A predictive model of chickpea (*Cicer arietinum* L.) yield

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Abstract

Chickpea evapotranspiration (ET) varied considerably among different irrigation regimes and yield was linearly related to cumulative water use. The results of irrigation experiments carried out at Lincoln University, Canterbury during 1998-99 and 1999-2000 were re-assessed in order to develop a simple empirical model for predicting seed yield. The general form of this model is based on functions of water use and green area index (GAI), which were used to predict total intercepted radiation. Two years of field data for chickpea, cultivar Sanford, were used to develop empirical relationships among water use, total intercepted radiation, GAI, total dry matter, pods/m^2 and seed yield. The model derived was successful in accurately predicting total intercepted PAR. A comparison of measured and modelled estimates of total intercepted PAR for three cultivars (Sanford, Dwelley and B-90) was significant ($r^2 = 0.79 - 0.97$). Seed yield of the three cultivars, both rainfed and irrigated, was predicted reasonably well. The root mean square deviations (RMSD) were 10.9 g/m^2 and 61.4 g/m^2 for rainfed and irrigated chickpeas, about 4% and 14% of the mean seed yields, respectively. Future work requires the inclusion of climate parameters, subroutines for crop specific processes and testing over a wider range of environments and cultivars.

Additional key words: *chickpea,* Cicer arietinum*, irrigation, empirical model, evapotranspiration, green area index, seed yield*

Introduction

The responses of chickpeas to supplementary irrigation have been studied in tropical, subtropical and temperate environments (Saxena *et al.*, 1990; Horn *et al.*, 1996; Singh and Virmani, 1996; Malhotra *et al.*, 1997; Prasad *et al.*, 1999; Zhang *et al.*, 2000). Large, inter-seasonal fluctuations in weather resulted in large, inter-seasonal fluctuations in water use, and therefore in production. Few attempts have been made to rationalise or to reconcile the variable responses to irrigation obtained in these environments. For example, the positive chickpea seed yield responses to irrigation water applied in the Mediterranean environment ranged from 44 to 100% (Malhotra *et al.*, 1997; Zhang *et al.*, 2000) and in India from 50 to 80% (Prasad *et al.*, 1999). In contrast, there are reports that irrigation reduced chickpea seed yield by 100% (Saxena, 1984; Ramakrishna and Reddy, 1993), due to excessive vegetative growth resulting in lodging. These large differences have obvious practical implications in terms of irrigating chickpeas for higher production.

To reconcile the conflicting yield responses to irrigation, a methodology has to be developed which can be used to predict with some certainty the expected benefits to be derived from irrigation. A model that can accurately estimate potential seed yield will facilitate the development of an irrigation-scheduling program under which water stress is eliminated. There are of course some drawbacks with the modelling approach, as most models are based on a number of assumptions, and these assumptions may vary geographically or climatically. Additionally, if these assumptions are incorrect, predictions will be inaccurate. Irrigation usually maximizes intercepted radiation through higher green area index (Muchow, 1985; Whitfield and Smith, 1989; Chapman *et al.*, 1993; Jamieson *et al.*, 1995) and crop water use (Thomas and Fukai, 1995a and b; Zhang *et al.*, 2000). It has been observed in a range of legume crops that the number of pods per plant has a clear correlation with final yield under a range of conditions, including different water regimes (Neyshabouri and Hatfield, 1986; Pannu and Singh, 1993; Haqqani and Pandey, 1994; Jamieson *et al.*, 1995). This correlation is attributed to the greater availability of reproductive sinks and the greater radiation use efficiency during the pod-filling period.

The present study was undertaken to develop an empirical model describing the physiological linkage affecting chickpea seed yield. The model can be used to estimate the potential seed yield when nutrients, pests and diseases are non-limiting.

