

Phenology and growth response to irrigation and sowing date of Kabuli chickpea (*Cicer arietinum* L.) in a cool-temperate subhumid climate

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(Revised MS received 16 September 2003)

SUMMARY

The photothermal response of three Kabuli chickpea (*Cicer arietinum* L.) cultivars, at different growth stages, to eight irrigation treatments in 1998/99 and four irrigation treatments in 1999/2000 was studied on a Wakanui silt loam soil in Canterbury, New Zealand (43°38S, 172°30E). The rate of development from emergence to flowering (e-f) and sowing to harvest maturity were strongly and positively associated ($R^2=0.87$, $P<0.001$) with mean temperature during those periods. All phenological stages considered (sowing to emergence, e-f, flowering to podding, podding to physiological maturity and physiological maturity to harvest maturity) depended upon accumulated thermal time (T_t) above a base temperature (T_b) of 1 °C.

An accurate prediction of time of flowering was made based on an accumulated mean T_t requirement of 629 °Cdays from e-f ($R^2=0.91$, $P<0.001$). Fully irrigated crops had higher maximum dry matter accumulation (maxDM; 1093 g/m²), duration of exponential growth (DUR; 99 days), weighted mean absolute growth rate (WMAGR; 12.2 g/m² per day) and maximum crop growth rate (MGR; 17.1 g/m² per day). In 1998/99 the positive response of maxDM and MGR depended on a significant ($P<0.01$) interaction between irrigation and sowing date. The maxDM during the season was highly correlated with DUR and MGR ($R^2=0.79$ and 0.65). It is concluded that to maximize chickpea biological yield in the dry season of the cool-temperate subhumid climate of Canterbury, irrigation should extend across all phenological stages.

INTRODUCTION

Indeterminate, diploid ($2n=16$), self-pollinated Kabuli chickpea (*Cicer arietinum* L.) is a quantitative long day plant and is one of the most widely cultivated cool season food legumes (Davis *et al.* 1990). It is best adapted to spring–early summer seasons of the Mediterranean and cool winter temperatures in the semi-arid tropics (Jettner *et al.* 1999). The world average seed yield of 796 kg/ha (FAO 2002) results in a shortfall between production and demand in most countries. Phenology (development) refers to ontological changes occurring at different distinct phases in a crop's life cycle (Angus *et al.* 1981). Water stress

can affect the phenological stages by shortening crop duration and speeding up maturity (Singh 1991). Chickpea yield is reputed to be most responsive when irrigated at flowering and pod filling (Malhotra *et al.* 1997). The dynamics of chickpea phenology vary with cultivar, photoperiod, temperature and soil water status and changes in morphology, development and maturity may determine the economic yield (Soltani *et al.* 1999). The most important step towards maximizing yield of chickpea is to ensure that the phenology of the crop or cultivar is well matched to resources and constraints of the production environment (Summerfield *et al.* 1990). Flowering time is important because environmental conditions during the reproductive phase have a major impact on final yield. The onset of flowering often determines the entire crop duration (Egli 1998).

Improvement of chickpea yield potential could be linked to increased biomass production, increased

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Table 1. Chemical properties for 0–30 cm soil depth for Iversen field research area during 1998/99 and Henley field research area during 1999/2000 of Lincoln University, Canterbury. Ca, K, P, Mg and Na, S, B, NH_4^+ -N and NO_3^- -N ($\mu\text{g/g}$ of soil); C (organic) and total nitrogen (TN) as mg/g

>Season	pH	Ca	K	P	Mg	Na	S	B	C	NH_4^+	NO_3^-	TN
1998/1999	6.3	10	13	18	22	8	3	0.4	24	4.3	1	2.0
1999/2000	5.8	10	8	13	30	8	9	0.6	31	5.0	<1	2.7

harvest index or both (Soltani *et al.* 1999). Biomass production is, in turn, associated with leaf area expansion, duration and water use (Zhang *et al.* 2000). Irrigation generally increases biomass accumulation of grain legumes, including chickpea, during dry seasons. However, the magnitude of the response varies widely with site, season and sowing date (Malhotra *et al.* 1997). Chickpea crops exhibit characteristic sigmoid growth curves with a slow accumulation of dry matter (DM) after seedling establishment followed by an exponential growth phase until pod set (Khanna-Chopra & Sinha 1987). Dry matter accumulation during the exponential phase is an expression of maximum crop growth rate (MGR) and there is a close association between maximum DM and MGR (Ball *et al.* 2000).

The present paper investigates phenological development of Kabuli chickpea cultivars, especially the response of phenology and flowering time to irrigation and sowing date in order to improve the understanding of chickpea growth and development in a cool-temperate subhumid climate at Canterbury, New Zealand.

MATERIALS AND METHODS

Two sites were used in research fields of Lincoln University, Canterbury, New Zealand (43°38S, 172°30E) on a Wakanui silt loam soil (Hewitt 1992). Barley (*Hordeum vulgare*) was grown in the season before the 1998/99 experiment, while perennial ryegrass (*Lolium perenne*) preceded the 1999/2000 experiment. The soil had an available moisture storage capacity of about 300 mm of water per 1 m soil depth (Anwar *et al.* 1999). The soil was of moderately high fertility in the 0–30 cm depth (Table 1). The climate of Canterbury is characteristic of a cool-temperate subhumid climate (Dapaah 1997), with about 600 mm of rain evenly spread over the year.

