

Environmental control of lentil (*Lens culinaris*) crop development

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SUMMARY

The lentil (*Lens culinaris* Medik.) cultivars Titore and Olympic were sown at Canterbury, New Zealand, on eight dates, from April to November in 1984 and in May and August in 1985. Of the four important physiological growth stages (sowing to emergence (S-E), emergence to flowering (E-F), flowering to physiological maturity (F-P_m) and physiological maturity to harvest (P_m-H)), the duration of all except E-F depended upon accumulated thermal time above 2 °C. The mean accumulated thermal times for E-F, F-P_m, P_m-H were 116, 565 and 293 °C days, respectively. Stage E-F required from 1165 °C days for an April sowing to 509 °C days for a November sowing. There was a highly significant positive relationship ($r^2 = 0.99$) between the rate of development during E-F and mean temperature. Photoperiod also affected development rate.

Neither of the two cultivars studied had a vernalization requirement for the induction of flowering. In both years, the development rate during E-F was highly dependent upon photoperiod-corrected temperature. The relationships presented show that development of lentil crops in Canterbury can be accurately predicted using accumulated temperature and photoperiod-corrected temperature.

INTRODUCTION

As with all crop plants, lentil growth is affected by climatic variation. Dry matter accumulation and yield may depend on the initiation and development of leaf area and on the amount of solar radiation intercepted by the crop. Variables such as temperature, soil moisture status and solar radiation receipt may alter crop growth.

In cereals and pulses, yield is also dependent upon the progress of the crop through various physiological stages. Unless the crop flowers, there is no economic yield. In lentil, as in other crops, development occurs in consecutive phases: germination, emergence, juvenile growth, flowering, pod filling, physiological maturity and harvest maturity. As with growth, these periods may be affected by climate. Generally the most important factors affecting crop development are temperature, moisture and photoperiod.

Crop development is often measured as the number of days the plant spends in the development phase under consideration. This may, however, produce a curvilinear relationship that is difficult to interpret. Angus *et al.* (1981) proposed a simple technique of expressing crop development as the integral of an instant development rate. If the integral is scaled to

give a value of one at the end of the phase, the mean development rate becomes the reciprocal of duration.

There have been many reports on the influence of temperature on crop development (Brown 1960; Jones & Laing 1978; Angus *et al.* 1980, 1981; Skjelvag 1981). In pulses, however, photoperiod has generally also been shown to exert a strong influence on development from emergence to flowering (Hadley *et al.* 1983) and vernalization may also affect time to flowering. Gladstones & Hill (1969) reported that vernalization and long photoperiods hastened flowering in lupin.

Lentil development is affected by photoperiod and temperature (Summerfield 1981). Summerfield *et al.* (1985) found that vernalization affects the duration of the period from emergence to flowering in some lentil cultivars.

This paper reports on the climatic factors affecting the development of two lentil cultivars over 2 years in Canterbury, New Zealand.

MATERIALS AND METHODS

Experiment 1 (1984/85) was a split-plot design with main plots sown on 6 dates. Subplots were a factorial combination of four treatments: full irrigation or none, and two lentil (*Lens culinaris*) cultivars, Titore

(a small-seeded New Zealand selection) and Olympic (a large-seeded New Zealand cultivar). Sowing dates were 16 April, 15 May, 26 July, 14 September, 15 October and 15 November 1984. The split-plot treatments were randomly allocated within each main plot. Plots were 1.5 × 20 m, with guard plots between irrigated and unirrigated plots. Irrigated plots received 30 mm of water through trickle irrigation tubes each time the calculated soil moisture deficit reached 50 mm.

The trial was on a Templeton silt-loam (New Zealand Soil Bureau 1954) which had been a red clover (*Trifolium pratense*)/perennial ryegrass (*Lolium perenne*) pasture for the previous 18 months. The seed bed was produced using standard farm practices. While soil fertility was moderately high, 250 kg of superphosphate/ha was applied to ensure adequate soil phosphorus. Weeds in main plots which lay fallow until later sowings were controlled with paraquat. There was a postemergence weed problem after the April sowing and metribuzin was applied at 0.175 kg a.i./ha. This caused some crop scorching.

All plots were sown at rates calculated to produce c. 150 plants/m². Sowing rates for Titore and Olympic were 50 and 70 kg/ha, respectively. In the May and September sowings, the sowing rate was increased by 10% and in the July sowing by 20%, to counteract an expected reduction in winter survival.