Materials and Methods

Site, treatments and sowing

The experiments were 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 0.24% 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 (sowing to 90% physiological maturity) was about 200 mm in 1998/99 and approximately 260 mm during the 1999/2000 season. The average temperature was 15.7 °C. Two sowing (3 November 1998 and 22 November) 1999 dates were used. The experimental layout was a randomized complete block design with four irrigation levels (Table 2). Each plot was 10 m long with 14 rows each 15 cm apart for both years. The chickpea cultivar was a Canadian Kabuli type, cv. Sanford, which is high yielding, early flowering and resistant to Aschochyta blight.

Irrigation strategy

To accurately apply irrigation water at different stages of crop growth, T-tape irrigation was used (Table 2). T-tape was placed in every second row (45 cm spacing). Irrigation occurred weekly if necessary and measured with a flow meter (Neptune, type Sz, size 25.4 mm). The amount of water applied (A) was calculated as the difference between potential evapotranspiration (Ep) and rainfall plus irrigation (R + I) during the preceding week.

i.e., $$A = \sum Ep - (I + R) \qquad \text{Equation 1}$$

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

Soil moisture content was measured weekly using the Time Domain Reflectometry (TDR) Trase system 1 Model 6050X1 for the top 0-30 cm. Moisture in the remaining soil depth was measured with a Troxler neutron probe (NMM) model 4300 at 10-cm intervals to a depth of 110 cm in all the plots.

Husbandry

In both years, the seedbed was prepared using standard farm practice. Weed control was achieved

Table 1. MAF soil quick test for 0 – 30 cm depth for Iversen field research area during 1998/99 and Henley field research area during 1999/2000, Lincoln University, Canterbury. Ca, K, P, Mg, Na S and C are expressed as micrograms/g soil and NH4+, NO3- and total nitrogen (TN) as a percentage.

Season	pH	Ca	K	P	Mg	Na	S	C	NH4+	NO3-	TN
1998–1999	6.3	10	13	18	22	8	3	2.4	4.3	1	0.20
1999–2000	5.8	10	8	13	30	8	9	3.1	5.0	< 1	0.27

Table 2. Experimental irrigation treatments for cv. Sanford Kabuli chickpea in Canterbury, 1998/99 and 1999/2000.

	Sowing date	
Irrigation treatments[A]	3 November 1998	22 November 1999
1 Nil	0 mm	0 mm
2 Full[B] (emergence to maturity)	231 mm	109 mm
5 Full (flower to pod)	99 mm	58 mm
7 Full (pod to maturity)	27 mm	58 mm

[A]Applied via a T-tape irrigation system
[B]Full irrigation was applied to replace water lost to evapotranspiration

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 that had a germination of ca. 90% were sown with a tractor driven cone seeder to give a population of approximately 45 plants/m^2.

Measurements/Sampling

Total dry matter (TDM) production, seed yield and harvest index (HI) were measured from a 2.0 m^2 harvest area from the central four rows of each plot when the crop reached physiological maturity (i.e., when 50% of plants had one brown pod). Samples were air dried to about 13% seed moisture or when seeds did not bend when bitten. Dried samples were machine threshed (using a Kurtpelz stationary thresher) and straw and seed separated. The seeds were passed through a sieve to eliminate all seed of less than 2 mm in diameter. The number of pods/plant and seeds/pod were measured from five randomly selected plants from the final 2.0 m^2 sample.

Canopy development was assessed as green area index (GAI) and duration (GAD). Green area index and the amount of radiation transmitted through the canopy (Ti) were measured using a LICOR LAI2000 Plant Canopy Analyser (LI-COR Inc., Lincoln, Nebraska, USA). Green area duration was calculated as the time integral of green area index (Hunt, 1978). In both years, GAI and Ti were measured every 10 days from 28 DAS till near harvest maturity. The proportion of radiation intercepted (Fi) by the canopy was calculated according to (Gallagher and Biscoe, 1978):

$$Fi = 1.0 - Ti \qquad \text{Equation 2}$$

The amount of photosynthetically active radiation (PAR) intercepted Sa was calculated from (Szeicz, 1974):

$$Sa = Fi \times Si \qquad \text{Equation 3}$$

where Si is the total incident PAR.

