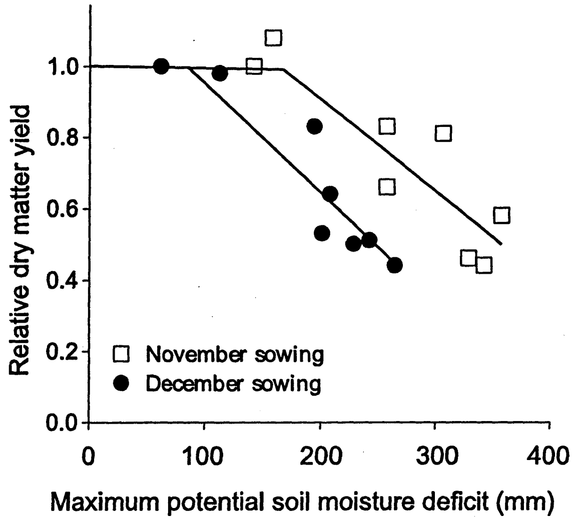

Figure 3. The relationship between chickpea relative dry matter production and potential soil moisture deficit in Canterbury, 1998/99.
$y_{November} = 1.43 + 2.6x$ (r^2=0.79),
$y_{December} = 1.26 — 3.1x$ (r^2=0.85)

a limiting deficit (cD_{max}) of 150 and 90 mm for the November and December sowings respectively, for this soil type. The slopes of the lines indicate that yield declined by 0.25 and 0.31% for the November and December sowings respectively for each mm increase of D_{max} above cD_{max}. Seed yield from the November sown chickpeas also showed a highly significant relationship when plotted against D_{max} ($r^2 = 0.72$, $p < 0.01$). This indicated an approximate limiting deficit of 150 mm for this soil. However, when the same correlation was done for the December sowing the results were not significant.

Discussion

Yield response to irrigation

In Canterbury, where rainfall during the growing season is usually less than 200 mm, Kabuli chickpea yield was related to water use and sowing date in a similar way to that for lentils (McKenzie and Hill, 1990). A yield of 4.6 t/ha was obtained by sowing in November and applying irrigation. In a previous trial in Canterbury, November sowing also produced the greatest chickpea seed yield (McKenzie and Hill, 1995).

Sowing date had the dominant effect on yield, as the irrigation by sowing date and sowing date by cultivar interactions indicated that the response to irrigation depended on the sowing date. The greatest total dry matter production and seed yields were from November sown plots when irrigation was applied from emergence to physiological maturity and until flowering. Singh *et al.* (1989), Nimje (1991) and Singh and Virmani (1996) reported similar results.

Water use and water-use efficiency

Water use (WU) depended on the irrigation regime. For both sowings, and for full (emergence to physiological maturity) and early (emergence to flowering) irrigation, water use was maximal and ranged from 350-450 mm, which agrees with previous work where in Canterbury, a fully irrigated lentil crop used 332 mm (McKenzie, 1987).

Cumulative WU of the three cultivars ranged from 175 to 426 mm. The TDM production and seed yield achieved for this amount of water use agree well with other data relating yield to water use in chickpea (Keatinge and Cooper, 1984; Siddique and Sedgley, 1987; Dalal *et al.*, 1997). Keatinge and Cooper (1984) and Siddique and Sedgley (1987) showed the benefit of early sowing to improve chickpea water-use efficiency and similarly, in this study, water-use efficiency was greater in the November than the December sowing.

The water use of chickpea depends on the soil moisture supply and the yield level and there is usually a close linear relationship between the amount of water used and yield (Singh and Bhushan, 1980). In this work, there was close association ($r^2 = 0.92$, $p < 0.001$) between water use and TDM production. However, there was no evidence of this translating into increased seed yield in the December sowing. Because chickpea is indeterminate and vegetative growth continues during flowering and fruit development, there may be competition for assimilates between continued vegetative growth and the developing reproductive sink (McKenzie and Hill, 1995). For the November sowing there was evidence of a positive association between high water use and high seed yield ($r^2 = 92$, $p < 0.01$); 13 kg seed/ha was produced per mm of WU. Seed yield is also associated with seed water-use efficiency (Dahan and Shibles, 1995).