In the present study irrigation treatments were selected to provide a wide range of potential soil moisture deficits during the vegetative stage, flowering, and pod filling to physiological maturity phases of plant development (Table 2). The experimental layout was a split-split plot randomized complete block design with eight irrigation levels during the 1998/99 season and four irrigation levels during 1999/2000 as main plots (Table 2). Subplots were two sowing dates

Table 2. The irrigation treatments (mm of water) applied via a T-tape irrigation system to Kabuli chickpea experiments, conducted in Canterbury, New Zealand, 1998/99 and 1999/2000

Irrigation treatments*	Sowing date	
	3 Nov 1998	7 Dec 1998
1998/99		
1 Nil	0	0
2 Full (e-m)	231	218
3 Full (e-f)	197	163
4 Half (e-f)	99	82
5 Full (f-p)	99	68
6 Half (f-p)	41	43
7 Full (p-pm)	27	75
8 Half (p-pm)	14	48
	18 Oct 1999	22 Nov 1999
1999/2000		
1 Nil	0	0
2 Full (e-m)	105	109
3 Full (f-p)	61	58
4 Full (p-m)	51	58

* Irrigation treatments: nil, rain fed only; full, irrigation to replace water lost through evapotranspiration; half, irrigation to replace half the full amount lost. Further details in text.

(3 November and 7 December in 1998/99 and 18 October and 22 November in 1999/2000). Three high-yielding, early-flowering, *Aschochyta* blight-resistant Kabuli chickpea cultivars (Sanford, Dwelley and B-90) were sub-subplots. They were randomly assigned within each subplot, with two replicates, giving a total of 96 plots in 1998/99. In the second season (1999/2000) the sub-subplots were two Kabuli chickpea cultivars (Sanford and B-90), with three replicates, giving a total of 48 plots. Each subplot was 10 m long with 14 rows that were 15 cm apart in both experiments.

To accurately apply irrigation water, T-tape was placed in every second row (30 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 (Eqn 1).

$$A = \sum \text{Ep} - (I + R) \quad (1)$$

where Ep is the rate of potential evapotranspiration (mm/day); 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.

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 pre-sowing (7 days before) and pre-emergence (7 days after sowing). 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. Seed, which had a germination of $\geq 90\%$, was sown with a tractor-driven cone seeder to give a population of approximately 50 plants/m². The experiments received no fertilizer, fungicide or insecticide.

Crop phenology was monitored at 1–2 day intervals throughout the season and five stages of crop development were determined. These were: emergence (the time when 50% of seedlings had emerged in any plot); flowering (50% of the plants had one open flower at any node on the main stem in any plot); podding (50% of plants had at least one emerged green pod in any plot); physiological maturity (50% of the plants had at least one mature (brown) pod in any plot); and harvest maturity (when plants were dry enough to be combine harvested). The time taken to complete each phenological phase, i.e. sowing to emergence (s-e), emergence to flowering (e-f), flowering to podding (f-p), podding to physiological maturity (p-m) and sowing to harvest maturity (s-h) was recorded in days and the inverse of that was defined as the rate of development. The response of 'development rate' for e-f and s-h to temperature, photoperiod and temperature corrected for photoperiod were examined. The temperature data, photoperiod from sunrise to sunset and long-term means were collected from the records of the Broadfield Meteorological Station at Lincoln University. The average mean daily photoperiod (P) and daily mean temperatures (T) were calculated for each of the growth phases. Thermal time (T_i) between any two phenological stages was calculated as the time integral of mean T above a base temperature (T_b) of 1 °C, using Eqn 2. Literature estimates of base temperature for chickpea range from 0 to 8 °C (Singh 1991; Summerfield *et al.* 1990).

$$T_i = \sum_{\text{Stage A}}^{\text{Stage B}} [(T_{\min} + T_{\max})/2] - T_b \quad (2)$$

where T_{\min} is the minimum temperature, and T_{\max} the maximum temperature between two stages of development.

The temperature corrected for photoperiod (T_{pp}) was calculated from the method of Gallagher *et al.* (1983) as in Eqn 3:

$$(T_{pp}) = [(T - T_b)(P - P_b)] / (24 - P_b) \quad (3)$$

where T is the mean temperature of the stage being considered, P is the mean photoperiod over the stage considered and P_b is the base photoperiod (15 h used in the present study).

Dry matter (DM) accumulation over the season was measured from 0.2 m² samples taken every 10 days from 28 days after sowing (DAS) until harvest maturity. The samples were oven dried at 70 °C for 48 h in a force draught oven and weighed. A functional growth analysis was made using a Maximum Likelihood Programme (MLP) from Rothamsted Experimental Station, UK (Ross *et al.* 1987). Generalized logistic curves of the form of Eqn 4 were used to describe DM accumulation of the crops (Gallagher & Robson 1984).

$$Y = C / [1 + T_x \exp[-b(x - m)]]^{1/T} \quad (4)$$

where Y is yield, C is the final above-ground dry matter and T , b and m are constants.

The weighted mean absolute growth rate (WMAGR – the mean growth rate over the period when the crop accumulated most of its DM), duration of exponential growth (DUR – duration of crop growth over which most growth occurred) and maximum crop growth rate (MGR) were derived for the crop using the values of C , T , b and m according to Eqns 5–7:

$$\text{WMAGR} = bC / 2(T + 2) \quad (5)$$

$$\text{DUR} = 2(T + 2) / b \quad (6)$$

$$\text{MGR} = bC / (T + 1)^{(T+1)/T} \quad (7)$$

All variates were analysed using analysis of variance. The statistical package used was Genstat 5 (Genstat 5 Committee of the Statistics Department, Rothamsted Experimental Station, Hertfordshire, UK). For the data in graphs where interaction between irrigation and sowing dates was significant, an interaction s.e. bar is presented for the comparison of treatment effects.