Water use was assumed to be equivalent to the evapotranspiration (Et) between sowing and physiological maturity. Water use was calculated using the soil water balance approach:

$$Et = (P + I) - SWC - Ro - D \qquad \text{Equation 4}$$

where Et = evapotranspiration, P = rainfall (mm), I = irrigation (mm), ΔSWC = change in soil water content from time 1 to time 2 at 0 – 100 cm in 1998/99 and 0 - 110 cm depth in 1999/2000, Ro = runoff (mm), D = drainage (mm).

In this experiment Ro was assumed to be zero, as the experimental site was level, and irrigation was applied (T-tape) at a rate that was well below the infiltration capacity of the soil. Drainage was also assumed to be zero below 100 - 110 cm soil depth, as the volumetric water content of the soil at depth did not exceed field capacity at any time.

Water-use efficiency (kg dry matter/ha/mm of water use and kg seed yield/ha/mm of water use) of chickpea was calculated as the total dry matter production and final seed yield of the treatment divided by the quantity of total water used over that period.

Data were also collected for chickpea cv. Dwelley and cv. B-90 with the same experimental layout mentioned above for model validation. Simulated results were compared with corresponding observed results. Predicted (P) and observed (O) values were used to quantify root mean square deviations (RMSD) between a number (n) of predicted and observed paired results,

$$\text{i.e.,} \quad RMSD = [\sum(O - P)^2/n)]^{0.5} \qquad \text{Equation 5}$$

RMSD is a measure of the accuracy of the prediction and represents a weighted average difference between predicted and observed data. Willmott (1982) argues that RMSD is one of the best measures of model performance as it summarises the mean difference between observed and predicted values.

Model development

Crop dry weight accumulation is driven by the interception and use of intercepted radiation to produce biomass, via utilization coefficient or radiation-use efficiency (U). U is reduced whenever extremes of temperature, soil water deficit or excess, or plant nutrient deficit limit photosynthesis (French and Turner, 1991; Thomson and Siddique, 1997). Biomass is partitioned among the various plant components as determined by crop phenological stages. A series of studies has highlighted the importance of increased partitioning of dry matter to reproductive yield components in chickpea for improved genotypic yield performance (Singh, 1991; Leport *et al.*, 1999; Davies *et al.*, 2000). The physiological basis of yield determination can be expressed as seed yield (Y) in terms of the following components:

$$Y = Sa \times U \times HI \qquad \text{Equation 6}$$

where Sa is intercepted solar radiation, U is the utilisation coefficient and HI is harvest index (Gallagher and Biscoe, 1978).

Equation 6 was used to verify the prediction of seed yield for Kabuli chickpeas. As shown in Figure 1, the predicted and actual seed yield for all treatments over the two years showed a highly significant relationship ($r^2 = 0.74$). This indicated that seed yield of Kabuli chickpeas in Canterbury (sub-humid temperate environment) can be predicted reasonably well from intercepted PAR data, the utilisation coefficient and harvest index. The overall yield response under the different irrigation levels was the net effect of variations in intercepted radiation, the utilisation coefficient and harvest index. Any reduction in intercepted PAR due to water stress during the vegetative stage can be compensated for by irrigation during subsequent stages that increase the utilisation coefficient and harvest index. These findings can form the basis of irrigation management to maximise yields of Kabuli chickpea in Canterbury.

In addition, an attempt was made to incorporate empirical functions of evapotranspiration, green area index, intercepted solar radiation, total dry matter production and pods/m^2 factors to predict seed yield. A schematic representation of the model showing the major components and their interrelationships is shown in Figure 2.

