Effect of irrigation on growth and yield of *Kabuli* chickpea (*Cicer arietinum* L.) and narrow-leafed lupin (*Lupinus angustifolius* L.)

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Abstract

The response in growth and yield of *Kabuli* chickpea (*Cicer arietinum* L.) cv. Princepe and narrow-leafed lupin (*Lupinus angustifolius* L.) cv. Fest to different irrigation levels when unirrigated (water stressed), given half irrigation, full irrigation and double irrigation (waterlogged) and full irrigation with 150 kg N ha^{-1} (optimum, control plots) was investigated on a Templeton silt loam soil at Lincoln University in 2007/08. Irrigation had a marked effect on growth and yield. There was a 51 % increase in the weighed mean absolute growth rate (WMAGR) with full irrigation over no irrigation. In *Kabuli* chickpea, WMAGR with full irrigation was 18.6 g m^{-2} day^{-1} and in narrow-leafed lupin it was 23.0 g m^{-2} day^{-1}. Seed yields of fully-irrigated crops were treble the unirrigated treatment. With full irrigation, seed yield of chickpea was 326 and that of lupin 581 g m^{-2}. Seed yield of the two legumes fell 45 % with double irrigation compared with full irrigation. Nitrogen (N) fertilizer did not increase seed yield in either legume. The increased seed yield resulted from increased radiation interception. With full irrigation, total intercepted photosynthetically active radiation (PAR) increased by 28 % and 33 % over that in nonirrigated plants in *Kabuli* chickpea and narrow-leafed lupin, respectively. The results of this study suggest that to achieve their yield potential, crops should be irrigated to replace water deficit over the whole of crop growth.

Introduction

On East Coast farms in New Zealand there is a requirement for irrigation to achieve potential yield of most crops (McKenzie *et al.*, 1999). Numerous reports indicate that irrigation more than doubles seed yields of grain legumes over unirrigated crops (i.e. water deficit conditions); narrow-leafed lupin (*Lupinus angustifolius* L.) (Herbert, 1977), lentil (*Lens culinaris* Medik.) (McKenzie, 1987), field bean (*Vicia faba* L.) (Husain, 1984), pinto beans (*Phaseolus vulgaris* L.) (Dapaah *et al.*, 2000), and *Kabuli* chickpea (*Cicer arietinum* L.) (Anwar, 2001). Water deficits reduce growth and yield (Castellanos *et al.*, 1996; Anwar *et al.*, 2003b; Thomas *et al.*, 2004). In irrigated fields, water logging may occur due to rain, after irrigation, or from over irrigation. Water logging has been shown to negatively affect crop yield (Greenwood and McNamara, 1987; Bacanamwo and Purcell, 1999).

Grain legumes accumulate nitrogen (N) from symbiotic N fixation and uptake from both soil and N fertilizer (Chapman and Muchow, 1985). Grain legumes require large amounts of N for seed development and N needs are extracted from vegetative parts (Sinclair and de Wit, 1976). As N fixation only partially meets the demand of seed growth, there might be a need for N from other sources such as fertilizer (Gan *et al.*, 2003;

Gutiérrez-Boem *et al.*, 2004). Before nodulation is fully established, legumes might experience N deficiency. Legume growth and seed yield responses might occur if N fertilizer is applied at a low rate (Sprent and Minchin, 1983). However, there have been no consistent responses of soybean (*Glycine max* L.) seed yield to N fertilizer (Salvagiotti *et al.*, 2008). Kosgey (1994) reported that additional N fertilizer had no effect on seed yield but Verghis (1996) indicated that seed yield of chickpea increased by 18 % with a N fertilizer application of 90 kg N ha^{-1} in a soil with low available N. McKenzie and Hill (1995) observed that seed yield increased by 17 % and 43 % with N fertilizer at 50 and 100 kg N ha^{-1}, in both *desi* and *Kabuli* chickpea.

While there are numerous studies on the effect of irrigation on yield and growth, information on the effect of over irrigation and of N fertilizer on legume growth and yield is required to confirm results from elsewhere. Therefore a field study was conducted with different levels of water supply ranging from a water deficit to excess water, with and without N fertilizer, to obtain an understanding of the variation in growth and yield of *Kabuli* chickpea and narrow-leafed lupin. This work will provide information which can be used in developing mechanistic legume models for predicting the yield of grain legumes in a cropping system. This information will be useful for farmers in making decisions on irrigation and fertilizer application to legumes. The present study was designed to examine the growth and yield response of the two legumes to different irrigation levels and N fertilizer application.

Materials and Methods

Site and climate

The experiment was conducted at the Horticultural Research Area, Lincoln University, Canterbury (43^{o} 38’ S, 172^{o} 30’ E) between November 2007 and April 2008. Prior to the experiment the field was in perennial ryegrass (*Lolium perenne* L.). The soil is a Templeton silt loam (New Zealand Department of Scientific and Industrial Research, 1968) which is further classified as an immature pallic soil (Hewitt, 1998) with a water holding capacity, at field capacity, of 32 mm per 10 cm soil depth. Soil fertility was moderately high in the 0 - 15 cm layer according to a New Zealand Ministry of Agriculture and Fisheries soil test (Table 1).

Table 1: Soil chemical properties for the 0-15 cm soil layer at the Horticultural Research Area, Lincoln University, Canterbury in 2007/08. Olsen-soluble P, Ca, Mg, K, Sulphate S and Na measured as µg g^{-1} soil, anaerobic mineralizable N as kg ha^{-1} and base saturation as a percentage.

pH	P	Ca	Mg	K	S	Na	N	Base saturation
6.1	26	1060	74	109	3	25	36	53.3

Climate data were recorded at Broadfields Meteorological Station, Lincoln University, located about 1 km from the experimental site. Total solar radiation from October 2007 to April 2008 was 4 % higher than the long term average. Maximum and minimum temperatures were similar to the long term average. Rain from October 2007 to April 2008 was 3 % higher than the long term mean and a total of 363 mm fell. The higher rain, during this period, was due to more rain in October, December and February. In October and February rain was 47 % and 142 % higher than the long term average. In the other months, rainfall was lower than the long term average. Although rainfall was higher than the long term average, Penman evapotranspiration was 4 % higher than the long term mean. This gave drier conditions and a higher water deficit than the long term average (Figure 1).