RESULTS

Meteorological data for the two cropping seasons (1998/99 and 1999/2000) are presented in Fig. 1. Weather from October to April in 1998/99 was dry. The rainfall was about 40% below the long-term average. Rainfall in October, November, December, January, February, March and April was 57, 20, 24, 36, 38, 56 and 36 mm respectively compared with the 55-year corresponding mean values of 55, 56, 61, 50,

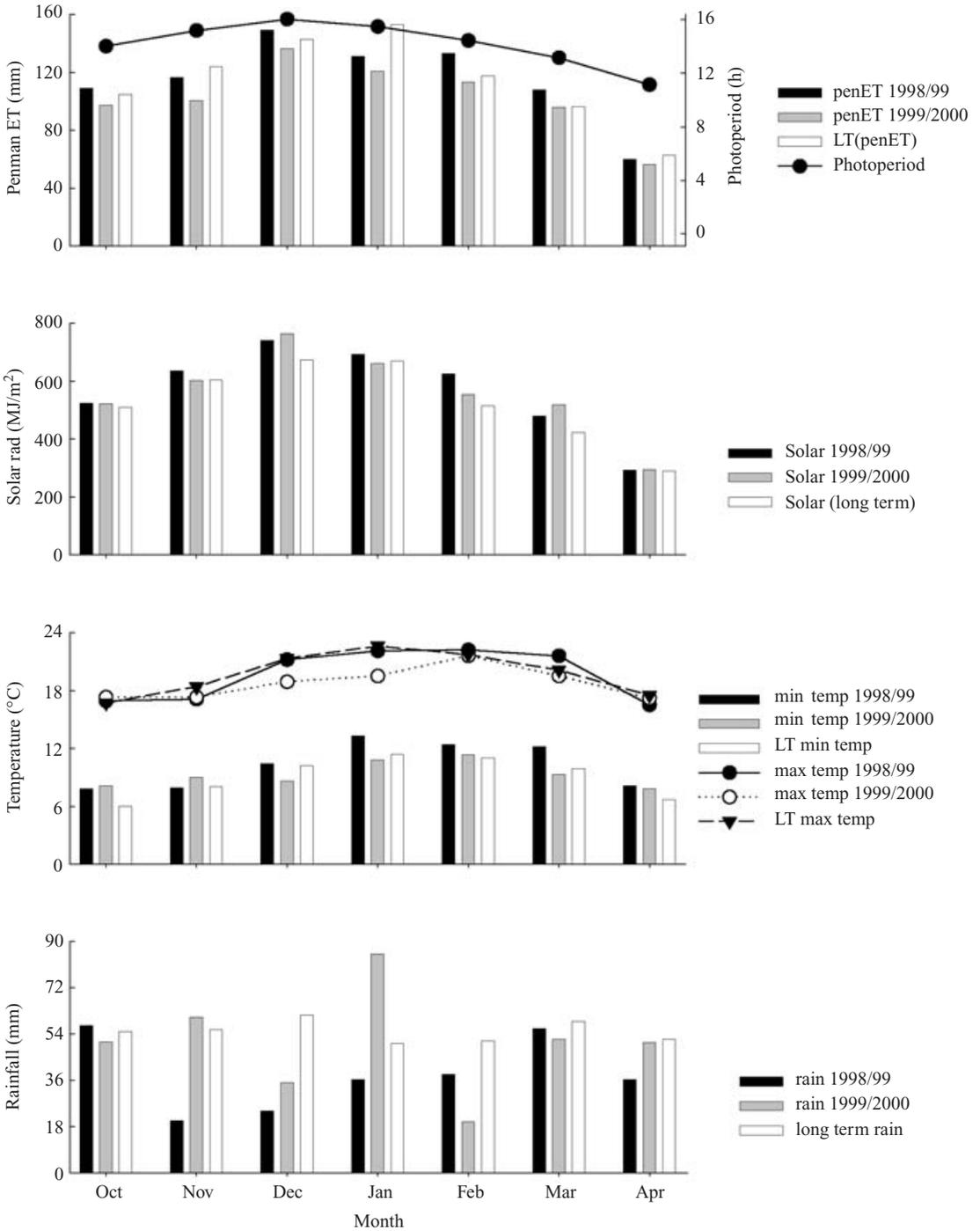


Fig. 1. Weather data for the 1998/99 and 1999/2000 growing seasons and long term means for Lincoln University, Canterbury, New Zealand. Photoperiod from sunrise to sunset including civil twilight (Keisling 1982), long-term means (LT) for rainfall and temperature (1944–99) and solar radiation and Penman evapotranspiration (penET) (1975–99).

Table 3. The main effects of irrigation and sowing date on the time (number of days after sowing) to reach each phenological stage in Kabuli chickpea in Canterbury, New Zealand, 1998/99 and 1999/2000

Irrigation treatments†	Emergence	Flowering	Podding	Physiological maturity	Harvest maturity
1998/99					
Nil	13	51	63	94	111
Full (e-m)	13	55	71	106	122
Full (e-f)	13	55	70	103	119
Half (e-f)	14	52	69	99	119
Full (f-p)	14	52	66	98	119
Half (f-p)	14	52	66	100	119
Full (p-m)	14	52	64	103	119
Half (p-m)	14	52	63	101	119
s.e. (D.F. = 7)	0.2	0.3	0.1	6.6	0.4
Sowing date					
Nov 3	16	56	72	90	118
Dec 7	11	49	61	111	117
s.e. (D.F. = 32)	0.3	0.5	0.4	8.4	0.01
1999/2000					
Sowing date					
Oct 18	16	61	79	120	152
Nov 22	14	65	74	109	142
s.e. (D.F. = 16)	0.2	0.3	0.1	0.4	0.3

† Irrigation treatments as in Table 2.