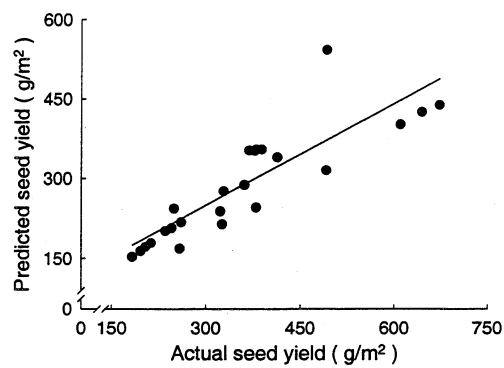

Figure 1. The relationship between predicted and observed seed yield of Kabuli chickpeas in Canterbury. $Y = 59.1 + 0.64 X$, $r^2 = 0.74$.

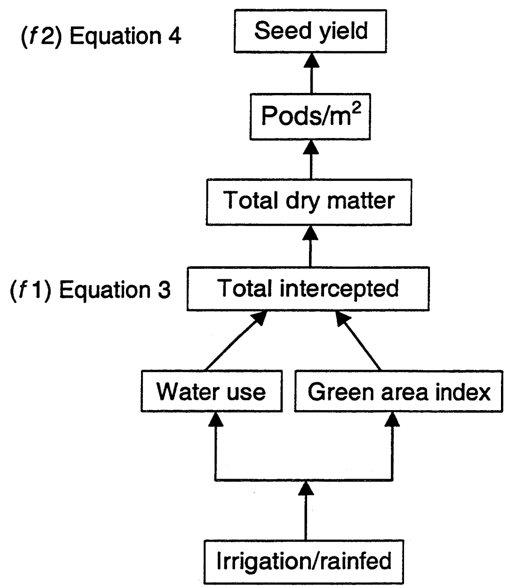

Figure 2. A schematic relational diagram of the model. Boxes represent model stages and arrows represent variables flow functions.

Stage 1 of the model: Function ($f1$)

The amount of photosynthetically active radiation (PAR) intercepted by a crop canopy is generally related to the incident total solar radiation and green area index (GAI) (Beer's Law (Monteith, 1977); Mckenzie and Hill, 1991; Thomson and Siddique, 1997). In addition, central to canopy development, there is a long established relationship that exists between GAI and evapotranspiration (Et) (Briggs and Shantz, 1913; de Wit, 1958; Siddique and Sedgley, 1986; Mwanamwenge *et al.*, 1998; Rao *et al.*, 2000). Therefore, an empirical relationship between GAI, Et and total intercepted PAR of the form:

$$\text{intercepted PAR} = a + b\,(Et) + c\,(GAI) \qquad \text{Equation 7}$$

was derived from the field data, where a, b and c represent the coefficients derived in fitting the relationship by multiple regression analysis ($r^2 = 0.82$; Fig. 3 and Table 2).

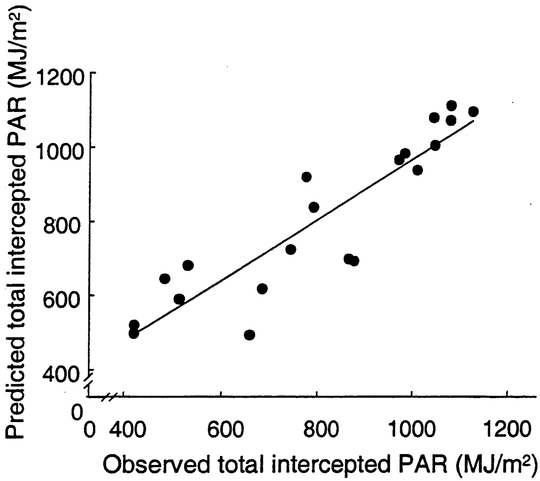

Figure 3. The relationship between predicted and observed total intercepted PAR of Kabuli chickpea in Canterbury. Y = 149.72 + 0.82 X, r^2 = 0.82.

