THE EFFECT OF IRRIGATION ON RADIATION ABSORPTION, WATER USE AND YIELD OF CONVENTIONAL AND SEMI-LEAFLESS PEAS

Z.M. Zain, J.N. Gallagher and J.G.H. White
Plant Science Department
and
J.B. Reid
Soil Science Department, Lincoln College, Canterbury

ABSTRACT

The growth, water use and yield of conventional and semi-leafless peas were studied for two spring sowings under dryland and irrigated conditions on a Templeton silt loam soil at Lincoln during the 1981/82 season. Irrigation was applied weekly in amounts equal to the difference between the potential evapotranspiration and rainfall of the preceeding week from either the vegetative, flowering or pod swelling phase until maturity.

For the first (23 October) sowing, dry seed yield increased from 2,110 kg/ha without irrigation to 4,360 kg/ha with irrigation throughout growth. Equivalent figures for the second (16 December) sowing were 1,150 and 2,940 kg/ha. Intermediate yields were obtained when the period of irrigation was restricted. Drought decreased the ratio of seed: total dry matter slightly for both sowings. The decrease in total dry matter production caused by drought was due to a 40% reduction in growth efficiency (energy content of crop/solar energy absorbed during growth) and a decrease in the radiation absorbed by green surfaces of between 20 and 30%. Neither the differences in yield between cultivars nor the cultivar x irrigation interaction were significant.

Both cultivars had an average water use efficiency (WUE) of about 25 kg/ha/mm at both times of sowing. The WUE of irrigated plots averaged 25 kg/ha/mm for the early sowing and 20 kg/ha/mm for the late sowing; there were no significant differences between irrigation treatments. The WUE of the unirrigated treatments was about 40% greater than that of the irrigated treatments in the first sowing and about 95% greater in the second sowing.

In this dry season therefore, there was no advantage to the semi-leafless cultivar either in yield or WUE. Irrigation applied during any phase, except pod growth for the early sowing, promoted growth and yield.

Additional Keywords: dry matter production, growth efficiency, water use efficiency, neutron moisture meter.

INTRODUCTION

Irrigation has consistently been shown to increase pea yields in Canterbury (Stoker, 1977; Martin and Tabley, 1981; White, *et al.*, 1982). On Templeton silt loam soils, increases in pea seed yields ranging from 25% to 188% have been obtained from irrigation, though these results were not analysed quantitatively in relation to the prevailing weather. An understanding of the influence of weather on the response of crop yield to irrigation is needed both to help plan likely demand for water resources and to determine optimal irrigation strategies. To achieve this understanding, information is needed about the factors controlling water use by crops and the influence of drought on the physiological processes crucial to yield determination. Such information may also provide useful guidance to plant breeders in their search for genotypes more able to resist drought.

Conventional, fully leaved peas, are very susceptible to drought (Manning *et al.*, 1977) but there are reports that the recently bred semi-leafless (SL) peas produce more dry matter per unit of evapotranspiration (i.e. they have a higher water use efficiency (WUE)) and are more tolerant of drought (Wilson, *et al.*, 1981). The SL type are also likely to be useful because of their standing ability which makes them easier to harvest.

The grain yield of many crops is often closely related to their total dry matter production (Monteith and Scott, 1982). It has also been shown that the total dry matter production for many crops is proportional to the amount of radiation they intercept (Shibles and Weber, 1965; Biscoe and Gallagher, 1977; Littleton *et al.*, 1979). It has therefore been suggested that crop yields can usefully be analysed in terms of three factors: the amount of radiation absorbed, the efficiency with which this is converted into the chemical energy of crop dry matter (the growth efficiency) and the efficiency with which total dry matter is partitioned into yield (Monteith, 1977). In this respect it is interesting to note that Harvey (1980) found that a leafless pea phenotype expanded its leaf area more slowly than a conventional type and was presumably at a disadvantage in terms of radiation interception during early growth.