51, 59 and 52 mm (Fig. 1). Total rainfall during the entire growing season (sowing to 90% physiological maturity) was about 200 mm. The maximum and minimum temperatures were similar to their long-term averages, but mean temperature increased by about 5% in the months of January, February and March 1999. Solar radiation from January to March 1999 was about 7% higher than the long-term average and the Penman evapotranspiration (penET) during February and March was about 10% higher than the long-term average.

Total rainfall from October 1999 to April 2000 was 353 mm, about 90% of the long-term average. Overall, rainfall during the growing season (sowing to physiological maturity) was approximately 260 mm. In 1999/2000, the maximum and minimum temperatures were similar to the long-term averages (Fig. 1). However, the mean monthly maximum temperatures during December 1999 and January 2000 were 18.9 and 19.5 °C, respectively, compared with the 55-year mean values of 21.3 and 22.6 °C. Solar radiation from December 1999 to March 2000 was about 10% higher than the long-term mean. In January 2000 the penET was about 25% lower than normal. Photoperiod (sunrise to sunset including civil twilight) was calculated for both the seasons using a computer routine program adopted from LINZ (1999).

Phenological development

Irrigation during any phase of development significantly ($P < 0.001$) increased the chronological time required for flowering, podding, physiological and harvest maturity (Table 3) in 1998/99, but not in 1999/2000. Time from sowing to emergence (s-e) and flowering (s-f) varied significantly ($P < 0.001$) among sowing dates (Table 3). In 1998/99, the December-sown crops emerged earlier (11 days) while the October 1999/2000 sown crop required 16 days to complete this phase. There was no difference in the time to reach each phenological stage among the cultivars. The phase s-f required an average of about 53 days (range 49–65 days). The number of days to podding was faster by 11 days in the December 1998/99 sowing but plants reached physiological maturity 21 days later than the November sowing. Crops generally flowered, podded and reached physiological maturity faster in 1998/99 than in 1999/2000. The crop duration from sowing to harvest maturity ranged from 117 to 152 days (Table 3).

The duration of s-e and emergence to flowering (e-f) showed a linear decrease, as a function of mean daily temperature (Fig. 2*a,c*). The rate of development from s-e and e-f was strongly ($R^2 = 0.90$ and 0.87 , $P < 0.001$) and linearly related to mean temperature (Fig. 2*b,d*). Extrapolation of the regression lines gave a base temperature (T_b) of 0.25 and