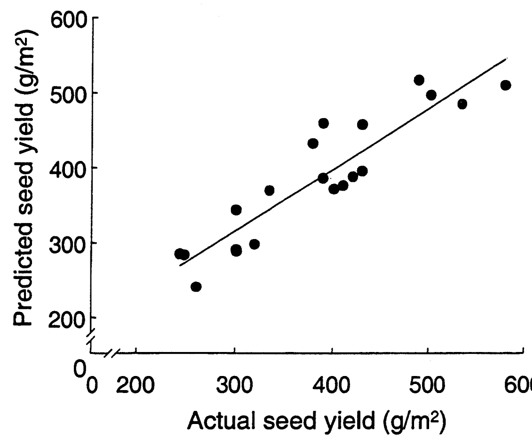

Figure 4. The relationship between predicted and actual seed yield of Kabuli chickpea in Canterbury, 1998-2000. Y = 54.77 + 0.86 X, r^2 = 0.86.

Table 3. Parameters and statistics multiple regression analysis for Equations 3 and 4. Data from two years (1998/99 and 1999/2000) field trial for cv. Sanford chickpea. GAI: green area index, Et: evapotranspiration (mm), PAR: intercepted solar radiation (MJ/m^2), GAD: green area duration (days), TDM: total dry matter (g/m^2), seed yield (g/m^2).

PAR = a + b (Et) + c (GAI)		Seed yield = a + b (PAR) + c (TDM) + d (pods/m^2)	
Coefficient	S.E. coefficient	Coefficient	S.E. coefficient
a = 127.43	92.03	a = 5.3255	0.531
b = 0.7033	0.499	b = 0.0853	0.113
c = 91.587	40.76	c = 0.2762	0.130
r^2 = 0.79		d = 0.0522	0.044
S.E.= 107.67		r^2 = 0.81	S.E.= 41.71

Stage 2 of the model: Function (*f*2)

Green area index (GAI) over time determines the total amount of solar radiation intercepted by a crop has a prominent influence on crop growth (Sinclair, 1984). Thus, the rate of establishment of leaf area and time taken to reach critical GAI is particularly important to subsequent crop growth (Gallagher, 1978; Thomson and Siddique, 1997) and final seed yield (Sinclair *et al.*, 1981). It was evident that higher GAI allowed more PAR interception during the growing season (Anwar, 2001). There was a close relationship between intercepted PAR, GAI and crop yield as reported by Laing *et al.* (1981) in faba bean, Siddique *et al.* (1990) in wheat, Armstrong and Pate (1994) in pea, and Dapaah *et al.* (2000) in Pinto bean. Further, seed yield is also correlated to total dry matter production (TDM) and pods/m^2 (Thomas and Fukai, 1995a and b; Leport *et al.*, 1999; Davies *et al.*, 2000). Based on the above physiological approach, an empirical relationship between seed yield, PAR, TDM and pods/m^2 of the form:

