# THE NON-EXISTENCE OF MOISTURE SENSITIVE PHASES IN *VICIA FABA* L. GROWN UNDER IRRIGATION IN CANTERBURY

M.M. Husain, J.N. Gallagher, G.D. Hill and M. Othman
Plant Science Department
and
J.B. Reid
Soil Science Department, Lincoln College, Canterbury

## ABSTRACT

The reponse of autumn and spring-sown crops of *Vicia faba* L. cv. 'Maris Bead' to irrigation during the vegetative, flowering and pod-filling phases was investigated during the 1981/82 and 1982/83 growing seasons on a Templeton silt-loam soil. The aim of the experiment was to determine whether crop yield was especially sensitive to moisture stress during any of these phases. During any phase, trickle irrigation was applied weekly in amounts equal to the difference between the estimated evapotranspiration and rainfall of the previous week.

Averaged over the two seasons, the yields of the unirrigated spring and autumn-sown crops were 2.4 and 3.7 t/ha respectively; full irrigation increased yield by about 45%.

In two seasons when monthly rainfall from October to January was 20% above average (1982/83 = 65 mm) and 20% below average (1981/82 = 43 mm) and potential evapotranspiration was about 500 mm, grain yield increased linearly with the quantity of irrigation and rainfall received by the crops up to about 500 mm irrespective of timing. The average response of grain yield to the quantity of water received for the spring-sown crops was about 3.5 kg.ha/mm with the response of autumn-sown crops being roughly 50% greater. Thus irrigation during any developmental phase generally increased yeld with the response per unit water applied being similar. The results of these four experiments (with field beans) and several experiments in the literature do not support the existence of moisture senstitive periods in field beans.

***Additional Keywords:*** *trickle irrigation, grain yield, moisture sensitive period, evaporation, potential soil moisture deficit, field beans, tick beans.*

## INTRODUCTION

Much work in Canterbury has shown that irrigation can double the yield of grain legumes in dry years (Stoker, 1975a, 1975b, 1977; Martin and Tabley, 1981; White *et al.*, 1982). With an expanding demand for water resources and increasing costs associated with irrigation, there is a need to ensure the maximum return from each unit of irrigation water applied. The need of grain legume crops for water is often related to so-called 'moisture-sensitive periods'. Salter and Goode (1967) defined such periods as "certain developmental phases in which the plant is, or appears by its observed reponse, to be more sensitive to moisture conditions than at other stages of development". However, in many of the experiments from which Salter and Goode (1967) drew their conclusions "moisture conditions" were often either not measured quantitatively or specified in a way such that their relevance to plant growth was obscure. Nonetheless, if moisture sensitive periods could be indentified for field beans in Canterbury, it would have important implications for irrigation practice.

Newton (1980) showed that irrigation could increase the yield of both autumn and spring-sown crops of field beans in Canterbury by about 45%. However, Newton's (1980) irrigation treatments were not designed to determine the existence of moisture-sensitive periods. Salter and Goode (1967) identified flowering as a moisture sensitive period for fields beans but evidence supporting this conclusion for *Vicia faba* and other grain legumes is sparse, especially when yield is related to a relevant and well defined measure of either drought or water use (Downey, 1972; Turk and Hall, 1980). In arid condtions in Australia, however, Hearn and Constable (1981) used an analysis based on estimates of actual evaporation rates from stressed and full irrigated treatments to show that pod-fill was a moisture-sensitive period for soya beans. In contrast, Penman (1970) and French and Legg (1979) showed that the yield for field beans declined linearly with the maximum potential soil moisture deficit once some limiting value of that deficit had been reached. They found no clear evidence for moisture-sensitive peiods in 10 years of experiments.

This paper reports preliminary results of experiments which examined the response of autumn and spring-sown crops of field beans to irrigation applied during specific developmental phases. A particular aim was to determine whether any moisture-sensitive periods exist for this crop in the Canterbury environment.