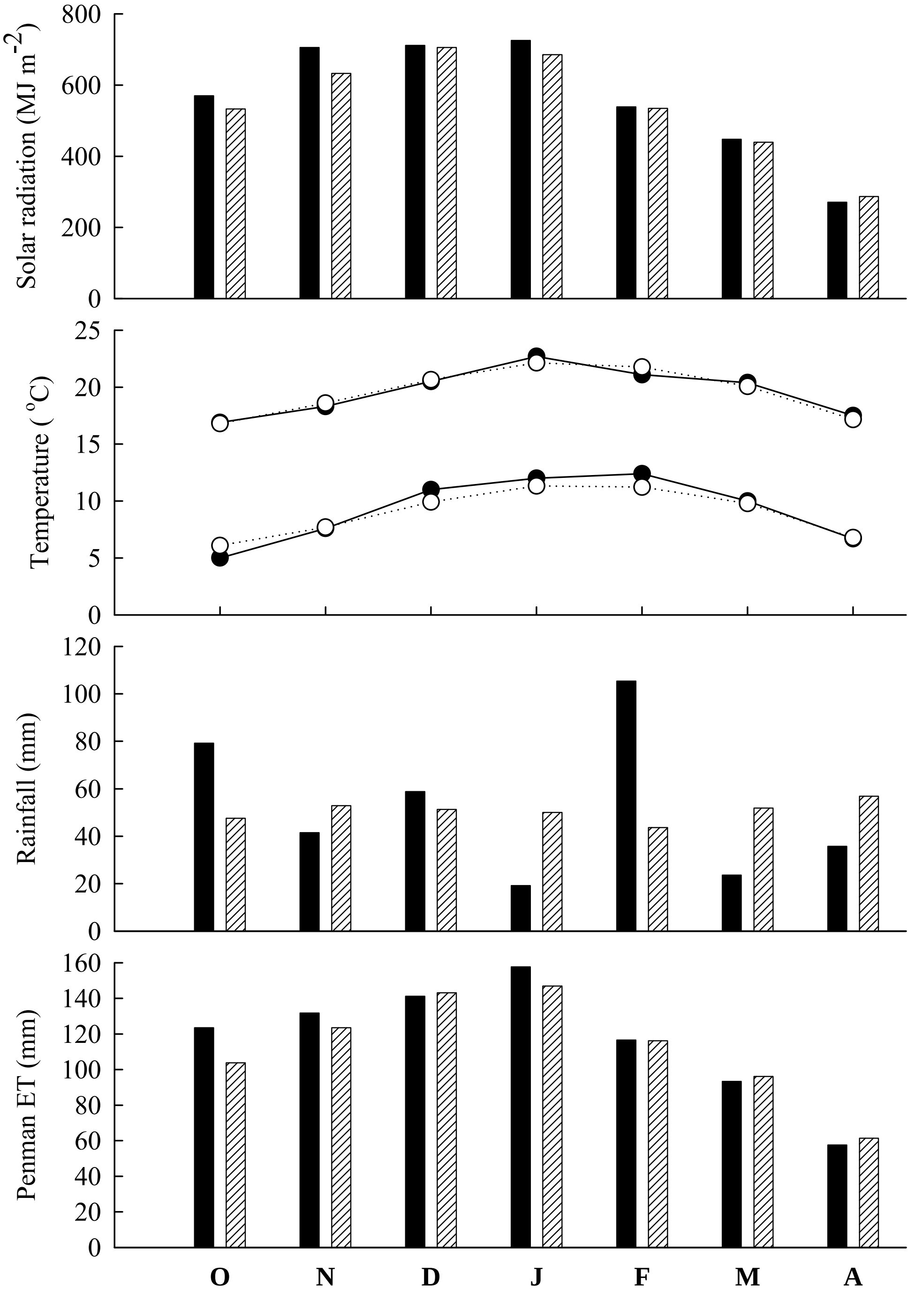

Figure 1: Weather data for 2007/08 (■,●) and long term means (▨,○) at Lincoln University, Canterbury, New Zealand. Long term values recorded from 1961 to 2008.

Experimental design and crop husbandry

A split-plot design with three replicates was used. Five irrigation levels (Table 2) were assigned as main plots and two legume species, *Kabuli* chickpea (*Cicer arietinum* L) (cv. Principe) and narrow-leafed lupin (*Lupinus angustifolius* L) (cv. Fest) were assigned as sub-plots. No space was left between sub-plots in each main plot but 3 m and 5 m spaces were left between main plots and replicates, respectively. Sub-plot size was 29.4 m^2, 14 m x 2.1 m (14 rows). Rows were 15 cm apart. A T-tape irrigation system was used to ensure even distribution of irrigation water over the whole plot. Tapes were placed in every second crop row. The amount of water applied was measured by a flow meter (Neptune, type Sz, size 25.4 mm). Irrigation was applied when the volumetric soil moisture content was around 20 %. The amount of irrigation water applied for full irrigation was equal to the actual soil moisture deficit, i.e. the difference between the actual soil moisture content of the current week and field capacity. The volumetric soil moisture content at field capacity was estimated to be 32 %. The volumetric soil moisture content was measured using Time Domain Reflecometry (TDR) Trase system 1 Model 6050X1 from 0 - 30 cm soil depth. This volumetric moisture content was converted into depth of water per unit depth of soil per unit area i.e. millimetre of water $centimetre^{-1}$ of soil and eventually into litres of water. The flow meter ensured accurate application of irrigation water.

Table 2: Irrigation treatments assigned in the experiment 2007/08.

	Amount of irrigation (mm)	
Irrigation treatment	*Kabuli* Chickpea	Narrow-leafed lupin
Nil	0	0
Half	165	165
Full	331	394
Double full	661	787
Full + N (Control)	331	394

Seed was cleaned and treated with the fungicide WAKIL® XL (metalaxyl-M a.i. 175 g kg^{-1}, fludioxonil a.i. 50 g kg^{-1}, cymoxanil a.i. 100 g kg^{-1}) at 2 kg (dissolved in water) 1,000 kg^{-1} of seed. Seed was inoculated before sowing. Seed, with a germination > than 85 %, was sown with a cone seeder to obtain target plant populations of 50 and 100 plants m^{-2} for *Kabuli* chickpea and narrow-leafed lupin, respectively. Weed control used different herbicides at various growth stages. Treflan (trifluralin, a.i. 400 g l^{-1}) was applied at 1 - 2 l ha^{-1} pre-sowing and Simazine 500 (simazine a.i. 500 g l^{-1}) at 1.5 l ha^{-1} pre-emergence. Calcium ammonium nitrate (27 % N) was applied after sowing at 150 kg N ha^{-1} only to the control treatment of full irrigation with N.

Measurements and analysis

Above-ground dry matter (DM) accumulation was determined by the weekly increase in total crop DM. Samples were taken at random using two 0.1 m^2 quadrats. Samples were then dried to constant weight. Sigmodial growth curves were fitted as a general logistic function as described by Gallagher and Robson (1984) using the maximum likelihood programme (Ross *et al.*, 1987).

$$Y = C/(1 + T \exp(-b(x-m)))^{1/T} \quad \text{Equation 1}$$

Where C is the expected maximum crop DM and T, b and m are constants. These values were used to calculate the weighted mean absolute growth rate (WMAGR), duration of exponential growth (DUR) and the maximum growth rate (MGR).

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

$$DUR = 2(T+2)/b \quad \text{Equation 3}$$

$$MGR = bC/(T+1)^{((T+1)/T)} \quad \text{Equation 4}$$

Three crop phenological developmental stages, first flower, first pod and physiological maturity were recorded by observations at 1 - 2 day intervals. First flowering was recorded when 50 % of plants in a plot had one flower. First pod was recorded when 50 % of plants in a plot had set one pod. Physiological maturity was when 50 % of plants in a plot had one brown pod. Plots were harvested when plants had completely senesced. At harvest maturity, total DM production, seed yield and harvest index (HI) were determined from an area of 1 m^2 taken from the 5 central rows of each plot using two 0.5 m^2 cuts.

Leaf area index (LAI) and the fraction of radiation transmitted (T_i) through the canopy were measured using a LICOR LAI 2000 Plant Canopy Analyser (LI-COR Inc., Lincoln, Nebraska, USA). Leaf area duration was calculated following Hunt (1978). Measurements were taken at 7 - 10 day intervals from 28 d after sowing until the onset of complete plant senescence. In a plot, at each session, 2 above canopy and 6 below canopy measurements were taken. The fraction of radiation intercepted (F_i) was determined using the techniques of Gallagher and Biscoe (1978). Radiation use efficiency (RUE) values were estimated using two methods, (1) as the ratio of above-ground DM at final harvest to total intercepted PAR, (2) as the slope of the linear relationship between accumulated above-ground DM and accumulated intercepted PAR using linear regression up to maximum DM (Sinclair and Muchow, 1999).

Statistical analysis used the Genstat package (Version 10.1, Lawes Agricultural Trust, Rothamsted Experimental Station, Rothamsted).

Results

Dry matter accumulation (Plant growth analysis)

Regardless of irrigation treatment, legume species and N fertilizer, DM accumulation was adequately described by a sigmoid curve (Figure 2). On average, over the two legumes, there was no difference between the control plot with full irrigation and with N fertilizer (2,123 g m^{-2}) and the control with full irrigation alone (1,777 g m^{-2}) (Table 3). Full irrigation significantly increased both the WMAGR and MGR. The average values for the two species for WMAGR were 51 % higher in fully irrigated plots (*c.* 20.8 g m^{-2} day^{-1}) than in unirrigated plots (*c.* 13.7 g m^{-2} day^{-1}). Fully irrigated plots had an averaged MGR of 30.9 g m^{-2} day^{-1}, a 48 % increase over unirrigated plots. Water logging (double the full irrigation treatments) and N fertilizer did not significantly affect WMAGR or MGR. The maximum growth rate of *Kabuli* chickpea was 26.1 g m^{-2} day^{-1} and it was 29.7 g m^{-2} day^{-1} in narrow-leafed lupin (Table 3). The duration of exponential growth was not affected by irrigation or N fertilizer (Table 3).