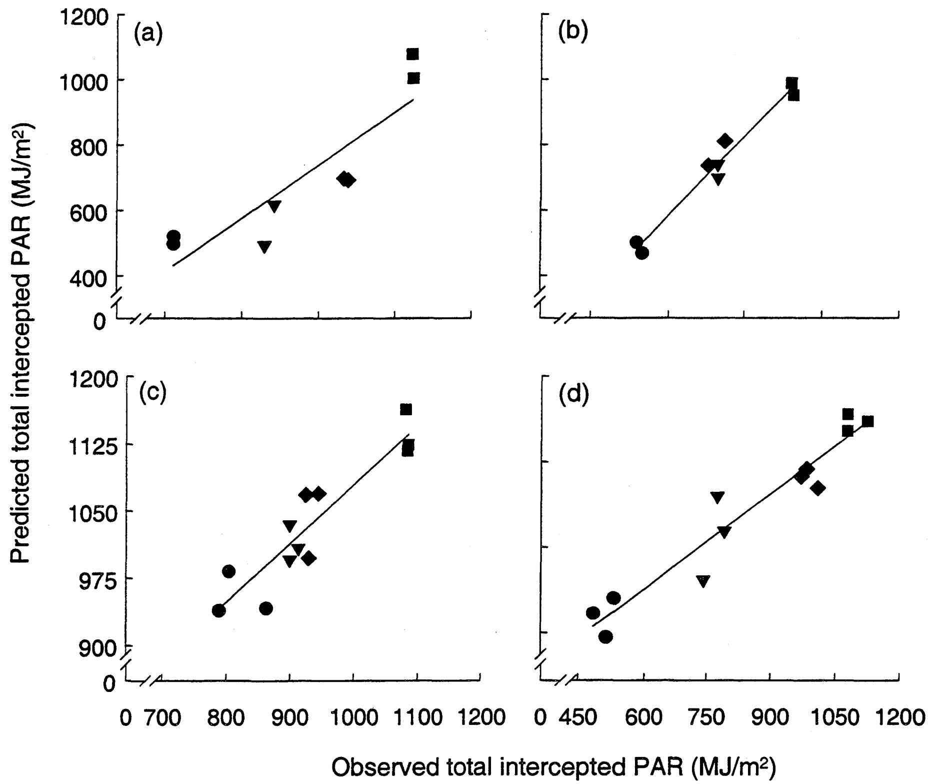

Figure 5. The relationship between predicted and observed total intercepted PAR of cv. Sanford Kabuli chickpea in Canterbury. Rainfed (●); full irrigation from emergence to maturity (■); full irrigation from flowering to pod (♦) and full irrigation from podding to maturity (▼). a) November sowing, 1998/1999: Y = 89.83 + 0.81 X, r^2 = 0.79; b) December sowing, 1998/1999: Y = -143.04 + 1.22 X, r^2 = 0.97; (c) October sowing, 1999/2000 : Y = 423.51 + 0.65 X, r^2 = 0.84; (d) November sowing, 1999/2000: Y = 252.22 + 0.75 X, r^2 = 0.93.

Seed yield = a+b(PAR)+c(TDM)+d(pods/m^2)   Eq'n 8

was derived from two years of field data, where a, b, c and d represent the coefficients derived from fitting the relationship by multiple regression analysis ($r^2 = 0.86$; Fig. 4 and Table 3).

Results and Discussion

The empirical model derived from two years (1998/99 and 1999/2000) field measurements of cv. Sanford Kabuli chickpea was successful in predicting total intercepted PAR and seed yield of chickpea in Canterbury. A comparison of all the measured and modelled values of total intercepted PAR of the three cultivars (Sanford, Dwelley and B-90) sown at different dates is presented in Figs. 5, 6 and 7. The relationships are highly significant ($r^2 = 0.79 - 0.97$) and exhibit slopes of 0.62 – 1.22.

Total intercepted radiation showed a linear increase, as a function of water use and green area index (GAI), both of which were influenced by irrigation. This relationship is consistent with the linear increase in total intercepted radiation due to water supply (Muchow, 1985; Thomas and Fukai, 1995a). This response occurred through the interaction of the fraction of radiation intercepted and radiation use efficiency. Irrigation was necessary to maximise GAI (Haloi and Baldev, 1986; Thomas and Fukai, 1995a) and thereby achieve greater intercepted radiation. The lower values of the data points in the above figures (Figs. 5 – 7) correspond to rainfed plots indicating low GAI, as the photosynthesis process is highly sensitive to water deficits (Lawlor, 1995). The crop developed a high GAI with irrigation and was able to achieve a high intercepted radiation (Anwar, 2001), but without irrigation the crops experienced significant water stress. There was a high correlation ($r^2 = 0.82$) of the measured and predicted total intercepted PAR (Fig. 3) in both 1998/99 and 1999/2000. This confirmed that the coefficients a, b and c derived for first stage of the model (Eq'n. 7) can be used to describe the total intercepted PAR for all the chickpea cultivars sown on different dates.