The experiments described here had two main objectives: 1. to compare the water use efficiency, growth

TABLE 1: Mean temperature, vapour pressure deficit, solar radiation, rainfall, potential evapotranspiration at Lincoln College, October 1981 to March 1982; figures in parentheses are long term means.

Month	Temperature °C Maximum	Minimum	Vapour pressure deficit kPa	Solar radiation $MJ/m^2/d$	Rainfall mm	Potential evapotrans-piration mm
1981 October	10.7 (16.8)[1]	6.3 (6.7)[1]	0.41 (0.37)[2]	18.2 (18.0)[2]	94 (49)[3]	110 (103)[3]
November	17.8 (18.8)	9.1 (8.1)	0.38 (0.39)	20.6 (20.7)	35 (53)	113 (120)
December	22.2 (20.4)	12.0 (10.4)	0.57 (0.50)	19.2 (21.1)	15 (57)	132 (132)
1982 January	23.0 (21.3)	11.3 (11.5)	0.86 (0.60)	21.7 (21.0)	28 (60)	169 (137)
February	23.7 (20.9)	11.0 (11.4)	0.74 (0.59)	20.7 (19.5)	16 (54)	137 (116)
March	21.3 (19.2)	10.6 (9.9)	0.53 (0.45)	15.5. (14.7)	12 (57)	108 (94)

[1]1944-1960 [2]1976-1982 [3]1930-1981
Source: Lincoln College, Plant Science Department Review of Research No. 1, 1982.

efficiency, partitioning efficiency and yield of conventional and semi-leafless peas; 2. to examine the response of yield to irrigation applied during different developmental phases.

MATERIALS AND METHODS

Two experiments were conducted on a Templeton silt loam at the Lincoln College Research Farm. The site had previously been cropped with Tama ryegrass followed by autumn-sown tick beans (1980/81). The 1981/82 season was drier than average and potential evapotranspiration calculated using the version of Penman's formula given by French and Legg (1979) was also faster than average from January to March (Table 1).

Two 2 × 4 factorial experiments, arranged in randomised blocks with four replications were used. The factors and levels were as follows:

Cultivar:-
- Rovar
- Semi-leafless (SL type near isogenic to Rovar; Wilson *et al.*, 1981).

Irrigation:-
- No irrigation (Nil)
- Irrigation from pod swelling to maturity (P-M)
- Irrigation from flowering to maturity (F-M)
- Irrigation from vegetative to maturity (V-M)

The flowering and pod swelling stages were defined as being when 50% of the plants showed at least one open flower or one pod greater than 20 mm length beginning to swell on the first two flowering nodes or pod bearing nodes.

Each plot was 10 m long × 3 m wide with 20 rows at 15 cm row spacing. The first experiment was sown on 23 October 1981 and the second sowing on 16 December 1981. The target population was 120 plants/m^2. Buffer plots, the same size as the treatment plots, were sown with Maro peas to stop the lateral movement of water between plots and prevent edge effects. The total area of experiment and boundary crops was 0.5 ha.

A Ministry of Agriculture and Fisheries (M.A.F.) soil quick test gave the following results: pH 5.6, P (Olsen) 12, Ca 8, K 8, Mg 4. Flowmaster superphosphate at 250 kg/ha was broadcast and incorporated into soil at sowing.

Trickle irrigation was applied at about 6 mm/hour. The amount of water applied was equal to the difference between potential evapotranspiration (Ep) estimated using the approach outlined by Ritchie (1972) and rainfall plus irrigation in the previous week. The calculation assumed the soil to be at field capactiy at sowing. Irrigation started on 4 December 1981 for the first sowing and 24 January 1982 for the second. Subsequent irrigations were applied weekly. The objective of the irrigation strategy was to keep the potential soil moisture deficit (French and Legg, 1979) at about the same level during the period of irrigation.