Maximum potential soil moisture deficit

Seed yield in chickpea is the result of many growth processes expressed in the yield components. These growth processes are markedly influenced by water availability, which is highly variable in most environments (Singh and Virmani, 1996). There is no previous information on the response of a chickpea crop to water deficits. This study has enabled the definition of the critical maximum potential soil moisture deficit (cD_{max}) for this soil type, which was approximately 150 and 90 mm for the November and December sowings respectively. Husain (1984) and McKenzie (1987) found a cD_{max} of approximately 73 mm for field beans (*Vicia faba*) and 132 mm for lentils on the same soil type.

Conclusions

This study has shown that these Canadian Kabuli chickpea cultivars have the potential to produce seed yields of greater than 4 t/ha in Canterbury providing they are November sown and are irrigated to prevent soil moisture deficits.

There was a highly significant linear relationship between water use and seed yield in the November sown chickpea crop; water use was 426 mm for the fully irrigated treatment and at least 175 mm for the non-irrigated plants. The critical maximum potential soil moisture deficit for this type of soil was approximately 150 and 90 mm for the November and December sowings respectively.

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References

Cornforth, I.S. and Sinclair, A.G. 1984. Fertiliser recommendations for pasture and crops in New Zealand, 2nd edition. New Zealand Ministry of Agriculture and Fisheries, Wellington. 76 pp.

Dahan, R. and Shibles, R.M. 1995. Comparative responses of chickpea (*Cicer arietinum* L.) cultivars to water deficit. II. Leaf development, growth rates, water use and yields. 2nd European Conference on Grain Legumes, Copenhagen, July 1995, 118.

Dalal, R.C., Strong, W.M., Doughton, J.A., Weston, E.J., McNamara, G.T. and Cooper, J.E. 1997. Sustaining productivity of a Vertisol at Warra, Queensland, with fertilisers, no-tillage or legumes. 4. Nitrogen fixation, water use and yield of chickpea. *Australian Journal of Experimental Agriculture 37*, 667-676.

Hewitt, A.E. 1992. New Zealand soil classification. DSIR Land Resources Scientific Report No. 19. Lower Hutt, New Zealand.

Horn, C.P., Birch, C.J., Dalal, R.C. and Doughton, J.A. 1996. Sowing time and tillage practice affect chickpea yield and nitrogen fixation. 1. Dry matter accumulation and grain yield. *Australian Journal of Experimental Agriculture* ***36***, 695-700.

Husain, M.M. 1984. The response of field bean (*Vicia faba* L.) to irrigation and sowing date. Unpublished PhD Thesis, Lincoln College, University of Canterbury, New Zealand.

Jamieson, P.D., Wilson, D.R. and Hanson, R. 1984. Analysis of responses of field peas to irrigation and sowing date. 2. Models of growth and water use. *Proceedings Agronomy Society of New Zealand* ***14***, 75-81.

Jamieson, P.D., Francis, G.S., Wilson, D.R. and Martin, R.J. 1995. Effects of water deficits on evapotranspiration from barley. *Agricultural and Forest Meteorology* ***76***, 41-58.

Keatinge, J.D.H. and Cooper, P.J.M. 1984. Physiological and moisture-use studies on growth and development of winter-sown chickpeas. *In* Proceedings of the Workshop on Ascochyta Blight and Winter Sowing of Chickpeas, ICARDA, Syria, May 1981, (eds. M.C. Saxena and K.B. Singh), pp. 141-157. ICARDA, Aleppo.