A comparison between measured and modelled estimates of seed yield for each of 10 situations (sowing date and season), is presented in Table 4. The data for pinto beans are from Dapaah's (1997) field trial in Canterbury. The overall RMSD obtained in this study were 73.0 g/m^2 for non-irrigated and 53.7 g/m^2 for irrigated crops. This was 27% and 12% of the mean seed yields, respectively, suggesting that the model performs reasonably well. When measured and model estimates of seed yields for only chickpea crops were compared, RMSD decreased to 10.9 g/m^2 in

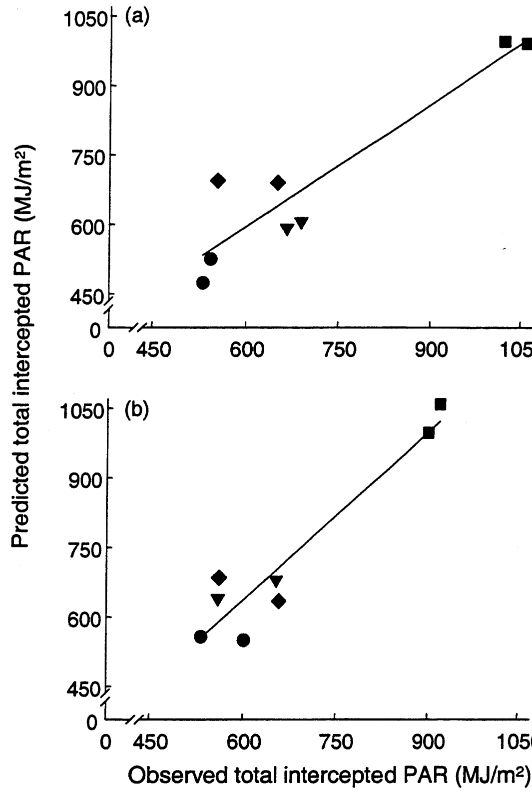

Figure 6. The relationship between predicted and observed total intercepted PAR of cv. Dwelley chickpea in 1998/99. Rainfed (●); full irrigation from emergence to maturity (■); full irrigation from flowering to pod (♦) and full irrigation from pod to maturity (▼). a) November sowing: Y = 68.50 + 0.88 X, $r^2 = 0.87$; b) December sowing: Y = -86.32 + 1.20 X, $r^2 = 0.90$