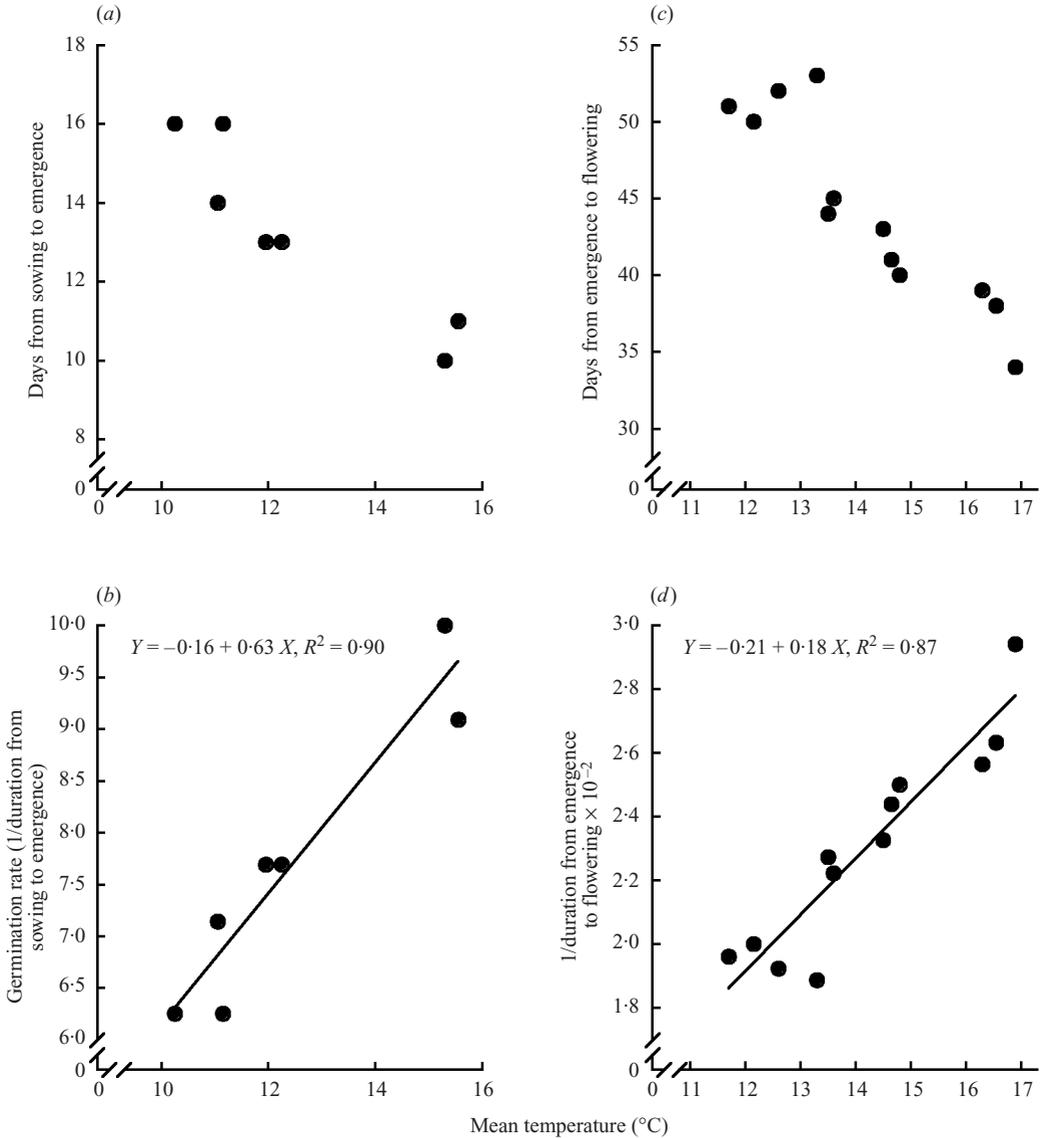


Fig. 2. Relationship between mean temperature and (a) days from sowing to emergence, (b) rate of development from sowing to emergence, (c) days from emergence to flowering and (d) rate of development from emergence to flowering of Kabuli chickpeas in Canterbury, New Zealand (1998–2000).

1.17 °C. Therefore, T_b was chosen to be 1 °C. The rate of development from E-F showed a significant linear relationship ($R^2=0.52, P<0.01$) with photoperiod above a suggested base photoperiod (P_b) of 14.9 h (Fig. 3a). Furthermore, taking account of the response of the rate of development from e-f and mean temperature to photoperiod by examining temperature corrected for photoperiod ($T_b=1$ °C and $P_b=15$ h) showed a significant linear relationship ($R^2=0.83, P<0.01$) (Fig. 3b).

Thermal time

There was a significant ($P<0.001$) difference in thermal time (T_D) duration from sowing to harvest maturity (s-h) of Kabuli chickpea crops between sowing date and seasons (Table 4). The e-f, flowering to podding (f-p), podding to physiological maturity (p-m) and physiological maturity to harvest maturity (m-h) phases were significantly ($P<0.001$) affected by irrigation in the 1998/99 season and were strongly

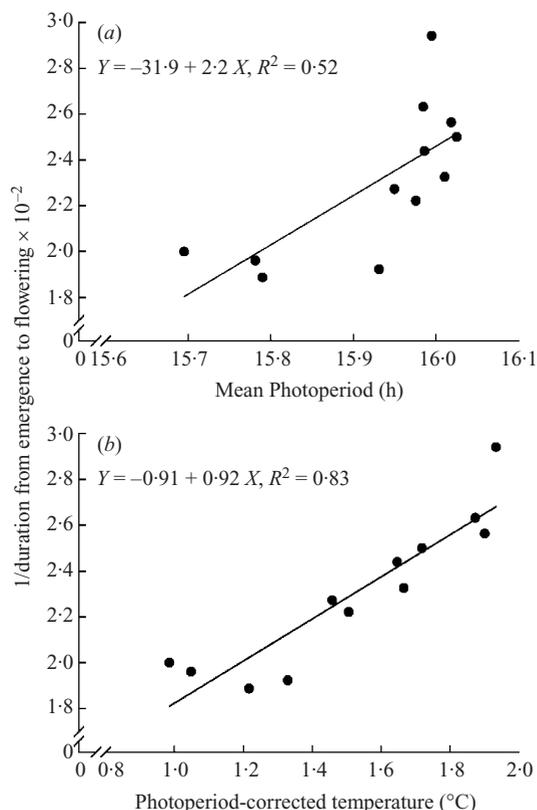


Fig. 3. Relationship between rate of development from emergence to (a) mean photoperiod and (b) photoperiod-corrected temperature in that period of Kabuli chickpeas in Canterbury, New Zealand (1998–2000).

related to temperature. The T_1 for e-f and s-h for the December-sown crops was higher than in the November-sown crops (Table 4). Generally, crops with late or no irrigation had a significantly ($P < 0.001$), shorter T_1 requirement to reach e-f and s-h. The mean T_1 requirement for f-p, p-m and m-h phases was 254, 575 and 316 °Cdays respectively.

The T_1 duration was used to predict flowering for Kabuli chickpeas using the technique of McKenzie & Hill (1989) with photothermal time for lentils. As shown in Fig. 4, the relationship between the predicted and actual dates of flowering was highly significant with $R^2 = 0.91$, indicating flowering date for Kabuli chickpea could be accurately predicted.