Above-ground DM, seed yield and harvest index (HI)

Averaged over the two legume species, there was a threefold increase in above-ground DM from nil to full irrigation. However, TDM fell by 30 % from full irrigation to double irrigation (Table 4). Narrow-leafed lupin responded more to irrigation than *Kabuli* chickpea. While there was a fourfold increase in TDM in narrow-leafed lupin there was a threefold increase in *Kabuli* chickpea. Under waterlogged conditions (double irrigation), TDM decreased by 30 % from full irrigation in both *Kabuli* chickpea and narrow-leafed lupin. With full irrigation, total dry matter (TDM) yield was 1,205 and 2,267 g m^{-2} for *Kabuli* chickpea and narrow-leafed lupin, respectively (Figure 3). Addition of N fertilizer had no significant effect on TDM and there was no interaction between N and legume

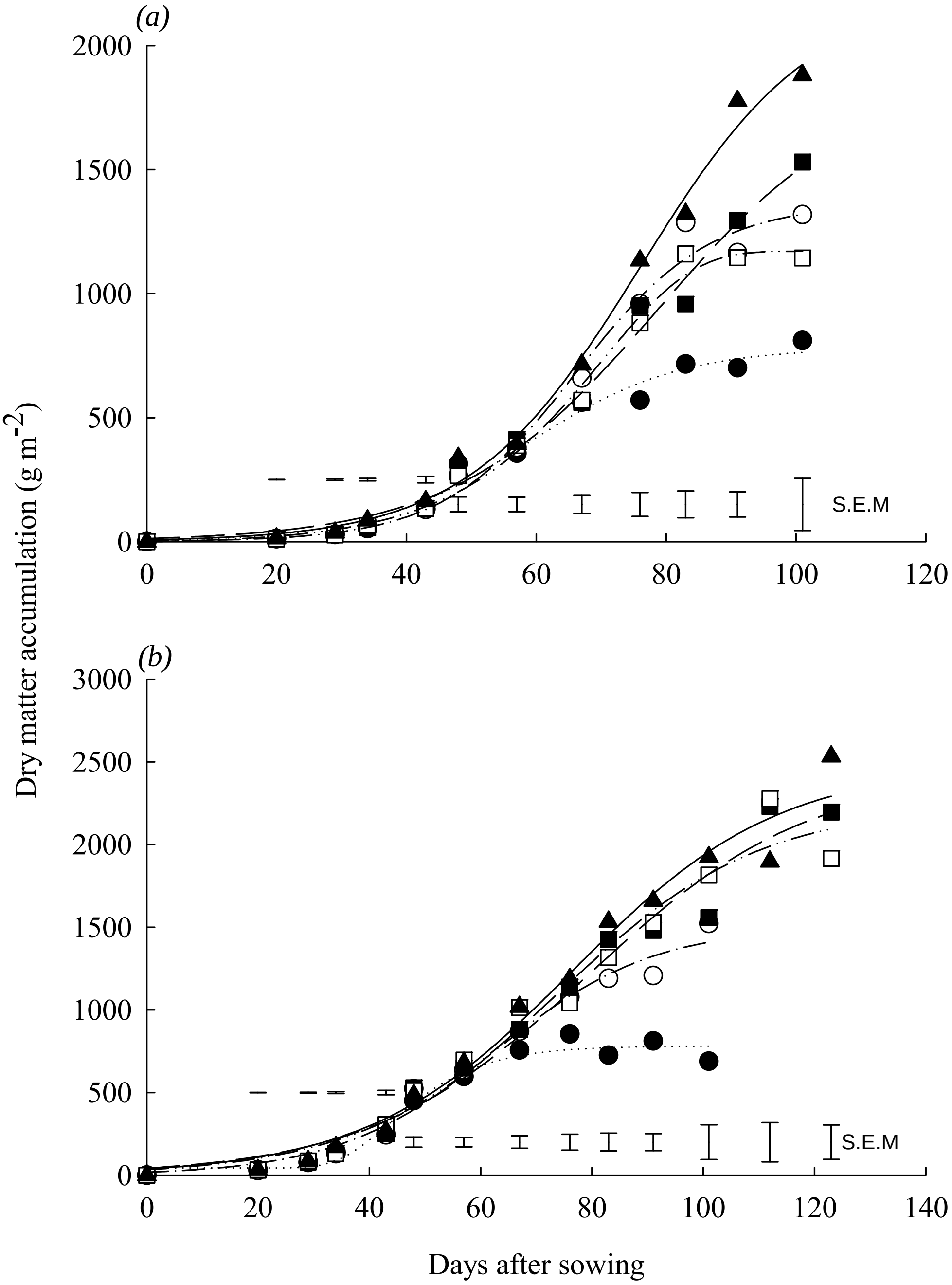

Figure 2: Accumulated dry matter of *Kabuli* chickpea *(a)* and narrow-leafed lupin *(b)* grown under different irrigation levels; nil (●), half (○), full (■), double (□) and full + N (▲) at Lincoln University, Canterbury, New Zealand in 2007/08. $Y = C/(1 + T \exp(-b(x-m)))^{1/T}$. S.E.M = standard error of mean with D.F. = 8.

species on TDM at final harvest. Averaged over legume species, the above-ground DM with full irrigation and N fertilizer was 1,856 g m^{-2} (Table 4).

Seed yield with full irrigation was three times higher than with nil irrigation. Averaged over the two legumes, full irrigation gave the highest seed yield at 454 g m^{-2}. Double irrigation (waterlogged condition) decreased the yield by 45 % below full irrigation yield (Figure 3). Full irrigation increased seed yield of narrow-leafed lupin six fold. However, there was only a twofold increase in *Kabuli* chickpea seed yield. This was reversed with double irrigation. Seed yield of narrow-leafed lupin decreased 42 % but *Kabuli* chickpea yield decreased by 51 % (Figure 3). Seed yield of the two legumes was not affected by fertilizer N (Table 4).

Table 3: The effect of irrigation level and N fertilizer application on maximum dry matter, (MaxDM), duration of exponential growth (DUR), weighted mean absolute growth rate (WMAGR) and maximum growth rate (MGR) of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

Irrigation level (I)	MaxDM ($g\ m^{-2}$)	DUR (days)	WMAGR ($g\ m^{-2}\ day^{-1}$)	MGR ($g\ m^{-2}\ day^{-1}$)
Nil	690	56	13.7	20.9
Half	1277	74	17.8	26.5
Full	1777	86	20.8	30.9
Double	1536	87	18.0	26.7
S.E.M (D.F. = 8)	172.8	9.3	1.6	2.4
Significance	**	ns	*	*
Significant trends				
Linear (I_L)	ns	ns	ns	ns
Quadratic (I_Q)	*	ns	*	*
Species (S)				
Kabuli chickpea	1302	76	17.5	26.1
Narrow-leafed lupin	1660	83	19.9	29.7
S.E.M (D.F. = 10)	74.9	5.8	0.8	1.3
Significance	**	ns	ns	ns
Nitrogen fertilizer				
Kabuli chickpea at Full + N	2105	96	22.7	33.5
Narrow-leafed lupin at Full + N	2140	92	23.9	35.5
Means of Full + N	2123	94	23.3	34.5
Designed contrast (Full + N vs. Full)	***	ns	ns	ns
CV %	19.6	28.2	17.4	18.2
Significant interactions				
I x S	*	ns	ns	ns
I_L x S	*	ns	ns	ns
I_Q x S	ns	ns	ns	ns
(Full + N vs. Full) x S	ns	ns	ns	ns

ns = non-significant, * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$.

Average HI values, over the two legumes, were not significantly different among irrigation levels. However, there was a significant interaction between irrigation level and legume species (Table 4). While the HI of *Kabuli* chickpea tended to decline with irrigation, the HI of narrow-leafed lupin increased with increased irrigation up to full irrigation. In *Kabuli* chickpea, the crop gave the highest HI (0.34) with half irrigation and the lowest with double irrigation (0.19). In contrast, narrow-leafed lupin had the highest HI (0.26) under full irrigation and the lowest in the non irrigated plots (0.17) (Figure 4). Averaged over irrigation levels, *Kabuli* chickpea had a significantly higher HI than narrow-leafed lupin. There was no effect of N fertilizer on HI (Table 4).

Yield components

Full irrigation gave the highest number of seeds. Lowest seed number was from the unirrigated and double irrigated plots. On average, *Kabuli* chickpea produced 1 seed pod^{-1} whilst, narrow-leafed lupin had 4 seeds pod^{-1} (Table 5). The number of pods was not affected by N fertilizer application and the fertilizer by species interaction was not significant. Full irrigation gave the highest number of seeds and the lowest number was recorded in unirrigated and double irrigated plots. Averaged over the two legumes, the 100 seed weight was not affected by irrigation or N fertilizer. *Kabuli* chickpea seed (26 g 100 seed^{-1}) was nearly twice as heavy as the lupin seed (16 g 100 seed^{-1}) (Table 5).