Kharag, B.S., Malhotra, R.S., Saxena, M.C. and Bejiga, G. 1997. Superiority of winter sowing over traditional spring sowing of chickpea in the Mediterranean Region. *Agronomy Journal* ***89***, 112-118.

Lawn, R.J. and Ahn, C.S. 1985. Mung bean (*Vigna radiata* (L.) Wilczek / *Vigna mungo* (L.) Hepper.). *In*: Grain Legume Crops, (eds. R.J. Summerfield and E.H. Roberts), pp. 584-623. William Collins Sons, London.

McKenzie, B.A. 1987. The growth, development and water use of lentils (*Lens culinaris* Medik.). Unpublished PhD Thesis, Lincoln College, University of Canterbury, New Zealand.

McKenzie, B.A. and Hill, G.D. 1990. Growth, yield and water use of lentils (*Lens culinaris*) in Canterbury, New Zealand. *Journal of Agricultural Science, Cambridge* ***114***, 309-320.

McKenzie, B.A. and Hill, G.D. 1995. Growth and yield of two chickpea (*Cicer arietinum* L.) varieties in Canterbury, New Zealand. *New Zealand Journal of Crop and Horticultural Science* ***23***, 467-474.

NZHSC 1988. The New Zealand Harmonised System Classification. Department of Statistics, *New Zealand Amendment Set* ***9(1)***, 7-8.

Nagarajrao, Y., Mallick, S. and Singh, G. 1980. Moisture depletion and root growth of different varieties of chickpea under rainfed conditions. *Indian Journal of Agronomy* ***5***, 289-93.

Nimje, P.M. 1991. Irrigation and fertilizer requirement of chickpea genotypes in deep vertisols. *Indian Journal of Agronomy* ***36***, 111-114.

Siddique, K.H.M. and Sedgley, R.H. 1987. Canopy development modifies the water economy of chickpea (*Cicer arietinum* L.) in South-western Australia. *Australian Journal of Agricultural Research* ***37***, 599-610

Siddique, K.H.M. and Sykes, J. 1997. Pulse production in Australia past, present and future. *Australian Journal of Experimental Agriculture* ***37***, 103-111.

Singh, G. and Bhushan, L.S. 1980. Water use, water-use efficiency and yield of dryland chickpea as influenced by P fertilisation, stored soil water and crop season rainfall. *Agricultural Water Management* ***2***, 299-305.

Singh, P., Saxena, N.P., Monteith, J.L. and Huda, A.K.S. 1989. Defining, modelling, and managing water requirement in chickpea. *In:* Chickpea in the Nineties: Proceedings of 2nd International Workshop on Chickpea Improvement, ICRISAT Centre, Patancheru, December 1989, (eds. H.A. van Rheenen and M.C. Saxena). pp. 73-79. ICRISAT, Patancheru, and ICARDA, Aleppo.

Singh, P. and Virmani, S.M. 1996. Modelling growth and yield of chickpea (*Cicer arietinum* L.). *Field Crops Research* ***46***, 41-59.

Smithson, J.B., Thompson, J.A. and Summerfield, R.J. 1985. Chickpea (*Cicer arietinum* L.) *In*: Grain Legume Crops. (eds. R.J. Summerfield and E.H. Roberts). pp. 312-390. William Collins, London.

Steele, W.M., Allen, D.J. and Summerfield, R. J. 1985. Cowpea (Vigna *unguiculata* (L.) Walp.). *In*: Grain Legume Crops. (eds. R.J. Summerfield and E.H. Roberts). pp. 520-583. William Collins, London.

Thomas, and Fukai, S. 1995. Growth and yield response of barley and chickpea to water stress under three environments in Southeast Queensland. I. Light interception, crop growth and grain yield. *Australian Journal of Agricultural Research* ***46***, 17-33.

Verghis, T.I. 1996. Yield and yield development of chickpea (*Cicer arietinum* L.). Unpublished PhD Thesis, Lincoln University, Canterbury, New Zealand.