Dry matter accumulation (functional growth analysis)

Irrespective of cultivar or sowing date, dry matter (DM) accumulation was well described by a sigmoid pattern with a decrease at the end due mostly to falling leaflets (Fig. 5). Full irrigation significantly

increased DM accumulation pre and post anthesis. Duration of the initial phase was shorter and the initial growth rate was higher in 1998/99 (Fig. 5a, b). The linear growth phase, which accounted for one third to half of the duration from emergence to harvest, was the period when the major proportion of DM accumulation (i.e. 72–93%) took place (Table 5). In both years (1998–2000) full irrigation from emergence to physiological maturity (full (e-m)) gave a significantly ($P < 0.001$) higher maximum dry matter (maxDM) production than nil and late irrigation from pod-set to maturity (nil (p-m) and late (p-m)). Averaged over 2 years, fully irrigated crops produced 64% more maxDM at 1093 g/m² than nil and late irrigation. Maximum crop growth rate (MGR) also followed a similar trend (Table 5). Averaged over 2 years, MGR was 26–30% higher in the fully irrigated crops (c. 17 g/m²/day) than in the unirrigated crop (c. 13.4 g/m²/day). In 1998/99, the effect of irrigation on maxDM and MGR depended on sowing date (Fig. 6). In the November sowing full irrigation increased maxDM and MGR by about 111 and 34%, respectively. At two irrigation levels (nil and full (f-p)), December-sown plants accumulated more maxDM (10–28%) than November-sown plants. However, at all irrigation levels MGR was higher in the November sowing than the December-sown plants.

The duration of the exponential phase of crop growth over which most growth occurred (DUR) and the weighted mean absolute growth rate (WMAGR), the mean growth rate over the period when the crop accumulated most of its DM, was also significantly ($P < 0.001$) affected by irrigation. Fully irrigated crops had the longest DUR at 99 days (Table 5). In 1998/99, full (e-m) showed the fastest WMAGR. In 1999/2000, irrigation decreased WMAGR by 15%.

DISCUSSION

The present study revealed that temperature was the dominant factor that affected Kabuli chickpea phenology among sowing dates (SD) and under different irrigation levels, consistent with previous results (Summerfield *et al.* 1994; Siddique *et al.* 1999). The key difference in phenology between SD was in the time from s-e and from f-m. When chickpea seed was sown in October and November, the crop required c. 16 days for emergence because of low temperature (c. 12 °C mean) and during December (c. 16 °C mean) it only took 11 days. The rate of development from s-e showed a strong and significant relationship with temperature ($R^2 = 0.90$, Fig. 2b) indicating that prediction of emergence was reliable. The thermal time for this phase ranged from 164–234 °Cdays, a similar value to that for lentils (McKenzie & Hill 1989). The December-sown crop encountered higher temperatures (c. 20 °C+, maximum) and decreasing photoperiod during its vegetative growth phase that

Table 4. *The main effect of irrigation and sowing date on the thermal time for physiological growth phases of Kabuli chickpea in Canterbury, New Zealand, 1998/99 and 1999/2000*

Irrigation treatments†	Thermal time for phase (°Cdays), $T_b = 1\text{ }^\circ\text{C}$					
	s-e	e-f	f-p	p-m	m-h	Total (s-h)
1998/99						
Nil	189	607	214	529	316	1802
Full (e-m)	186	681	292	599	279	1968
Full (e-f)	186	682	270	560	285	1912
Half (e-f)	194	612	310	508	355	1912
Full (f-p)	194	612	262	512	358	1912
Half (f-p)	194	612	256	577	340	1912
Full (p-m)	194	612	223	666	285	1912
Half (p-m)	194	612	206	651	312	1912
s.e. (D.F. = 7)	2.5	2.3	5.2	33.0	11.5	0.8
Sowing date						
Nov 3	217	581	311	306	494	1845
Dec 7	165	677	197	845	138	1966
s.e. (D.F. = 32)	4.7	6.4	9.9	58.0	8.3	1.9
1999/2000						
Sowing date						
Oct 18	234	604	248	649	489	2174
Nov 22	181	733	136	576	442	2018
s.e. (D.F. = 16)	2.5	5.3	4.3	5.3	4.9	3.4

s-e, sowing to emergence; e-f, emergence to flowering; f-p, flowering to podding; p-m, podding to physiological maturity; m-h, physiological maturity to harvest maturity; s-h, sowing to harvest maturity and T_b , base temperature.

† Irrigation treatments in Table 2.

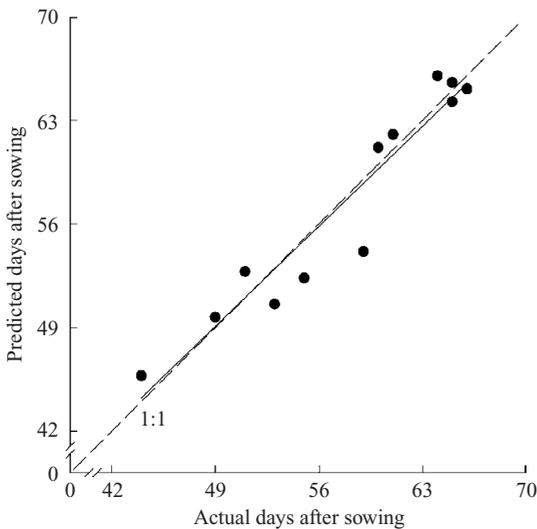


Fig. 4. Relationship between predicted and actual dates of flowering in Kabuli chickpea in Canterbury, New Zealand, 1998–2000 ($Y = 1.86 + 0.96X$, $R^2 = 0.91$).

enhanced phenological development, thus shortening the period from s-f (49 days) and the start of pod filling (Table 3). The estimate of the base temperature of $1\text{ }^\circ\text{C}$ was within the range of previous estimates for

chickpea (range $0\text{--}8\text{ }^\circ\text{C}$) (Singh 1991; Summerfield *et al.* 1990).