Table 4: Effect of irrigation level and N fertilizer application on seed yield, above-ground DM and crop harvest index of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

Irrigation level (I)	Seed yield (g m^{-2})	Above-ground DM (g m^{-2})	Harvest index
Nil	139	536	0.25
Half	280	961	0.30
Full	454	1736	0.27
Double	248	1212	0.20
S.E.M (D.F. = 8)	32.4	133.6	0.02
Significance	***	***	ns
Significant trends			
Linear (I_L)	ns	**	*
Quadratic (I_Q)	***	**	ns
Species (S)			
Kabuli chickpea	262	1012	0.27
Narrow-leafed lupin	352	1508	0.22
S.E.M (D.F. = 10)	23.3	75	0.01
Significance	*	***	**
Nitrogen fertilizer			
Kabuli chickpea at Full + N	330	1574	0.21
Narrow-leafed lupin at Full + N	501	2138	0.23
Means of Full + N	415	1856	0.22
Designed contrast (Full + N vs. Full)	ns	ns	ns
CV %	29.4	23.1	14.9
Significant interactions			
I x S	*	*	**
I_L x S	*	*	*
I_Q x S	ns	ns	ns
(Full + N vs. Full) x S	ns	ns	ns

ns = non-significant, * = P < 0.05, ** = P < 0.01 and *** = P < 0.001.

Full irrigation gave the highest number of seeds m^{-2} (Table 5). No irrigation and double irrigation decreased seeds m^{-2} by 75 % and 40 %, respectively. The number of seeds m^{-2} in narrow-leafed lupin was more than twice as high as in *Kabuli* chickpea. Additional N fertilizer did not significantly change the number of seeds m^{-2} (Table 5).

In both *Kabuli* chickpea and narrow-leafed lupin, pods plant^{-1} and seeds m^{-2} were strongly related to seed yield (Table 6). There were also higher significant relationship between crop growth parameters and the two traits (Table 7; Figures 5, 6).

Leaf area index, radiation interception and radiation use efficiency

In *Kabuli* chickpea, non-irrigated plots reached a maximum LAI of 2.32 while fully-irrigated plots reached a maximum LAI of 3.96 at 76 days after sowing (DAS) (Figure 7a). While fully-irrigated narrow-leafed lupin had a maximum LAI of 6.21, unirrigated narrow-leafed lupin only had a maximum of 2.2 at 61 DAS (Figure 7b). For both legumes the LAI with double full irrigation was not significantly different from that with full irrigation. Nitrogen fertilizer only increased the LAI of *Kabuli* chickpea at 91 DAS (Figure 7a).

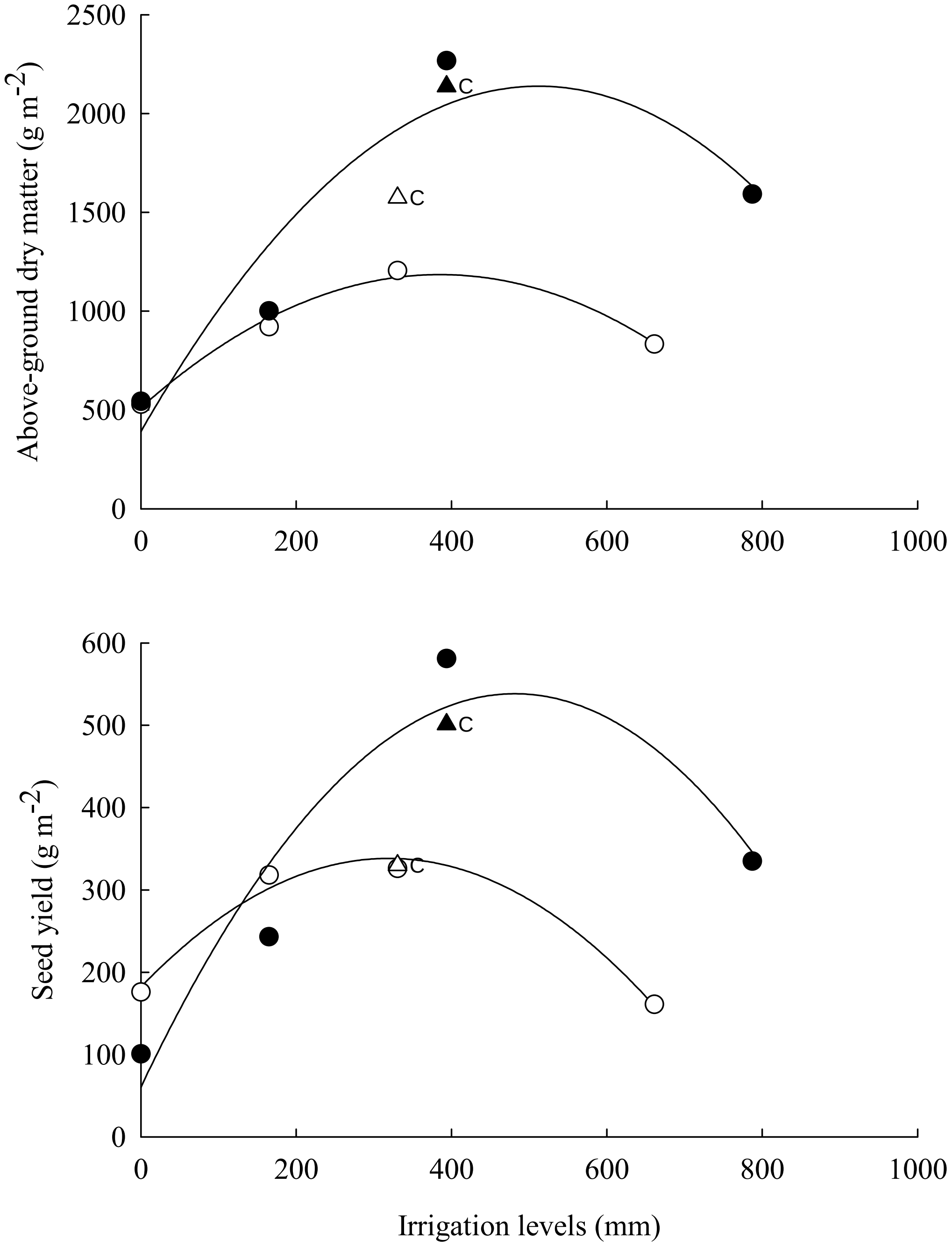

Figure 3: Total above-ground dry matter and seed yield responses of *Kabuli* chickpea and narrow-leafed lupin to different levels of irrigation. For *Kabuli* chickpea (○), relationships between irrigation levels and TDM and seed yield are
Y = -0.005X^2 + 3.50X + 511.28 (R^2 = 0.99) and
Y =-1.53X^2 + 0.98X + 182.02 (R^2 = 0.98).
For narrow-leafed lupin (●), relationships between irrigation levels and TDM and seed yield are
Y = -0.01X^2 + 6.83X + 390.34 (R^2 = 0.89) and
Y = -0.002X^2 +1.98X + 60.30 (R^2 =0.89);
respectively. Controls: full irrigation with 150 kg N ha^{-1} for *Kabuli* chickpea (△C) and for narrow-leafed lupin (▲C).

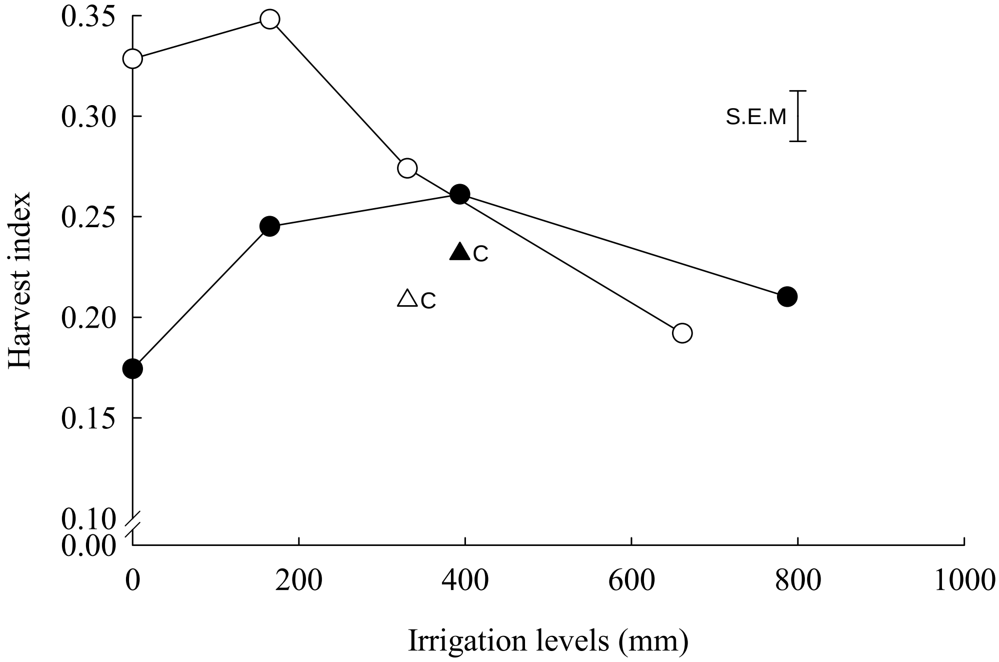

Figure 4: Harvest index response of *Kabuli* chickpea (○) and narrow-leafed lupin (●) to irrigation level. Controls: full irrigation with 150 kg N ha^{-1} for *Kabuli* chickpea (△C) and for narrow-leafed lupin (▲C). S.E.M = standard error of mean.