Experiment 2 (1985/86) was a randomized complete block design with a factorial combination of two sowing dates and four irrigation treatments. Crops were sown on 20 May and 26 August 1985. As in 1984, irrigation was applied through trickle tubes at about 5 mm/h. Water application was measured using a Neptune, type sz, 25.4 mm flow meter. Irrigation was applied according to a soil water balance which used 0.75 × daily pan evaporation before complete crop cover and daily potential evapotranspiration thereafter. When a potential soil moisture deficit of 50 mm was reached, the fully irrigated plots received 30 mm of water, treatment 2 received 20 mm, treatment 3 received 10 mm and treatment 4 plots received no water. Thus, the four irrigation treatments were: (i) full irrigation, i.e. application of 30 mm of water when the potential soil

moisture deficit reached 50 mm; (ii) two-thirds full irrigation; (iii) one-third full irrigation; (iv) no irrigation.

Experiment 2 was situated close to Expt 1. Soil characteristics were similar to those in Expt 1 but soil nutrient concentrations were marginally higher. As in Expt 1, 250 kg of superphosphate/ha was applied before sowing.

Sampling

In Expt 1 the April, July and October sowings were sampled for dry matter accumulation, leaf area index, numbers of branches, pods and seeds, and seed weight. In Expt 2, both sowings were sampled only for dry matter accumulation and leaf area index. In Expt 1, one 0.1 m² quadrat was cut each month in winter and once per fortnight from the end of August; in Expt 2, two 0.1 m² quadrats were cut at the same frequency.

The phenological stages studied were as follows: (i) emergence, the date when 50% of the final population had emerged; (ii) flowering, the date when 50% of the plants had at least one open flower; (iii) physiological maturity, the date when 50% of the plants had at least one pod filled and drying off; (iv) harvest maturity, when plants were physically able to be harvested.

The development phases (see Table 1) between phenological stages were then related to either accumulated temperature or photoperiod or both.

Mean temperature and photoperiod from sunrise to sunset were taken from data recorded at the Lincoln College Meteorological Station which was c. 700 m from the experimental site (Fig. 1). Maximum and minimum daily temperatures were used to calculate thermal time (*tt*) as the time integral above a base temperature (*T_b*) of 2 °C. The following equation was used:

$$tt = \sum_{\text{stage a}}^{\text{stage b}} \frac{(\text{minimum} + \text{maximum})}{2} - T_b \quad (1)$$

Temperature corrected for photoperiod (*P_{tt}*) was calculated from the method of Gallagher *et al.* (1983).

$$P_{tt} = [(\bar{T} - T_b) \times (\bar{P} - P_b)] / (24 - P_b) \quad (2)$$

Table 1. Development phases studied in two lentil experiments in Canterbury, New Zealand, in 1984/85 and 1985/86

Abbreviation	Meaning
S-E	Period from sowing to emergence
E-F	Period from emergence to flowering
F-P _m	Period from flowering to physiological maturity
P _m -H	Period from physiological maturity to harvest
S-H	Entire crop duration from sowing to harvest

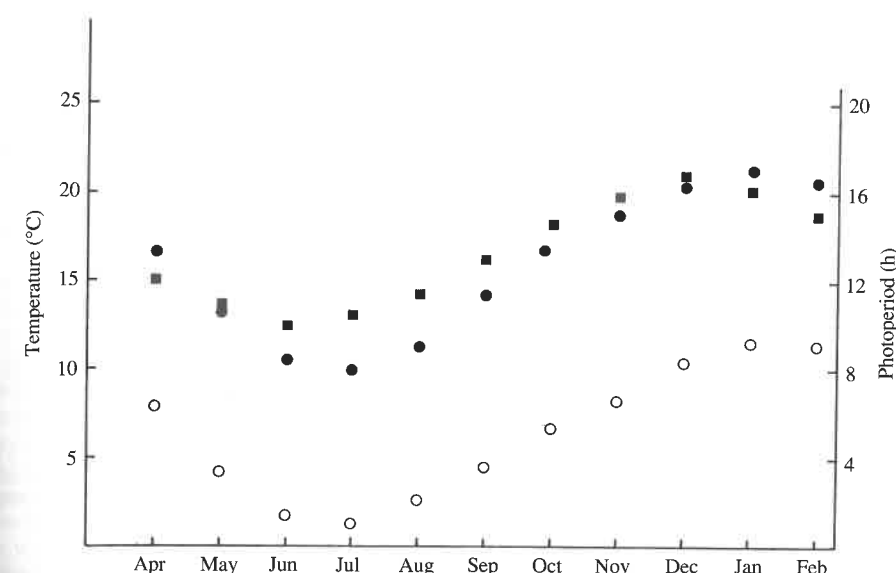


Fig. 1. Long-term maximum (●) and minimum (○) temperatures and photoperiod (■) from sunrise to sunset at Lincoln College, Canterbury, New Zealand.

where \bar{T} is the mean temperature of the stage being considered, \bar{P} is the mean photoperiod over the stage being considered and P_b is the base photoperiod. The equation can also be used to accumulate photothermal time by summing each increment of daily photoperiod-corrected temperature. Although this technique was developed for barley, it has been used for field beans (*Vicia faba* L.) in Canterbury (Husain *et al.* 1988) with accurate results.