The two field environments were characterized by high solar radiation ($16\text{--}25\text{ MJ/m}^2/\text{day}$). The mean daily minimum temperatures during the growing season in 1999/2000 were consistently lower than long-term averages ($c. 8\text{--}11\text{ }^\circ\text{C}$, Fig. 1), which resulted in differences in crop duration. However, the thermal time duration from s-m was similar between the two seasons with means of $1905\text{ }^\circ\text{Cdays}$ and $2096\text{ }^\circ\text{Cdays}$ in 1998/99 and 1999/2000, respectively. Similar results were observed by Horn *et al.* (1996) in Australia. Comparisons between the rainfed and irrigated treatments indicated that drought stress could induce substantial reductions in the duration to flowering and crop maturity in Kabuli chickpea. Similar responses to drought have been reported for other grain legume species including lupins (French & Turner 1991), and faba bean (De Costa *et al.* 1997). The mechanism appears to involve an increase in leaf or canopy temperature (Finch-Savage & Elston 1977), which accompanies water stress. In the rainfed plots, thermal time duration from s-m decreased from $1968\text{ }^\circ\text{Cdays}$ to about $1800\text{ }^\circ\text{Cdays}$. The estimated mean thermal time durations for flowering (from s-f) were $650\text{ }^\circ\text{Cdays}$ and up to harvest ($2000\text{ }^\circ\text{Cdays}$) in the present study agrees closely with the estimates of Singh (1991) and Ramteke *et al.* (1996) for chickpea.

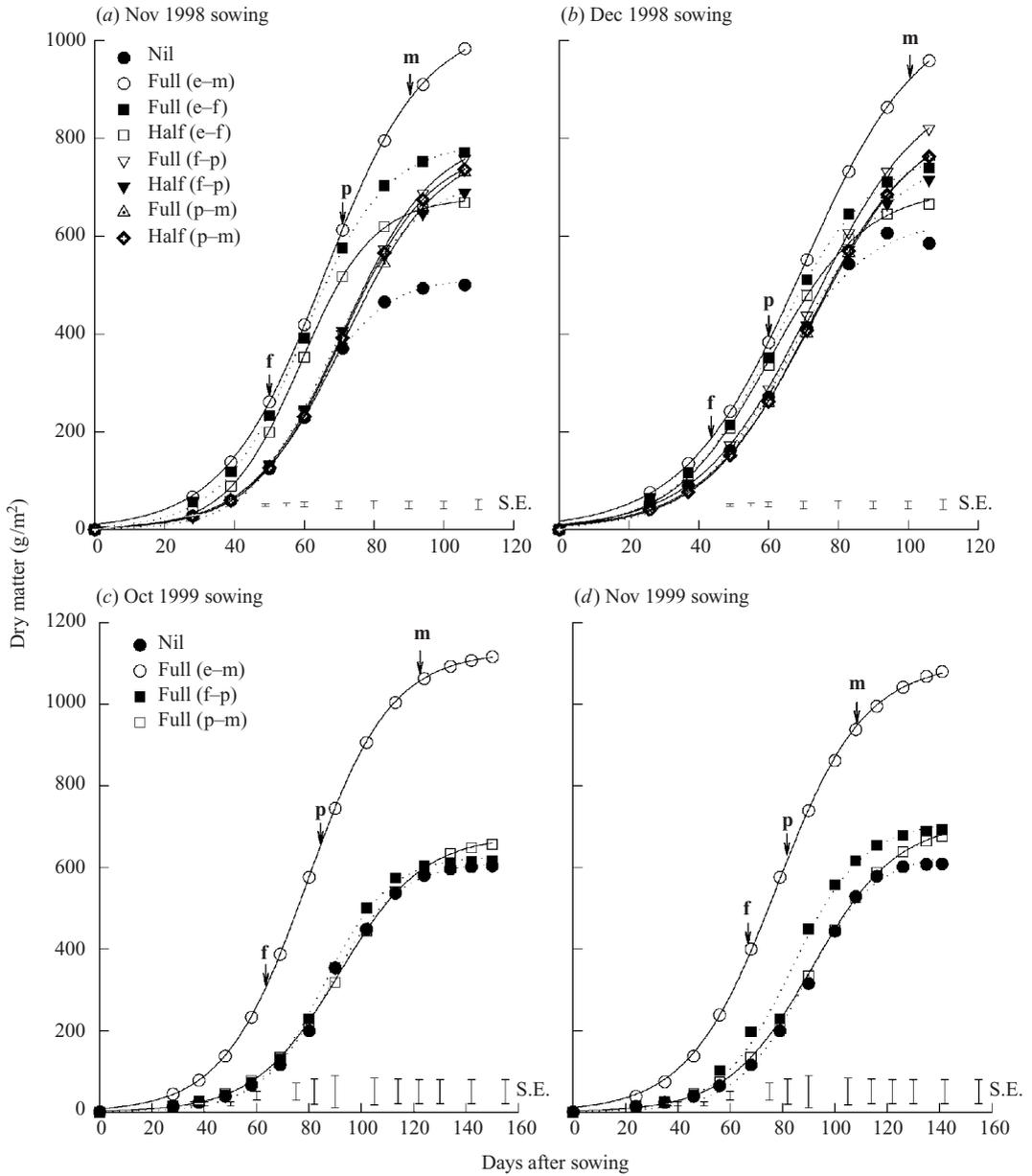


Fig. 5. Dry matter accumulation of chickpea as affected by irrigation levels and sowing date in Canterbury (1998–2000). $Y=C/(1+T \exp(-b(x-m)))^{1/T}$. Irrigation treatments described in the text. Arrows indicate (f) flowering, (p) podding and (m) physiological maturity.