In this work, with full irrigation, crops achieved canopy closure and intercepted more than 95 % of the incoming incident radiation at LAIs of 2.9 and 3 for *Kabuli* chickpea and narrow-leafed lupin, respectively. In contrast, in non-irrigated plots, crops achieved a maximum fraction of radiation intercepted of less than 90 % as maximum LAIs were only 2.3 and 2.4 for *Kabuli* chickpea and narrow-leafed lupin, respectively (Figure 8). As a result, Full irrigation increased total PAR of *Kabuli* chickpea by 28 %, the total intercepted PAR of narrow-leafed lupin increased by 33 %. Double irrigation and N fertilizer did not significantly reduce total intercepted PAR compared to full irrigation of the two legumes (Table 8).

In *Kabuli* chickpea, final RUE increased 80 % and the RUE of narrow-leafed lupin increased 216 % with full irrigation. In the no irrigation plots *Kabuli* chickpea had a RUE of 0.83 g DM MJ^{-1} PAR and narrow-leafed lupin had a RUE of 0.69 g DM MJ^{-1} PAR. However, with full irrigation the final RUE of *Kabuli* chickpea was 1.49 g DM MJ^{-1} PAR and that of narrow-leafed lupin was 2.17 g DM MJ^{-1} PAR (Table 8). Radiation use efficiency (based on the slope of the linear relationship between accumulated above-ground DM and accumulated intercepted PAR) of *Kabuli* chickpea fell by 34 % and that of narrow-leafed lupin fell by 30 % in no irrigation plots compared with full irrigation. With full irrigation, RUE values were 2.07 and 2.50 g DM MJ^{-1} PAR for *Kabuli* chickpea and narrow-leafed lupin, respectively. Nitrogen increased the RUE of *Kabuli* chickpea by 28 % (Figure 9).

Table 5: Effect of irrigation level and N fertilizer application on yield components of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

Irrigation level (I)	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight (g)	Seeds m^{-2}
Nil	6	2	23	611
Half	11	3	24	1262
Full	25	3	20	2464
Double	20	2	17	1489
S.E.M (D.F. = 8)	2.57	0.09	1.92	196.1
Significance	**	*	ns	***
Significant trends				
Linear (I_L)	**	ns	*	**
Quadratic (I_Q)	*	**	ns	***
Species (S)				
Kabuli chickpea	27	1	26	1066
Narrow-leafed lupin	9	4	16	2173
S.E.M (D.F. = 10)	2.43	0.05	0.73	119.1
Significance	***	***	***	***
Nitrogen fertilizer				
Kabuli chickpea at Full + N	40	1	22	1464
Narrow-leafed lupin at Full + N	13	4	16	3085
Means of Full + N	26	3	19	2274
Designed contrast (Full + N vs. Full)	ns	ns	ns	ns
CV %	52.9	8.1	13.6	28.5
Significant interactions				
I x S	ns	*	**	*
I_L x S	ns	*	***	ns
I_Q x S	ns	*	ns	*
(Full + N vs. Full) x S	ns	ns	ns	ns

ns = non-significant, * = P < 0.05, ** = P < 0.01 and *** = P < 0.001.

Table 6: Correlation matrices between seed yield and yield components of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

	Seed yield	Total dry matter	Harvest index	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight
Kabuli chickpea						
Total dry matter	0.70**					
Harvest index	0.31ns	-0.42 ns				
Pods plant^{-1}	0.28ns	0.69**	-0.62*			
Seeds pod^{-1}	0.61*	0.13 ns	0.56*	0.07 ns		
100 seed weight	0.24ns	-0.34 ns	0.86**	-0.56*	0.42 ns	
Seeds m^{-2}	0.79**	0.92**	-0.26ns	0.65**	0.22ns	-0.37ns
Narrow-leafed lupin						
Total dry matter	0.98**					
Harvest index	0.56*	0.44 ns				
Pods plant^{-1}	0.86**	0.90**	0.34 ns			
Seeds pod^{-1}	0.66**	0.66**	0.50 ns	0.74**		
100 seed weight	0.51ns	0.45 ns	0.78**	0.44 ns	0.71**	
Seeds m^{-2}	0.99**	0.98**	0.53*	0.85**	0.62*	0.46ns

ns = non-significant, * = P < 0.05 and ** = P < 0.01.

Table 7: Correlation matrices between growth parameters and seed yield and yield components of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

	Seed yield	Harvest index	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight	Seeds m^{-2}
Kabuli chickpea						
MaxDM	0.57*	-0.43ns	0.54*	0.04ns	-0.28ns	0.73**
DUR	0.13ns	-0.26ns	0.07ns	-0.013ns	-0.11ns	0.18ns
WMAGR	0.61*	-0.28ns	0.66**	0.09ns	-0.19ns	0.75**
MGR	0.60*	-0.28ns	0.66**	0.09ns	-0.19ns	0.73**
Narrow-leafed lupin						
MaxDM	0.82**	0.32ns	0.89**	0.75**	0.49ns	0.82**
DUR	0.59*	0.16ns	0.63**	0.49ns	0.22ns	0.60*
WMAGR	0.65*	0.52*	0.66**	0.69**	0.72**	0.62*
MGR	0.62*	0.51*	0.63*	0.67**	0.72**	0.59*

ns = non-significant, * = P < 0.05 and ** = P < 0.01.