**TABLE 1: Husbandry Operations 1981/82 and 1982/83 seasons.**

| Operations | Description | | | | |
|---|---|---|---|---|---|
| 1. Previous Crops: | | | | | |
| 1981/82 | Spring sown lupins (autumn), winter sown mustard, radish and kale (spring) | | | | |
| 1982/83 | 5 years old pasture with red clover and Matua prairie grass | | | | |
| 2. Sowing Dates: | | | | | |
| 1981/82 | 1 May and 18 September | | | | |
| 1982/83 | 3 June and 10 September | | | | |
| 3. Plant Density and Spacing: | | | | | |
| 1981/82 | Giving 52 plants/m² (autumn); giving 62 plants/m² (spring) | | | | |
| 1982/83 | Giving 84 plants/m² (autumn); giving 75 plants/m² (spring). Spacing for all crops was 15 cm between rows. | | | | |
| 4. Soil test results for experimental sites: | pH | P | K | Ca | Mg |
| 1981/82 spring | 6.3 | 15 | 10 | 10 | 15 |
| 1982/83 autumn | 5.8 | 11 | 10 | 10 | 17 |
| spring | 6.2 | 11 | 4 | 13 | 17 |
| 5. Fertiliser: | | | | | |
| 1981/82 | Flowmaster superphosphate, muriate of potash at 50 kg/ha P and 25 kg/ha K respectively. | | | | |
| 1982/83 | Flowmaster superphosphate at 20 kg/ha P | | | | |
| 6. Weed control: | Simazine 1.3 kg/ha for all crops — but in 1981/82 autumn, weed control was poor. | | | | |
| 7. Disease control: | | | | | |
| 1981/82 | i) Benomyl (benlate 50% a.i.) and Rothocide at 50 and 80 g/100 kg beans for seed treatment against *Ascochyta fabae*.<br>ii) 9 sprays with Chlorothelonil at 1.5 litre with 190 litre water per hectare for autumn and 2 sprays with same chemical for spring. | | | | |
| 1982/83 | i) Seed treated as before with same chemical against *Ascochyta fabae*.<br>ii) 4 sprays as before with same chemical against *Aschochyta fabae*. | | | | |
| 8. Pest control: | | | | | |
| 1981/82 | None for autumn. For spring:<br>i) Methiocarb (Mesurol 75% a.i.) 300 g/kg beans against birds.<br>ii) Pirimiçarb (Paramole) 250 g/ha against black bean aphids (*Aphis craccivora*) before pod set. | | | | |
| 1982/83 | 1 spray with same chemical as before against aphids on 18 November. | | | | |

## MATERIALS AND METHODS

### Design and Treatments

The response of autumn and spring-sown *Vicia faba* cv. 'Maris Bead' to irrigation during vegetative, flowering and pod-filling phases of growth was investigated (Fig. 1) using a randomised complete block design with 4 replicates in 1981/82 and 1982/83. The plots were 30 x 2.4 m for spring and 35 x 2.4 m for autumn in 1981/82 and 30 x 3.6 m in both sowings of 1982/83 crops with a buffer plot between each treated plot to avoid lateral movement of water between heavily and lightly irrigated treatments.

Irrigation was applied weekly. The amount of water used by each treatment was estimated weekly from measurements of crop cover and weather using the approach of Ritchie (1972) with a version of the Penman formula described by French and Legg (1979). McNaughton *et al.* (1982) found that a similar formula overestimated evaporation by about 15% in the North Island of New Zealand but our measurements of crop evaporation, which will be reported elsewhere, showed good agreement with estimates based on French and Legg's (1979) version of the Penman formula. During the period for which any treatment was being irrigated, it received an amount of water equal to the difference between estimated potential evapotranspiration (Ep) and rainfall (R) plus irrigation (I) in the previous week. To try and avoid waterlogging however, no irrigation was applied if the difference between Ep and R plus I was less than 35 mm. Unfortunately, in the 1982/83 spring season, the E-F and