Time to flowering and maturity is often affected by both temperature and photoperiod. Flowering in many genotypes of chickpeas is moderated by photoperiod (Summerfield *et al.* 1994). Therefore, it is usually recommended that modelling the rate of progress towards flowering in chickpea is done in terms of photothermal response (Ellis *et al.* 1994). In the

present work, however, the relationship between flowering rate and photothermal time (Fig. 3*b*) explained less variability (87%) than did the relationship between flowering rate and temperature (Fig. 2*d*). Over the period e-f, the variation in mean photoperiod was small (14–16 h). This probably explains the lack of effect on time to flowering. Summerfield &

Table 5. The main effects of irrigation and sowing date on maximum dry matter (maxDM), duration of exponential growth (DUR), the weighted mean absolute growth rate (WMAGR) and maximum crop growth rate (MGR) of Kabuli chickpea in Canterbury, New Zealand 1998–2000

Irrigation treatments†	MaxDM dry matter (g/m ²)	DUR (days)	WMAGR (g/m ² per day)	MGR (g/m ² per day)
1998/99				
Nil	571	49	11.6	13.3
Full (e-m)	1067	99	10.9	16.8
Full (e-f)	766	60	12.8	16.2
Half (e-f)	677	61	11.2	14.9
Full (f-p)	865	87	10.0	15.1
Half (f-p)	731	70	10.5	14.6
Full (p-m)	815	84	9.9	14.3
Half (p-m)	811	82	10.1	14.8
S.E. (D.F. = 7)	13.9	6.5	0.7	0.3
Sowing date				
Nov 3	766	71	11.0	15.7
Dec 7	809	76	10.8	14.2
S.E. (D.F. = 32)	18.4	8.0	0.7	0.4
1999/2000				
Nil	607	47	13.3	13.4
Full (e-m)	1120	99	11.6	17.4
Full (f-p)	659	65	11.1	13.4
Full (p-m)	679	80	8.6	11.4
S.E. (D.F. = 16)	30.0	12.3	1.6	1.0

† Irrigation treatments as in Table 2.

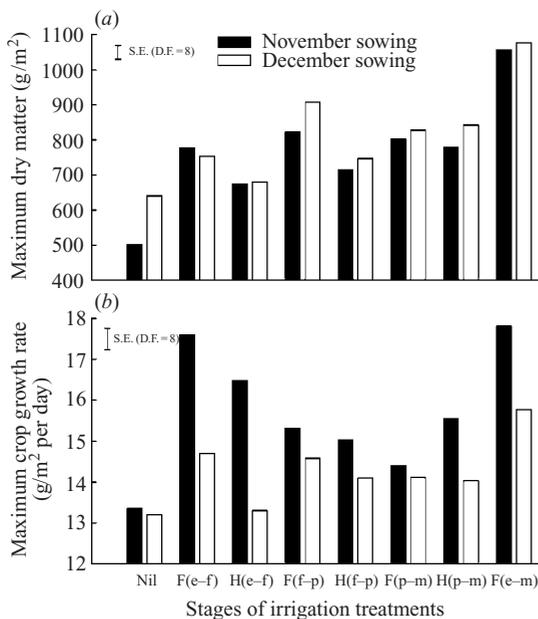


Fig. 6. The interaction between irrigation and sowing date of (a) maximum dry matter and (b) maximum crop growth rate of Kabuli chickpea in Canterbury, New Zealand, 1998/99. Irrigation treatments described in the text.

Roberts (1988) reported variation in response of legume species to photoperiod.

These results provide valuable new information for modelling chickpea growth and development in cool-temperate subhumid climates. Simulation models of lentil (McKenzie *et al.* 1994) and pinto bean (*Phaseolus vulgaris* L., Dapaah *et al.* 1999) growth and development have shown various responses to temperature and photoperiod. The lack of response to photoperiod shown in the present work with these chickpea cultivars indicates that simulation modellers will need to use appropriate equations when modelling all stages, but e-f in particular.

One other aspect of modelling that these results may influence is the response of phenology to irrigation. While all crop models include a function whereby irrigation alleviates water stress, resulting in increased dry matter production, many models do not consider the alteration of development times due to irrigation. The present data set clearly shows that irrigation can delay development, resulting in longer duration of growth, and higher yields.

Functional growth analysis of maxDM showed that the positive response to irrigation of chickpea was due to increases of both the duration of exponential growth and the maximum crop growth rate. Faster growth rates are associated with increased light interception that is the function of greater green

area index and duration (Ball *et al.* 2000). These findings can form the basis of irrigation management to optimize chickpea development. The yield potential of chickpea can be increased by modifying its phenology, because crop yield is fundamentally related to different phenological stages which affect the capture and utilization of different environmental resources such as solar radiation, nutrients and water (Saxena *et al.* 1990).

These results have provided chickpea growers in New Zealand with a valuable set of guidelines for sowing date and irrigation strategies. Clearly, sowing date is not as important with chickpeas as with both

lentils and peas. Phenological development of the chickpea crop permits later sowing than other legumes in Canterbury, as yields are high due to adequate crop duration and high growth rates. Chickpeas can therefore fit easily into cropping rotations, as an early or autumn sown crop can be harvested and followed rapidly by a sowing of chickpea.

The authors would like to thank Dr Bert Vandenberg of the University of Saskatchewan, Canada for supplying the Kabuli chickpea seed and the Lincoln University Research Committee for providing funds for the projects.

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