Neutron probe access tubes were installed to a depth of 1 m in all plots of two replicates i.e. 16 out of 32 plots, and weekly measurements were made of the soil moisture content profiles. Soil moisture contents near the suface (0 -0.2 m) were determined gravimetrically. The measurements were for a period of 60 days starting at 40 and 35 days after sowing for first and second sowing respectively. Measurements of volumetric soil moisture content were converted to water potential values (MPa) using the soil moisture characteristic determined for an adjacent area, 80 m from the site and of similar soil type. Vertical hydraulic fluxes (mm/d) at 0.75 m depth were computed from water characteristic data (Jackson, 1972) and matched to estimates made in the field by an internal drainage method (Hillel *et al.*, 1972). The cumulative water use data were adjusted for these fluxes and WUE was calculated as the ratio of total dry matter produced to water used during the period of measurement for two replicates.

The water holding capacity of the top 1 m at field capacity was 315 mm and the available water content to 0.7, 0.9 and 1 m was 107, 148 and 169 mm respectively.

Radiation transmission by the green sufaces of the crop conopy was measured weekly for each plot by inserting a probe containing two, 0.32 m long miniature tube solarimeters (Delta-T Devices, Burwell, Cambridge, England) (see Szeicz (1965) for details) underneath the canopy and comparing their output to another miniature tube solarimeter similarly aligned above the canopy, using a three channel integrator. Measurements of the interception of the total solar radiation made were converted to an equivalent figure for absorbed photosynthetically active radiation (PAR) (Gallagher and Biscoe, 1978).

The performance of the crops was then examined in terms of (i) PAR absobed (Sa), (ii) growth efficiency (ξg) — the ratio of the calorific value of the crop, estimated assuming a heat of combustion of 19.0 KJ/g appropriate for pea haulm and grain at maturity (Spector, 1956; Leith, 1975), to the PAR absorbed and (iii) partitioning efficiency (ξp) — the ratio of seed DM yield to total DM yield.

Plant and crop measurements were made every 14 days beginning 30 days after sowing. At each harvest, all above-ground biomass was taken from an 0.5 m^2 sample from each plot. The plants were counted and a 10 plant subsample was taken from which the area of green foliage was determined. All the plants (including subsample) were oven dried at 70 °C for 24 hours and their total dry matter recorded. At maturity, a 4 m^2 area of each plot was hand-harvested and machine threshed.

RESULTS

Seed Yield

The two cultivars produced similar dry matter seed yields (Table 2). For the first sowing, seed yield increased from 2110 kg/ha without irrigation to 4360 kg/ha with irrigation throughout growth. Equivalent figures for the second sowing were 1150 kg/ha and 2940 kg/ha. Intermediate yields were obtained when the period of irrigation was restricted.

TABLE 2: Dry matter seed yields (kg/ha)

	1st Sowing	2nd Sowing
Cultivar		
Rovar	2980 N.S.	1950 N.S.
Semi-leafless	2980	1920
S.E. mean	58.6	70.7
Irrigation		
No irrigation	2110 Cc	1150 Cd
Irrig. pod swelling to maturity	2170 Cc	1630 Bc
Irrig. flowering to maturity	3270 Bb	2030 Bb
Irrig. vegetative to maturity	4360 Aa	2940 Aa
S.E. mean	82.9	100.0
No significant interaction		

N.S. Not significant in F-Test

Means with a common letter are not significantly different at 5% and 1% level (capital letters), Duncan's New Multiple Range Test.

Growth, Yield and Radiation Absorption

The amounts of radiation absorbed by the crops during growth were poorly related to the total dry matter produced for the first sowing though the relationship was stronger in the second sowing (Figs. 1a, 1b). Three phases of radiation utilization could be distinguished: an early phase when utilization was poor, about 1 g/MJ, associated with small LAI and when leaves may have been light saturated; a phase of greater efficiency before drought or senescence set in with a conversion of about 2.5 and 2.0 g/MJ for the first and second sowings respectively and; a senescent phase when LAI was again small and conversion was less than 1 g/MJ.