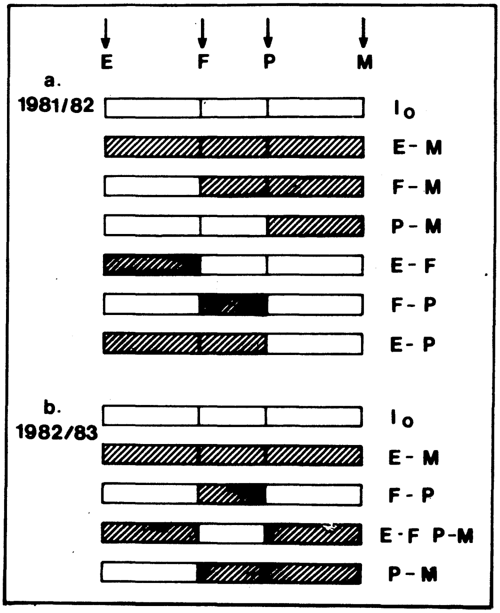


**Figure 1: Developmental phases during 1981/82 and 1982/83, when irrigation (shaded) was applied. E = emergence, F = flowering, p = pod-set and M = maturity. Flowering and pod-set were defined as when 50% of the plants had one open flower or a green pod 10 mm long.**

P-M treatment was accidentally given more than the fully irrigated crops. Table 1 gives details of crop husbandry. Trickle irrigation was used with laterals at 0.45 m spacing and 25 cm long micro tubes at 30 cm apart. The application rate of 5-6 mm/ha/hr was well within the infiltration capacity of the soil — a Templeton silt-loam overlying sand and gravel. Soil depth was always greater than 1.2 m. The available water capacity of the top 1.0 m of soil was 170 mm. Table 1 shows the results from a MAF soil test.

The weather from November until the end of January of 1981/82 was dry (Fig. 2a) with a rainfall about 45% of the average. Mean daily temperatures during December and January were about 10% greater than average (Fig. 2a) and on 18 afternoons the maximum temperature was greater than 25 °C. In 1982/83 however, rainfall during December was about 54% above average (Fig. 2b). Ep during October to January in both years was about 4.5 mm/d, about 4% greater than average.

**Measurements**

For 1981/82 spring crops, grain yield was estimated on 20 plants chosen at random from 8 samples of 0.25 $m^2$ taken from each plot. For autumn crops 10 plants were chosen for 4 samples of 0.25 $m^2$. Grain yields were then estimated as proportion of the fresh weight of sample and sub-sample. For both crops of 1982/83, grain yields were obtained by threshing 8 samples of 0.25 $m^2$ for each plot.

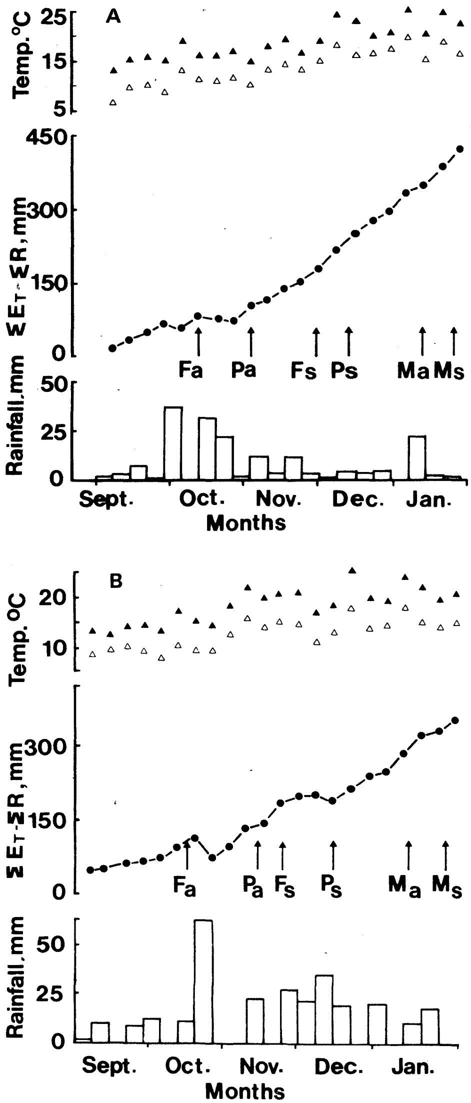


**Figure 2: Weekly distribution of rainfall, potential soil moisture deficit according to Penman formula for complete cover ($\Sigma E_T$ — $\Sigma$ R) and air temperature ( ▲ maximum, △ minimum) at Lincoln College. (a) 1981/82 (b) 1982/83.**

# RESULTS

**General**

Table 2 shows that, in 1981/82, the fully irrigated treatment yielded about 20% more than the unirrigated treatment for the autumn-sown crops. The fully irrigated