RESULTS

The thermal time required for each development phase is shown in Table 2. Since neither irrigation nor cultivar affected duration of the development phases, only the effect of sowing data is presented. The phase S-E was of similar duration in both experiments and required a mean thermal time of 116 °C days. The most variable phase was E-F, which showed a consistent decline in thermal time from a maximum of 1165 °C days for the April sowing to 509 °C days in the November sowing. The duration of phases F-P_m and P_m-H was similar in both experiments; the duration of all phases except E-F was strongly related to temperature.

Duration of development phases

Figure 2 shows the relationship between duration of phase E-F in days and the mean temperature over this period; the relationship is hyperbolic. At a mean of 8.4 °C, April-sown plants flowered 178 days after

sowing; while, at a mean of 15.7 °C, November-sown plants flowered in 38 days.

Converting the duration of the phase from emergence to flowering into a development-rate relationship with mean temperature (Fig. 3) indicated that mean temperature had a linear effect on rate of development. The highly significant regression showed

Table 2. Thermal time for four physiological growth phases (sowing to emergence (S-E), emergence to flowering (E-F), flowering to physiological maturity (F-P_m) and physiological maturity to harvest (P_m-H)) of lentil in Canterbury, in 1984/85 and 1985/86

Sowing date	Thermal time for phase (°C days) (<i>T_b</i> = 2 °C)				Total (S-H)
	S-E	E-F	F-P _m	P _m -H	
1984					
16 April	122.1	1164.7	506.2	201.4	1994.0
15 May	177.5	948.3	533.7	371.0	2082.5
26 July	155.1	711.4	566.3	332.4	1765.3
14 September	106.4	596.8	611.9	193.3	1508.4
15 October	98.5	534.0	563.8	282.6	1478.7
15 November	109.6	509.3	495.5	—	—
1985					
20 May	111.8	906.3	510.2	416.6	1944.9
26 August	105.4	654.7	734.2	255.1	1749.4
Mean	115.8	753.2	565.2	293.2	—
S.E.	17.47	231.23	78.46	84.45	—

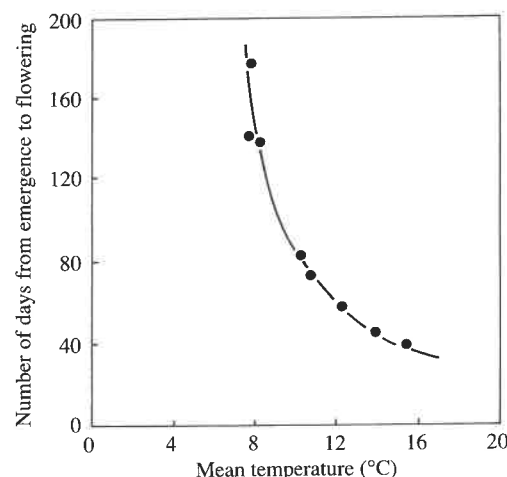


Fig. 2. Effect of mean daily temperature during emergence to flowering in lentil in Canterbury, in 1984/85 and 1985/86.

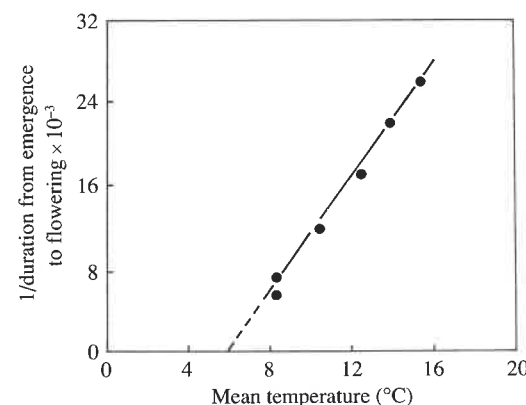


Fig. 3. Relationship between rate of progress from emergence to flowering and mean temperature in that period in lentil in Canterbury, in 1984/85 and 1985/86.

that rate of development was more than three times faster in November-sown plants than in April-sown plants. Extrapolation of the regression gives a suggested base temperature for the phase E-F of 6 °C.