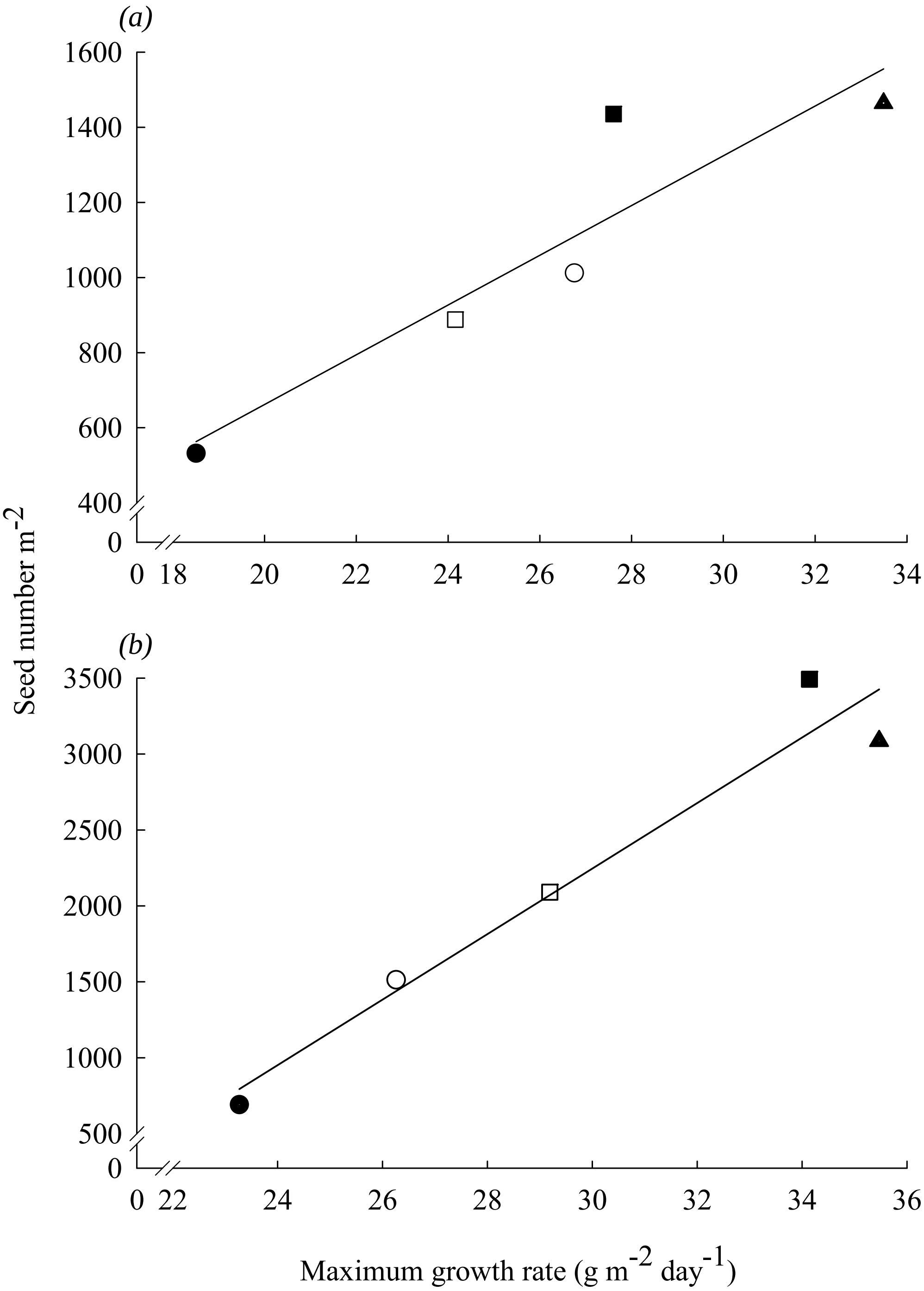

Figure 5: Relationship between maximum growth rate and seed number m^{-2} of *Kabuli* chickpea *(a)* and narrow-leafed lupin *(b)* grown under different irrigation levels; nil (●), half (○), full (■), double (□) and full + N (▲) at Lincoln University, Canterbury, New Zealand in 2007/08. The relationship equations are *(a)*, $Y = -662.91 + 66.24X$ ($R^2 = 0.85$) and *(b)*, $Y = -4228.73 + 215.81X$ ($R^2 = 0.95$).

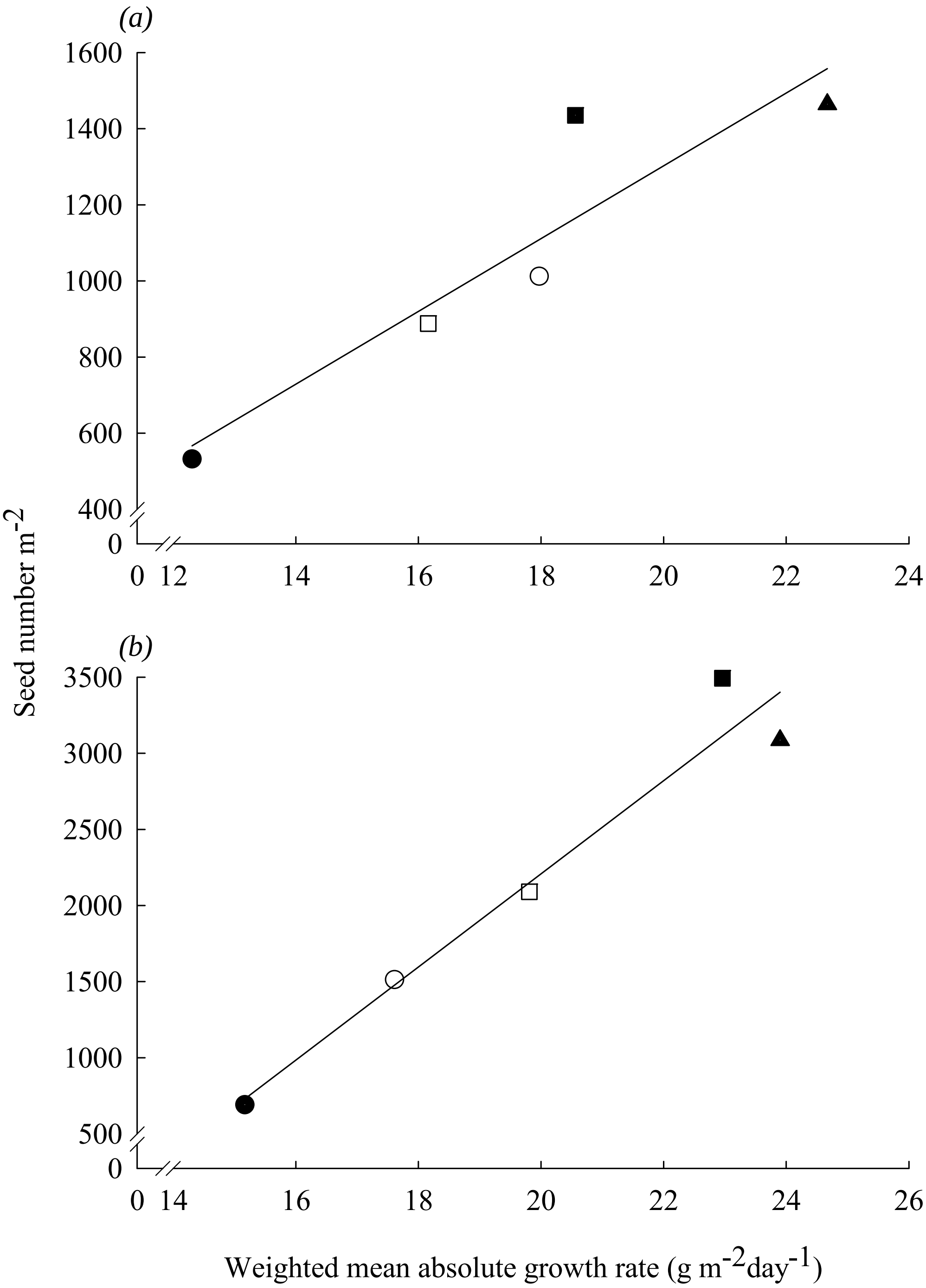

Figure 6: Relationship between weighted mean absolute growth rate and seed number m^{-2} of *Kabuli* chickpea *(a)* and narrow-leafed lupin *(b)* grown under different irrigation levels; nil (●), half (○), full (■), double (□) and full + N (▲) at Lincoln University, Canterbury, New Zealand in 2007/08. The relationship equations are
(a), $Y = -611.08 + 95.66X$ ($R^2 = 0.85$) and
(b), $Y = -3914.85 + 306.11\ X$ ($R^2 = 0.95$).