**TABLE 2: Response of grain yield to irrigation 1981/82.**

| Sowing | | Grain yield Y (t/ha) | Applied irrigation (I), mm | (Yn - Yo)/I (kg/ha/mm) | (Yn - Yo)/(I+R) (kg/ha/mm) | Y/(I+R) (kg/ha/mm) |
|---|---|---|---|---|---|---|
| | Io | 3.91 | — | — | — | 22.9 |
| | E-M | 4.74 | 263 | 3.2 | 1.9 | 10.9 |
| | F-M | 4.61 | 260 | 2.7 | 1.8 | 10.7 |
| Autumn | P-M | 4.58 | 275 | 2.6 | 1.9 | 10.3 |
| | E-F | 3.82 | 30 | -2.8 | -1.2 | 19.0 |
| | F-P | 3.61 | 55 | -6.4 | -3.2 | 15.8 |
| | E-P | 3.42 | 54 | -9.4 | -3.3 | 15.2 |
| | Mean | 4.10 | | -1.7 | -0.4 | 15.0 |
| | Significance | * | | N.S. | N.S. | *** |
| | L.S.D. (0.05) | 0.86 | | | | 3.4 |
| | S$\bar{x}$ | 0.35 | | 6.3 | 2.7 | 1.2 |
| | Io | 1.84 | — | — | — | 10.8 |
| | E-M | 2.83 | 285 | 3.5 | 2.2 | 6.2 |
| | F-M | 2.52 | 265 | 2.6 | 2.2 | 5.8 |
| Spring | P-M | 2.05 | 215 | 1.0 | 0.8 | 5.3 |
| | E-F | 2.11 | 50 | 5.4 | 1.5 | 9.6 |
| | F-P | 2.23 | 60 | 6.5 | 6.0 | 9.7 |
| | E-P | 1.98 | 110 | 1.3 | 0.6 | 7.1 |
| | Mean | 2.22 | | 3.4 | 2.2 | 7.8 |
| | Significance | ** | | N.S. | ** | *** |
| | L.S.D. (0.05) | 0.60 | | | 3.29 | 1.7 |
| | S$\bar{x}$ | 0.20 | | 1.7 | 1.1 | 0.6 |

* significant at 10% level
** significant at 5% level
*** significant at 1% level
N.S. non-significant

spring-sown crops in the same year yielded about 54% more than the unirrigated treatment. The equivalent figures for the 1982/83 sowings were 63% and 30% for the autumn and spring-sown crops respectively (Table 3). No treatment yielded significantly more than the fully irrigated treatment except for the P-M treatment in the 1982/83 spring-sown crops. However, the response of the P-M treatment was inconsistent between seasons. When only small amounts of irrigation were applied (less than about 100 mm), the small yield increases that resulted were not significant as the precision of the experiments was low; CV's ranged from 7 to 18%.

**Irrigation-yield responses**

The simplest measure of the response to irrigation is given by (Yn-Yo)/I, where Yn and Yo are the yields of the irrigated and unirrigated treatments respectively. Considering only those treatments where irrigation significantly increased yield, in 1981/82 the average response was about 3 kg/ha/mm irrigation applied for both autumn and spring-sown crops (Table 2). There was also a weak indication that full irrigation was used more effectively than irrigation applied during flowering to maturity. In the 1982/83 season and on the same basis, the average response to irrigation was 7.6 kg/ha/mm in the autumn-sown crops, nearly 70% greater than the spring-sown crops (Table 3). Again, there was no significant difference in response of yield to irrigation applied during different developmental phases except that the emergence to flowering and the pod-set to maturity treatment of autumn-sown crops had a slightly smaller response. However, considering all the crops, no consistent trends could be discerned. One problem with this simple analysis of the response of yield to irrigation is that it takes no account of rainfall.