A highly significant relationship between rate of development and mean photoperiod indicated that the base photoperiod for the phase E-F was *c.* 7.4 h. The relationship between rate of development and photoperiod-corrected temperature over both seasons was highly significant (Fig. 4). This linear relationship should allow accurate prediction of flowering time in lentil.

The technique used to predict time to flowering is similar to that reported by Roberts *et al.* (1988). In this study, daily photoperiod-corrected temperature was summed to determine the photothermal time

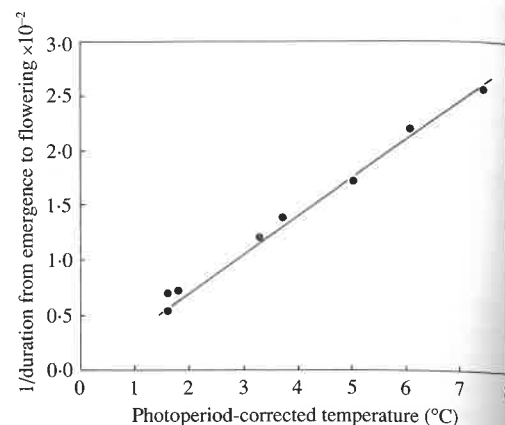


Fig. 4. Relationship between rate of progress from emergence to flowering and mean photoperiod-corrected temperature in that period in lentil in Canterbury, in 1984/85 and 1985/86. $Y = 0 + 0.0034X$ ($r^2 = 0.99$).

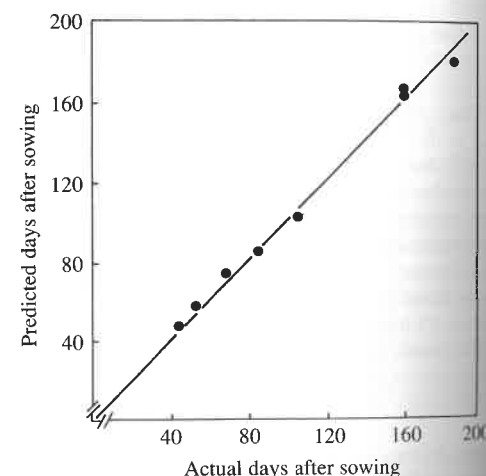


Fig. 5. Relationship between actual and predicted dates of flowering in lentil over two seasons in Canterbury.

required for flowering. Over the six sowing dates in the first season (1984/85), the mean photothermal time from emergence to flowering was 270 °C days. The number of days required to reach this target is the predicted duration of the phase E-F.

Figure 5 shows the relationship between the predicted and actual dates of flowering for all eight sowing dates over the two seasons.

DISCUSSION

Of the four physiological stages observed, S-E, E-F, F-P_m and P_m-H, the duration of all except E-F depended upon accumulated thermal time above a base of 2 °C. Over the different sowing dates, S-H

required 1480–2080 °C days. This compares with 2100 °C days at T_b of 0 °C required to complete the same period of growth in field beans (*V. faba*) reported by Husain (1984) in Canterbury.

Base temperature

Figure 3 suggests that the base temperature for development to flowering in the two cultivars studied was *c.* 6 °C, considerably higher than base temperatures reported by Angus *et al.* (1980) and Roberts *et al.* (1985). Regressing development rate against accumulated thermal time at base temperatures of 0–6 °C indicated that the best fit was a T_b of 1–4 °C. The relationship shown in Fig. 5 allows calculation of a base temperature corrected for photoperiod: it was 0 °C. From these and previously reported results, T_b of 2 °C was used to predict crop development.

In this work, T_b was assumed to have been stable. There is some suggestion from the literature that T_b may vary with crop age and the environment. Other factors which may affect T_b include photoperiod and vernalization requirement. Husain (1984) suggested that, if photoperiod is not accounted for, T_b may be artificially high, and Summerfield *et al.* (1985) reported that vernalization has a large effect on theoretical T_b and that T_b may be altered by photoperiod.

Vernalization

Vernalization has been shown to affect flowering significantly in lentil (Summerfield *et al.* 1985). In this experiment, if the two cultivars examined had a vernalization requirement, this would have had to have been included in any model to predict flowering date. However, there was no indication that either cultivar had a vernalization requirement. November-sown plants, which would not have been vernalized, flowered much more rapidly than autumn-sown plants.