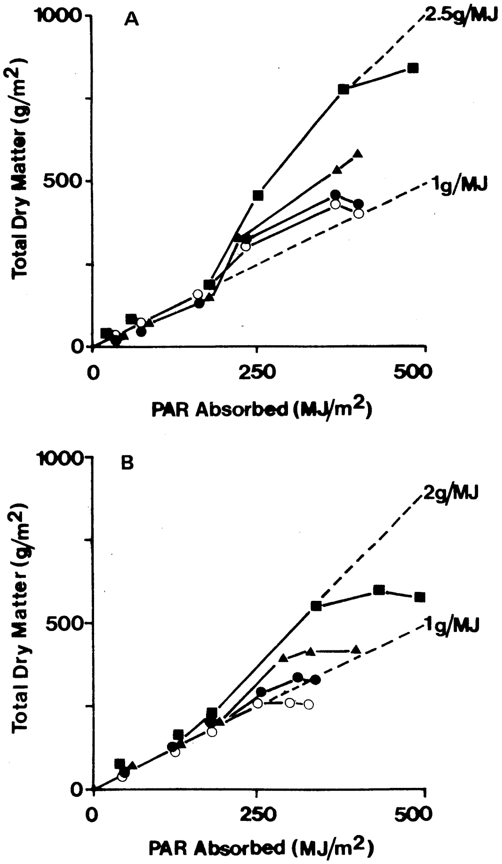

Figure 1: (a) The relation between total dry matter and PAR absorbed for the first sowing; (○) nil; (●) P-M; (▲) F-M and (■) V-M.
(b) The relation between total dry matter and PAR absorbed for the second sowing; (○) nil; (●) P-M; (▲) F-M and (■) V-M.

Table 3 shows that for the first sowing Rovar absorbed more radiation than SL. This was possibly due to the lower plant population of SL compared with Rovar. The mean plant populations measured 30 days after sowing for Rovar and SL were 119 and 84 plants/m^2 respectively. However, SL compensated for lower radiation absorption by having a significantly ($p < 0.01$) greater growth efficiency than

TABLE 3: Absorbed radiation, maximum dry matter production, growth and partitioning efficiency.

1st sowing	Radiation absorbed (PAR) (Sa) MJ/m²	Maximum total dry matter (TDM) g/m²	Growth efficiency (ξ g) %	Partitioning efficiency (ξ p)
Cultivar				
Rovar	410**	530 N.S.	2.40**	0.57**
Semi-leafless	360	550	2.94	0.54
S.E. mean	6.3	19.1	0.102	0.004
Irrigation				
No irrigation	360 Bb	280 Cc	2.00 Cc	0.54 Bb
Irrig. pod swelling to maturity	370 Bb	400 Cc	2.10 Cc	0.54 Bb
Irrig. flowering to maturity	370 Bb	550 Bb	2.87 Bb	0.58 Aa
Irrig. vegetative to maturity	450 Aa	840 Aa	3.71 Aa	0.55 Bb
S.E. mean	8.9	27.1	0.144	0.006
No significant interaction				
2nd sowing				
Cultivar				
Rovar	330**	390 N.S.	2.10 N.S.	0.58**
Semi-leafless	360	430	2.20	0.53
S.E. mean	4.9	14.4	0.076	0.005
Irrigation				
No irrigation	300 Cc	260 Cd	1.52 Dd	0.52 Bb
Irrig. pod swelling to maturity	320 BCbc	340 Cc	1.93 Cc	0.56 Aa
Irrig. flowering to maturity	340 Bb	430 Bb	2.37 Bb	0.58 Aa
Irrig. vegetative to maturity	410 Aa	590 Aa	2.80 Aa	0.58 Aa
S.E. mean	7.0	20.4	0.106	0.007
No significant interaction				

Rovar. As a result, there was no significant difference in the maximum total dry matter production between the two cultivars. Although the partitioning efficiency of Rovar was significantly ($p < 0.01$) higher than that of SL, the effect was small (5%) and there was no significant difference in seed yield between the two cultivars (Table 2).