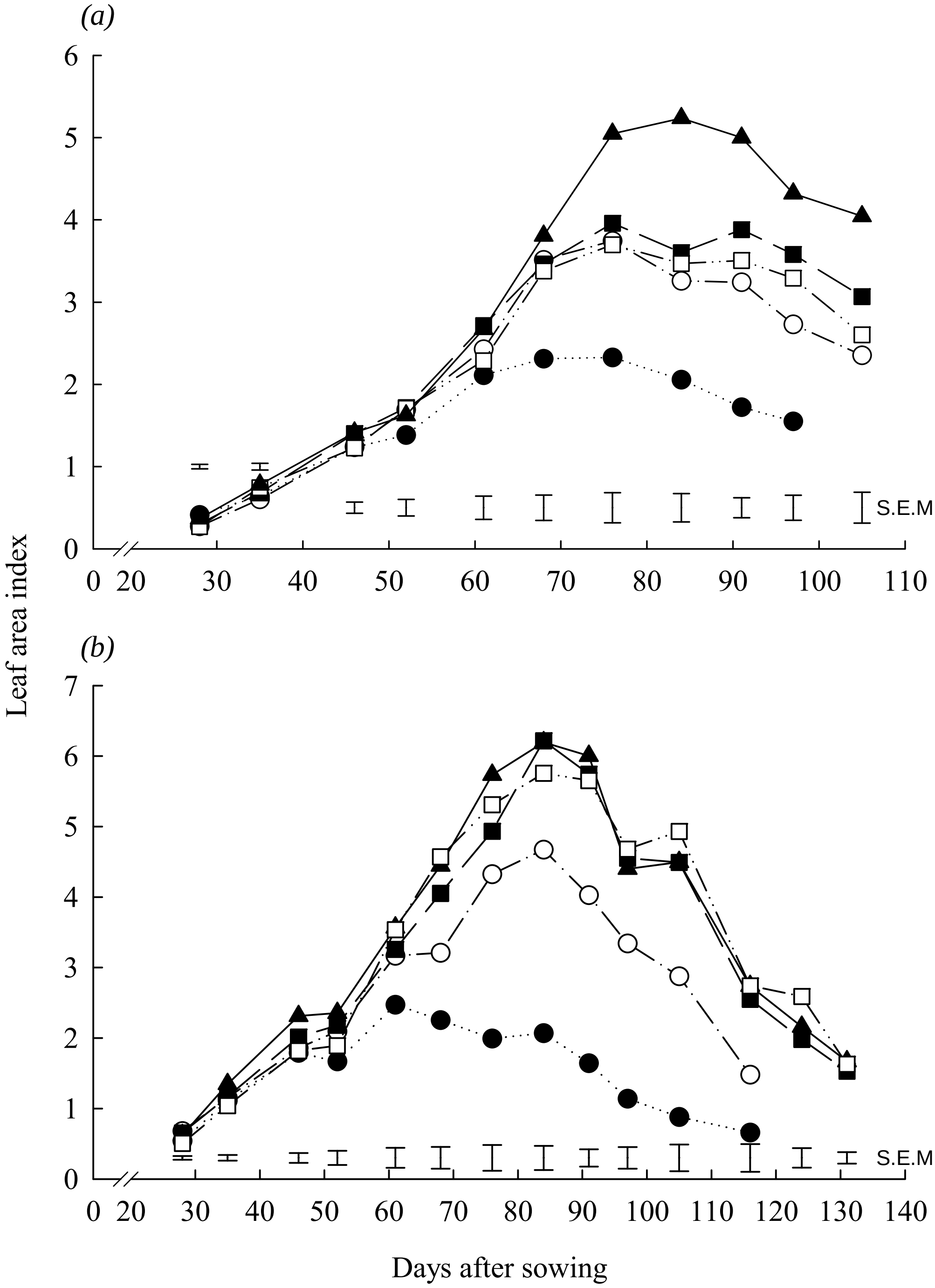

Figure 7: Effect of irrigation on leaf area index to physiological maturity of *Kabuli* chickpea (*a*) and narrow-leafed lupin (*b*) grown under different irrigation levels; nil (●), half (○), full (■), double (□) and full + N (▲) at Lincoln University, Canterbury, New Zealand in 2007/08. S.E.M = standard error of mean.

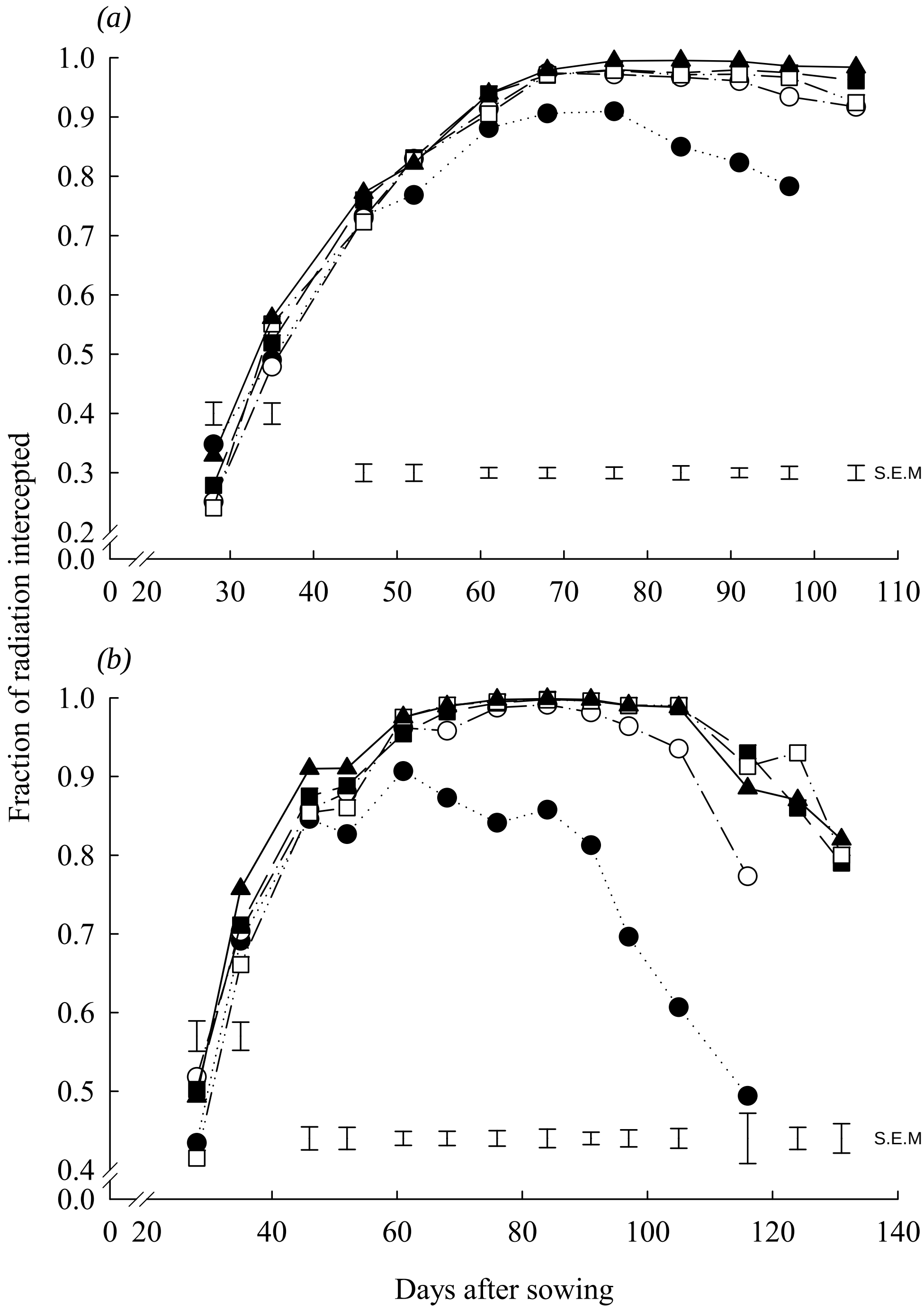

Figure 8: Effect of irrigation on the fraction of radiation intercepted until physiological maturity of *Kabuli* chickpea *(a)* and narrow-leafed lupin *(b)* grown under different irrigation levels; nil (●), half (○), full (■), double (□) and full + N (▲) at Lincoln University, Canterbury, New Zealand in 2007/08. S.E.M = standard error of mean.

Table 8: The irrigation by species interaction effect on total intercepted PAR and final radiation use efficiency (Final RUE) of *Kabuli* chickpea and narrow-leafed lupin grown at Lincoln University, Canterbury, New Zealand in 2007/08.

Irrigation level	Total PAR (MJ m^{-2})		Final RUE (g DM MJ^{-1} PAR)	
	Kabuli chickpea	Narrow-leafed lupin	*Kabuli* chickpea	Narrow-leafed lupin
Nil	630	785	0.83	0.69
Half	774	909	1.07	1.10
Full	807	1,042	1.49	2.17
Double	792	1,023	1.05	1.56
Full + N	819	1,051	1.92	2.03
S.E.M	25		0.17	
CV	2.2		20.1	

Discussion

Response to irrigation

Averaged over the two legumes, there was a threefold increase in TDM and seed yield in fully irrigated plots (Table 4). With full irrigation the seed yield of *Kabuli* chickpea was 326 g m^{-2} and that of narrow-leafed lupin was 581 g m^{-2} (Figure 3). Increased TDM and seed yield in fully irrigated plants were related to increases in growth rate, LAI, LAD, total intercepted PAR and RUE. Similar conclusions were made for lentil by McKenzie (1987), for field bean by Husain *et al.* (1988b) and for pinto bean by Dapaah *et al.* (2000).

Seed yield increases in response to irrigation were related to increased TDM and crop growth rate. Similar relationships were reported by Husain *et al.* (1988a) and Anwar *et al.* (2003a). Dapaah (1997) suggested that greater TDM in response to irrigation could have provided sufficient assimilates for yield component increases. Development of pods and seeds also depended on the growth rate and DM accumulation (Husain *et al.*, 1988b). The results showed that seed yield was significantly related to pods $plant^{-1}$, in narrow-leafed lupin and seeds m^{-2} in both *Kabuli* chickpea and narrow-leafed lupin (Table 6). The two seed yield components were significantly related to TDM and crop growth rate (Table 7; Figures 5, 6) Similar relationships were reported for different species by Muchow and Charles-Edwards (1982). Pandey (1984) emphasized the importance of critical assimilate supply in determining pod number in mung bean and in chickpea. These results support the theory that a minimum rate of assimilate supply is required for reproductive growing points, while maintaining continuous meristem viability (Charles-Edwards, 1986; Guilioni *et al.*, 2003).