Development rate to flowering

A linear relationship between development rate during S-F and temperature has been previously reported in lentil (Summerfield *et al.* 1985; Roberts *et al.* 1986). In this experiment, the relationship was highly significant (Fig. 3). While the value for r^2 could hardly account for more of the variance, several reports in

the literature indicate that lentil development is also affected by photoperiod (Saint-Clair 1972; Summerfield & Wien 1980; Summerfield 1981; Saxena & Wassimi 1984; Summerfield *et al.* 1985; Roberts *et al.* 1986). While increased mean diurnal temperature has been shown to reduce the time taken for flowering in lentil, increased photoperiod may do the same thing. Summerfield *et al.* (1985) showed that with six genotypes, the most rapid flowering always occurred with vernalized seeds grown under the highest temperatures, at the longest photoperiod. In chickpea (*Cicer arietinum* L.), Roberts *et al.* (1985) found that in all genotypes tested, at any night/day temperature combination, first flowers appeared sooner under 15 h than under 12 h photoperiods.

Roberts *et al.* (1986) reported that the phase from sowing to flowering in lentil may consist of four phases; pre-emergence, pre-inductive, inductive and postinductive; only the inductive phase was sensitive to photoperiod. In this experiment, the base photoperiod was 7.4 h in both Titore and Olympic. Roberts *et al.* (1986) found a wide range of base photoperiods in the lentil cultivars they tested, from 2.0 h for Precoc to 9.2 h for a local Syrian variety.

This study shows that, in Canterbury, lentil crop development depends on both temperature and photoperiod. The relationship between photoperiod-corrected temperature and rate of development during E-F was highly significant in two climatically different seasons. Using the technique, it is simple to predict flowering date accurately in Canterbury for the cultivars Titore and Olympic. Figure 5 indicates how accurately flowering date can be predicted, even in markedly contrasting seasons. Only in the April 1984 sowing was the predicted date of flowering markedly different from the actual date, when it was 7 days later. Such accuracy of prediction may seem surprising but these predictions are for flowering of the crop population not for first flowering of single replicate plants as reported by Roberts *et al.* (1988). Hence, any widely variable flowering date for a single plant would not affect the predicted date.

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Storage-root weight, diameter and length relationships in carrot (*Daucus carota*) and red beet (*Beta vulgaris*)

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SUMMARY

The functional relationships between \log_e diameter and \log_e weight, and between length and diameter of the storage roots in carrot and red beet were described by two linear equations. These equations were fitted to data from three red beet and two carrot experiments. The agreement between the fitted and observed data was close. With increasing plant population density of red beet, the slope of the relationship between length and diameter decreased and the intercept increased. Although these changes in slope and intercept were statistically significant ($P < 0.05$), their magnitude was of negligible practical importance. The relationship between \log_e diameter and \log_e weight was little affected by length; the relationship between length and diameter was little affected by \log_e weight.

Using these equations in independent experiments, the diameters of roots of both species were predicted from measured root weights. The roots were then assigned to various commercial diameter grades on the basis of either the measured or the predicted diameter. Except for a few roots of red beet greater than 85 mm in diameter, there was close agreement between the observed and predicted number of roots in each grade.

Any model which predicts root weight might be extended to predict yield of marketable size grades, using these equations as a calibration between weight, diameter and length.

INTRODUCTION

In this paper we examine data from field-grown carrots and red beet to determine the form of the relationships between storage-root weight, diameter and length, and to determine whether agronomic variables consistently affect these relationships. If the relationships are simple and consistent, then models which simulate the effects of environmental factors on total plant weight, or weight of a plant part, could be extended to estimate the weight of roots that will fall into specific diameter and length grades. This would be of major commercial interest. Equally, the weight of roots could be predicted from knowledge of their diameters, which could be of interest to experimenters.

Previously, workers have described storage root shape, using just a single parameter. For example, Bleasdale & Thompson (1963) defined cylindricality, C , as

$$C = \frac{W}{\pi r^2 l}, \quad (1)$$

where W is weight, r is radius and l is length. The ratio of length to diameter has also been used to describe shape (Bradley *et al.* 1967; Dowker *et al.* 1976;

Dowker & Jackson 1977). These single parameters describe only one aspect of the shape of a root, but other workers have used more complex measures (Snee 1972; Umiel *et al.* 1972). Such measures are useful as objective criteria to compare the effects of agronomic or genetic influences on root shape or specific aspects of root shape. However, they are of little value for predicting yields of roots in specific size grades. In this paper, we examine whether yield can be predicted using simple relationships between weight, diameter and length.

MATERIALS AND METHODS

All seven experiments were sown on a sandy loam of the Wick Series. Expts 5, 6 and 7 have not been previously published, but were done a number of years ago by Dr I. E. Currah (Expts 5 and 6) and by Mr B. D. Dowker (Expt 7).

Experiments 1, 2 and 3

Full details of the cultural practices are described in Benjamin & Bell (1985). In brief, these three experi-