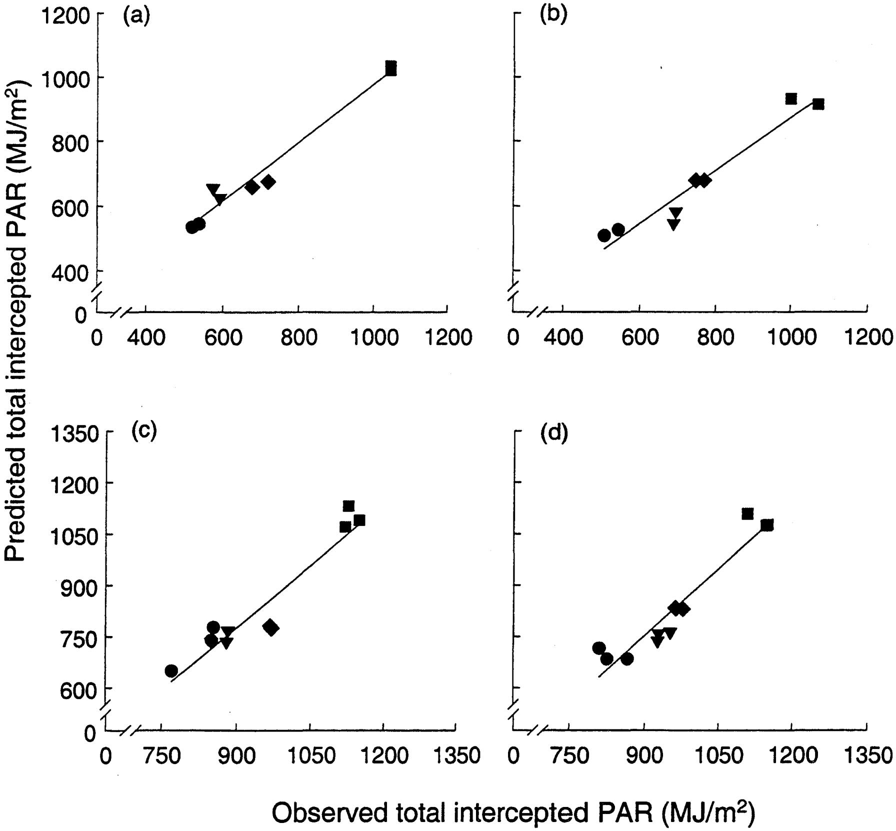

Figure 7. The relationship between predicted and observed total intercepted PAR of cv. B-90 Kabuli chickpea in Canterbury. Rainfed (●); full irrigation from emergence to maturity (■); full irrigation from flowering to pod (◆) and full irrigation from podding to maturity (▼). (a) November sowing, 1998/1999: Y = 69.22 + 0.91 X, r^2 = 0.97; (b) December sowing, 1998/1999: Y = 49.66 + 0.82 X, r^2 = 0.93; (c) October sowing, 1999/2000 : Y = -318.82 + 1.21 X, r^2 = 0.88; (d) November sowing, 1999/2000: Y = -420.40 + 1.30 X, r^2 = 0.91.

rainfed chickpeas, about 4% of the mean seed yields while RMSD for the irrigated crop was about 61.4 g/m^2, about 14% of the mean seed yield.

The performance of this simple empirical model was reasonable over the range of sowing date and seasons. Further aspects for improving the model involve simulating radiation use efficiency, water use efficiency and harvest index. From the chickpea trials (Anwar, 2001), the overall yield response under the different irrigation regimes was the net effect of variations of these variables. Additionally, as the model does not cater for extremes of weather conditions, a subroutine on these aspects could be added. The universality of the model needs further validation in different climatic areas and on other chickpea cultivars.

Table 4. Observed (O) and predicted (P) seed yield of irrigated and rainfed Kabuli chickpea and pinto beans (data from Dapaah, 1997) in Canterbury.

		Seed yield (g/m^2)			
		Rainfed		Irrigated	
Cultivar	Sowing date	O	P	O	P
Chickpea					
cv. Sanford	3 Nov 1998	353.1	330.0	567.6	543.6
cv. Sanford	7 Dec 1998	325.3	308.3	342.1	419.8
cv. Sanford	18 Oct 1999	286.2	272.0	519.5	476.6
cv. Sanford	22 Nov 1999	307.6	275.7	504.3	482.8
cv. Dwelley	3 Nov 1998	315.4	278.6	458.2	478.2
cv. Dwelley	7 Dec 1998	208.9	238.3	257.7	398.1
cv. B-90	3 Nov 1998	300.5	293.3	612.1	593.7
cv. B-90	7 Dec 1998	171.1	219.3	187.8	263.1
cv. B-90	18 Oct 1999	269.9	314.8	495.5	474.1
cv. B-90	22 Nov 1999	235.2	277.1	448.7	457.6
RMSD		10.9	61.4		
Pinto bean					
cv. Othelo	27 Oct 1994	268.0	154.3	288.0	180.1
cv. Othelo	24 Nov 1994	267.0	140.4	378.0	192.6
cv. Othelo	1 Nov 1995	195.0	137.6	319.0	224.6
Average		269.5	249.2	413.7	398.8
RMSD		73.0	53.7		

Conclusions

1. Prediction of total intercepted PAR was reasonably accurate.
2. This model provided an adaptable framework to predict seed yield of rainfed and irrigated Kabuli chickpea cultivars. However, some changes in the model may be required to incorporate crop-specific processes.
3. The model needs further testing and validation over a wider range of environments and cultivars.

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