Response to excess water

Seed yield was reduced by 45 % with double irrigation (designed to produce water logging). In peas, Greenwood and McNamara (1987) reported that seed yield fell 12 % with double irrigation. Toker *et al.* (2007) reported that chickpea seed yield could be reduced by 100 % by water logging. Narrow-leafed lupin seed yield was reduced by 60 % when waterlogged for 2 weeks (Davies *et al.*, 2000c). Water logging led to stomatal closure (Jackson and Hall, 1987), reduced leaf gas exchange and thus photosynthesis (Davies *et al.*, 2000b). In this work, the reduction in final RUE of narrow-leafed lupin by

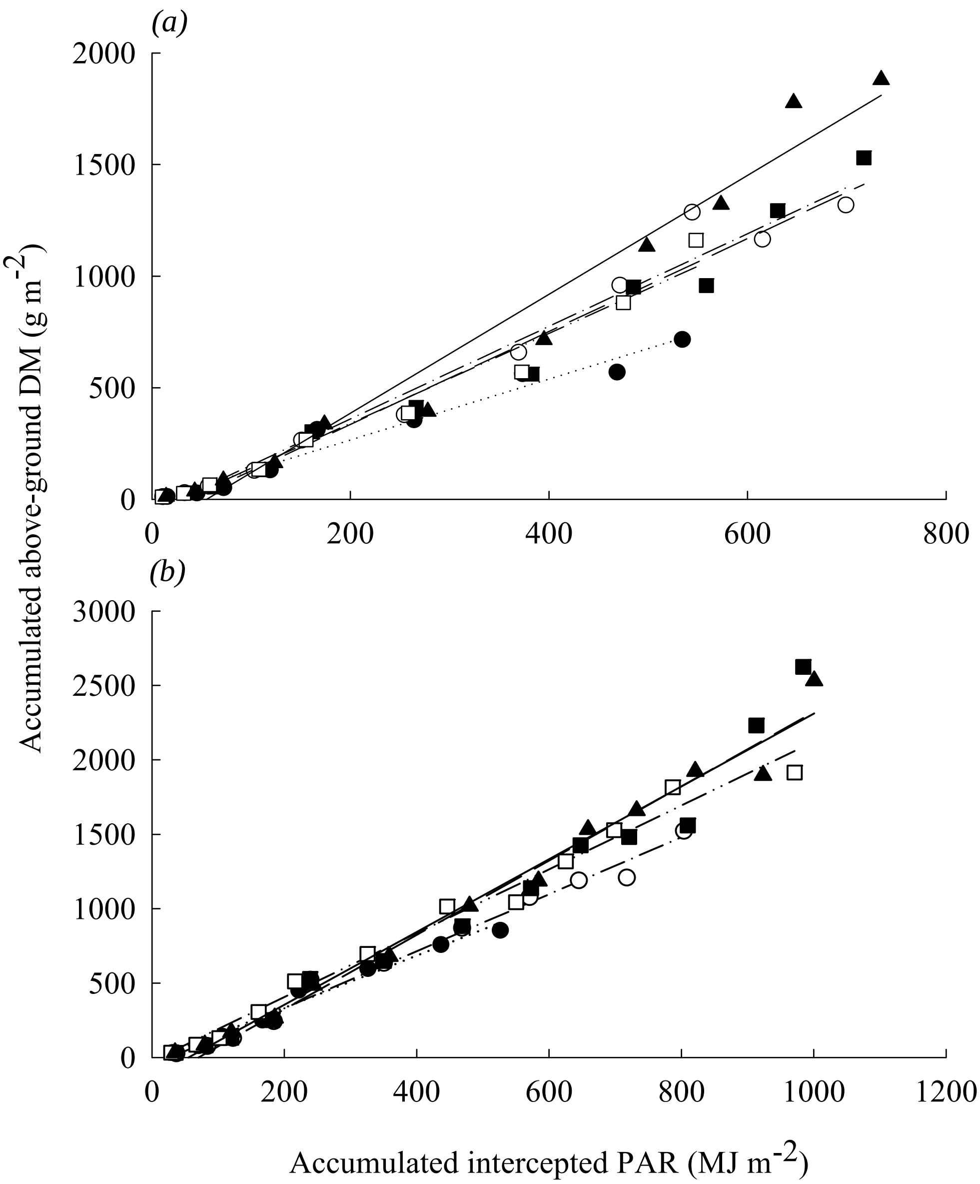

Figure 9: The relationship between accumulation of photosynthetically active radiation and above-ground dry matter production of two legumes grown under different irrigation regimes at Lincoln University, Canterbury, New Zealand in 2007/08. In any species, slopes preceded by *, ** and *** are significantly different from full treatment at $P < 0.05$, < 0.01 and <0.001, respectively.

Kabuli chickpea *(a)*:

Nil (●, ·······), Y = ***1.36X - 7.59 (R^2 = 0.96, n = 9)
Half (○,— · —), Y = 2.07X - 54.68 (R^2 = 0.97, n = 11)
Full (■,— —), Y = 2.07X - 80.37 (R^2 = 0.97, n = 11)
Double (□,— · · —),Y = 2.01X - 61.93 (R^2 = 0.97, n = 9)
Full + N (▲,——),Y = **2.66X - 146.87 (R^2 = 0.97, n=11)

Narrow-leafed lupin (*b*):

Nil (●, ·······), Y = *1.75X - 18.57 (R^2 = 0.98, n = 8)
Half (○,— · —), Y = **1.92X - 54.09 (R^2 = 0.99, n = 11)
Full (■,— —), Y = 2.50X - 175.37 (R^2 = 0.96, n = 13)
Double (□,— · · —), Y = 2.15X - 24.84 (R^2 = 0.98, n = 12)
Full + N (▲,——), Y = 2.44X - 134.57 (R^2 = 0.98, n = 13)

double irrigation might have been caused by a reduction in these processes, which in turn resulted in reduced seed yield. The reduction in seed yield of *Kabuli* chickpea by water logging can not be explained by these mechanisms as RUE in the double irrigated crop was not significantly lower than in the fully irrigated plots.

Response to nitrogen fertilizer

Seed yield of *Kabuli* chickpea and narrow-leafed lupin were not increased by N fertilizer at 150 kg N ha^{-1}. Lack of response in seed yield was reported by Bonfil and Pinthus (1995) and Walley *et al.* (2005) in chickpea and by Seymour and Brennan (1995) in narrow-leafed lupin. Sinclair and Horie (1989) argued that photosynthesis and RUE are increased by increases in specific leaf N. Sinclair and Muchow (1999) emphasized that leaf N and RUE can be increased by soil N fertility improvement. However, responses in crop growth rates and RUE to leaf N are typically curvilinear where RUE decreases if leaf N is below a ceiling point and RUE is not increased if leaf N is higher than the ceiling point (Sinclair and Muchow, 1999). Based on these arguments, there are several indications in this study for explaining the reason for no response in seed yield to added N fertilizer. In *Kabuli* chickpea, final RUE was not significantly different between fully irrigated and fully irrigated with N fertilizer plots. In narrow-leafed lupin, additional N fertilizer did not increase final RUE and crop grow rates were not significantly increased by N fertilizer. The lack of response in growth and RUE to additional N fertilizer might have been caused by a high leaf N content in fully irrigated plants, which may have reached a ceiling point. Wright *et al.* (1993) reported a ceiling value of $\geq$ 1.5 g N m^{-2} leaf area in peanut. They found no improvement in RUE when leaf N content was above this value. As discussed above, increased seed yield was related to increased TDM, crop growth rate and RUE. Hence, a high leaf N, in fully-irrigated plots, gave no response in TDM, crop growth and RUE to N fertilizer which might have been responsible for the lack of response in seed yield to added N fertilizer.

Conclusion

This work has shown that seed yield of *Kabuli* chickpea and narrow-leafed lupin was significantly increased by irrigation. Increases in seed yields were related to increased growth rates, TDM and intercepted PAR. Over irrigation reduced seed yield. Seed yield did not respond to additional N fertilizer at sowing. This work emphasized that to reach yield potential, crop should be irrigated when they need water as seed yield increase was related to the WMAGR rate, LAI and radiation interception during the whole of growth. Nitrogen fertilizer was not an option for increasing the yield of *Kabuli* chickpea and narrow-leafed lupin.

Acknowledgements

The authors thank the New Zealand's International Aid and Development Agency (NZAID) for giving SK a scholarship to study at Lincoln University. Funds for conducting the field research from the Lincoln Research Committee are gratefully acknowledged. Thanks also to Dave Jack, Don Heffer, Dr Annamaria Mills, Dr Keith Pollock, Merv Spurway and Roger Cresswell for their excellent technical assistances during field and laboratory operations.

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