For the second sowing, SL aborbed a significantly ($p < 0.01$) higher amount of radiation than Rovar. As there was no significant difference in plant population densities in the second sowing (mean 112 plants/m²), the higher Sa shows that, if grown at comparable plant population densities, SL can absorb more radiation than Rovar. However, there were no significant differences in growth efficiency, total dry matter production or seed yield betwen the two cultivars.

The average growth efficiencies of the fully irrigated treatments for the first and second sowings were 3.71% and 2.80% respectively; drought nearly halved this efficiency (Table 3). Drought also decreased the radiation absorbed by the unirrigated crops by 20-30%. In the first sowing, the partitioning efficiency for the treatment given irrigation from flowering to maturity was significantly ($p < 0.01$) higher than for treatments receiving no irrigation or irrigation from the pod swelling or vegetative stages to maturity. However, in the second sowing the partitioning efficiency for all the irrigated treatments was 10% higher than for the unirrigated treatments.

Soil Water Content

Soil moisture content to a depth of 0.8 m declined rapidly, especially in the unirrigated treatments but more slowly when irrigation was applied throughout growth for the first sowing (Fig. 2a). This decline shows that actual evaporation was apparently faster than potential so that the irrigation applied was insufficient to prevent a decrease in soil moisture content. In the second sowing however, the soil moisture content was maintained to about the same level by irrigation (Fig. 2b). The coefficients of variability (CV) for soil moisture content measurements in the first and second sowings were typically less than 12% and 18% respectively.

Water Use Efficiency

At both sowing times there was a tendency for SL to use more water but the difference was not significant (Table 4). The WUE values for the two cultivars were also the same. Unirrigated crops used water more efficiently than irrigated ones at both sowing dates.

DISCUSSION

Yield and Growth

There was no difference in seed yield between cultivars as found by Wilson *et al.* (1981). Irrigation increased yield in both sowings. The increase calculated from the mean of all irrigated treatments was 52% and 98% for the first and second sowing, respectively. The (Ep-rainfall) values were

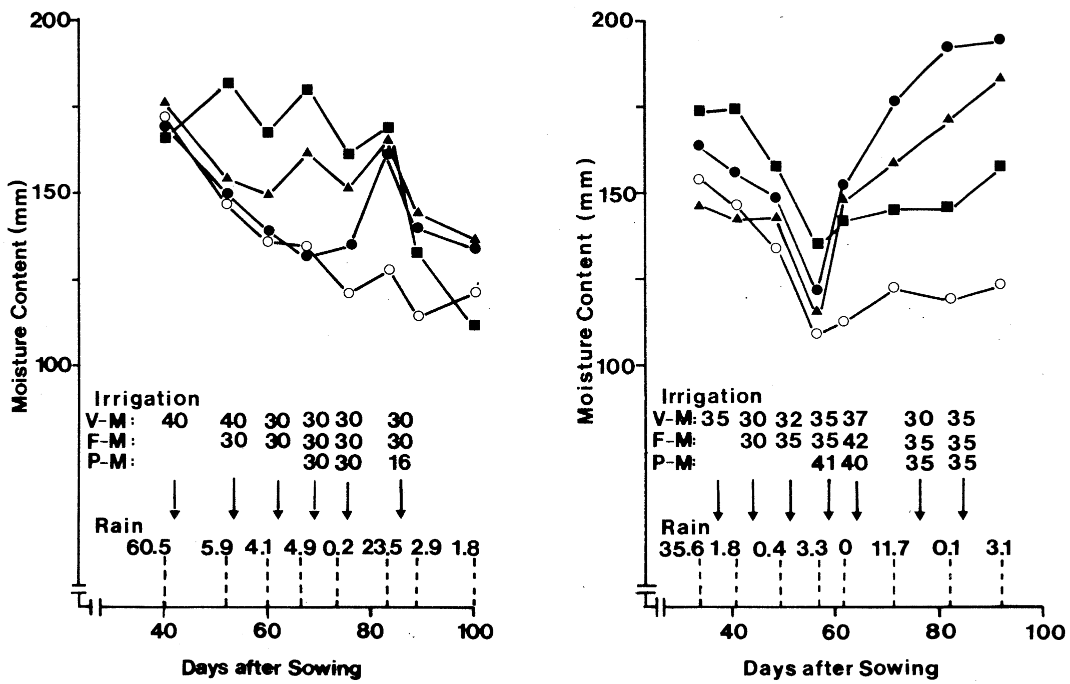

Figure 2: (a) Moisture content of top 0.8 m soil plotted against days after sowing for the first crop; (○) nil; (●) P-M; (▲) F-M and (■) V-M.
(b) Moisture content of top 0.8 m soil plotted against days after sowing for the second crop; (○) nil; (●) P-M; (▲) F-M and (■) V-M.

230 mm and 240 mm for the first and second sowing respectively. On a similar soil, mean yield increases of 25%, 38% and 188% were obtained for the 1975/76, 1974/75 and 1973/74 seasons respectively (Stoker, 1977); estimates of (Ep-rainfall) values for these seasons were 170 mm, 190 mm, and 240 mm respectively.

The strong response of yield to irrigation in all except the pod swelling to maturity treatment in the first sowing was probably related to the very dry season. The failure of the first sown crops to respond to late irrigation may be because insufficient water was applied (Fig. 2a) and light absorption was not increased significantly (Table 3).

Drought decreased the amount of radiation absorbed. Similar decreases in interception of solar radiation were found in a comparison between irrigated and unirrigated pigeon peas grown in Trinidad (Hughes *et al.*, 1981;Hughes and Keatinge, 1983).

Drought also decreased the overall growth efficiency by 40%. This decrease in ξg was much larger than that reported for a barley crop under drought in England where ξg was depressed by 25% (Legg *et al.*, 1979). However, the present results are comparable to the 50% reduction in ξg reported for pigeon pea (Hughes and Keatinge, 1983). The lower ξg values for the crops receiving less than full irrigation may be partly because these crops achieved only small leaf area indices, resulting in photosynthesis being light saturated on days of bright sunshine, and partly due to a direct effect of drought on photosynthesis via stomatal closure.

The three phases of radiation utilization (Fig. 1) were similar to those found by Littleton *et al.* (1979) for cowpeas grown under tropical conditions. The early phase of low efficiency suggests the need for complete cover to obtain better utilization of absorbed radiation. The maximum utilization of PAR in our experiment was about 2.5 g/MJ, obtained for the fully irrigated treatments during the phase of fast growth. This value is close to that obtained for cowpeas by Littleton *et al.* (1979) of about 2.3 g/MJ and similar to values of around 3.0 g/MJ obtained for temperate cereals in England (Gallagher and Biscoe, 1978) but much less than the exceptional value of 4.1 g/MJ reported for *Vicia faba* in England by Fasheun and Dennett (1982). However, the growth of this *V. faba* crop was estimated from samples of only three plants per harvest and experimental errors were not reported (Fasheun and Dennet, 1982).

Drought decreased the partitioning efficiency for both sowings. This result is similar to that of Wilson *et al.* (1981) whose results show a decline in partitioning efficiency of about 20% due to the influence of drought.

TABLE 4: Water use efficiency.

1st sowing	Cumulative water use mm	Water use efficiency kg/ha/mm
Cultivar		
Rovar	190 N.S.	25.6 N.S.
Semi-leafless	189	28.2
S.E. mean	17.3	2.35
Irrigation		
No irrigation	99 Bc	34.1 Aa
Irrig. Pod swelling to Maturity	190 Bb	18.4 Ab
Irrig. Flowering to Maturity	193 Bb	27.3 Aab
Irrig. Vegetative to Maturity	277 Aa	27.8 Aab
S.E. mean	24.5	3.32
No significant interaction		
2nd sowing		
Cultivar		
Rovar	149 N.S.	24.6 N.S.
Semi-leafless	174	25.3
S.E. mean	14.7	6.39
Irrigation		
No irrigation	61 Bb	39.2 Aa
Irrig. Pod swelling to Maturity	129 Bb	20.1 Aa
Irrig. Flowering to Maturity	216 Aa	17.5 Aa
Irrig. Vegetative to Maturity	240 Aa	23.0 Aa
S.E. mean	20.7	6.53
No significant interaction		

Water Use

The decline in soil moisture content of the top 0.8 m layer in the first sowing (Fig. 2a) showed that the evapotranspiration was greater than the supply of water from irrigation and rainfall even for the fully irrigated plots. Water use by small plots is likely to differ from that of uniform surfaces of large horizontal extent (Legg *et al.*, 1978) and there may be an increase in evapotranspiration where a small area of irrigated crop is surrounded by an unirrigated crop. In addition, it is relevant to note that even on large plots, actual evapotranspiration has been shown to exceed Ep by more than 10% for beans and several arable crops in England (French and Legg, 1979).

Water Use Efficiency

The average WUE of the first and second sowings was practically identical at about 25 kg/ha/mm (Table 4). Bierhuizen and Slayter (1965) reviewed results of pea experiments and found that WUE ranged from 55 kg/ha/mm to 15 kg/ha/mm and was inversely related to the mean daily vapour pressure deficit. Based on Ritchie's (1972) model, the average ratio of transpiration to evapotranspiration for our crops was 0.6 giving an average (transpirational) WUE of 42 kg/ha/mm. For a mean daily vapour pressure deficit of 0.60 kPa, our results fall within the scatter of those presented by Bierhuizen and Slatyer (1965). Our estimates of WUE were similar to those of Wilson *et al.* (1981) who found values of about 30 kg/ha/mm and 25 kg/ha/mm for unirrigated and irrigated crops in a season in which the mean daily vapour pressure deficit during growth was 0.61 kPa (cf. Table 1).

Between the two dates of sowing, the average growth efficiency fell by about 20% (Table 3) but the average WUE remained effectively constant (Table 4). This implies that the amounts of evaporation and assimilation per unit absorbed radiation decreased similarly. As the foliage morphology and the humidity deficits between the canopy and the air were similar for the two sowings, it may be inferred that the decline in evaporation per unit absorbed radiation arose from a decrease in canopy conductance. Assimilation would have decreased in parallel with evaporation if the difference between atmospheric CO_2 concentration and a weighted average concentration within the leaves of the crop (ΔC) remained constant. A conservative value of ΔC has been found for the leaves of some plants (Goudriaan and Van Laar, 1978; Wong *et al.*, 1979) and the possibility of a conservative value for crops has been raised (Monteith, 1981). Using a procedure similar to that of Cowan (1978) yields a value for ΔC of between 110 and 130 mg/m^3 for temperate species; assuming transpiration to be about 60% of evapotranspiration for our crops gave a ΔC value of 130 mg/m^3. Based on measurements of CO_2 exchange in the field, Louwerse

(1980) estimated values of ΔC for canopies of sunflower and barley to be about 135 mg/m^3. The close correspondance of Louwerse's results for ΔC with the crude estimates of ΔC made above may be fortuitous. Nonetheless, the intriguing possibility that for crops, as for leaves (see Wong *et al.*, 1979), stress slows photosynthesis and the stomata respond to changes in intracellular CO_2 concentration in such a way as to maintain ΔC stable warrants further investigation.

In summary, under the conditions of our study, a semi-leafless pea cultivar derived from a Rovar background yielded the same as a conventional cultivar. Irrigation decreased WUE but the effect was independent of stage of development suggesting that the response of growth to water is similar regardless of when the water is applied. Drought decreased yield mainly by decreasing the amount of radiation absorbed and the growth efficiency; it also decreased partitioning efficiency slightly.

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