Table 2 shows that taking account of rainfall during the period when irrigation was applied for the 1981/82 crops removed any suggestion of a difference in response to water supply. The same procedure when applied to the 1982/83 crops (Table 3) also reduced the variation about the mean response and suggested that water supplied during the pod-filling period produced the largest yield response. This is in marked contrast with the 1981/82 spring results when 215 mm irrigation during pod-filling failed to increase yield significantly. This difference in response might have

TABLE 3: **Response of grain yield to irrigation 1982/83.**

| Sowing | Treatment | Grain yield Y (t/ha) | Applied irrigation (I), mm | (Yn - Yo)/I (kg/ha/mm) | (Yn - Yo)/(I+R) (kg/ha/mm) | Y/(I+R) (kg/ha/mm) |
|---|---|---|---|---|---|---|
| | Io | 3.5 | — | — | — | 14.3 |
| | E-M | 5.7 | 305 | 7.1 | 3.9 | 10.3 |
| Autumn | F-P | 4.6 | 125 | 8.7 | 4.9 | 12.4 |
| | E-F and P-M | 5.2 | 280 | 5.9 | 3.8 | 9.8 |
| | P-M | 5.8 | 265 | 8.6 | 5.7 | 11.3 |
| | Mean | 5.0 | | 7.6 | 4.6 | 11.6 |
| | Significance | *** | | N.S. | N.S. | ** |
| | L.S.D. (0.05) | 0.63 | | | | 1.4 |
| | S$\bar{X}$ | 0.2 | | 1.2 | 0.71 | 0.5 |
| | Io | 2.9 | — | — | — | 10.9 |
| | E-M | 3.8 | 230 | 3.8 | 1.8 | 7.6 |
| Spring | F-P | 3.1 | 50 | 4.5 | 1.7 | 9.9 |
| | E-F and P-M | 3.9 | 240 | 4.2 | 2.4 | 7.8 |
| | P-M | 4.2 | 200 | 5.6 | 4.6 | 9.1 |
| | Mean | 3.6 | | 4.5 | 2.6 | 9.1 |
| | Significance | *** | | N.S. | * | ** |
| | L.S.D. (0.05) | 0.35 | | | 2.1 | 1.2 |
| | S$\bar{X}$ | 0.1 | | 1.7 | 0.7 | 0.4 |

* significant at 10% level
** significant at 5% level
*** significant at 1% level
N.S. non-significant

arisen from the influence of rainfall during earlier developmental phases. To persue this further, we examined the response of yield to the total water received by the crops during the period when more than 90% of total growth in dry matter (1 October-maturity) occurred.

Fig. 3 shows that, for all crops, grain yield increased linearly with total water received up to about 550 mm. Except for the pod-set to maturity treatment in the 1981/82 spring sowing, the observations fall within the 5% confidence bands. No irrigation treatment fell consistently above or below the response line. This suggests therefore, that in these experiments where water was supplied according to estimated need, the developmental stage when water was supplied did not affect response of yield to that water. The response of yield to water receipt varied considerably between sowings and seasons. However, there was a steady decline in the absolute response of yield (Y/(I+R)) with the increasing quantity of irrigation and rain (Tables 2, 3). This decreasing efficiency in water use was also associated with the quantity of water rather than the developmental stage when the water was received.

## DISCUSSION

**General**

Fully irrigated autumn and spring-sown crops, averaged over two seasons, yielded about 45% more than the unirrigated crops which is similar to the response to irrigation reported in Canterbury by Newton (1980). Work in England (Farah, 1981) showed a very large response of yield to irrigation with spring-sown crops of field beans (Maris Bead) - about 100%, in treatments sheltered from rain on a sandy-loam soil. Potential evaporation during Farah's (1981) experiments reached about 350 mm (GRI, 1976, 1977). The highest yield of about 5.8 t/ha from an autumn-sown crop in our experiment (Table 3) was similar to the maximum yield of 5.4 t/ha reported by Newton (1980). However, the average yield of about about 3.7 t/ha in our experiments (Tables 2, 3) was about 40% greater than the average farm yield of 2.6 t/ha in Canterbury (Newton and Hill, 1978). The large response to irrigation reported here as well as those reported by Newton (1980) can be explained in terms of the seasonal water-balance. In both seasons of our experiments the potential soil moisture deficit ($\Sigma E_T - \Sigma R$, where, $E_T$ is the potential transpiration with complete crop cover and R is rainfall) reached about 400 mm by January (Fig. 2) and weather conditions were similar during Newton's (1980) experiments. The results of the present experiments as well as those reported by Newton (1980) show that irrigation is needed to avoid the consequences of drought with shallow-rooted crops such as field beans in Canterbury. However, the magnitude of yield response varied considerably between sowings and this is considered below.

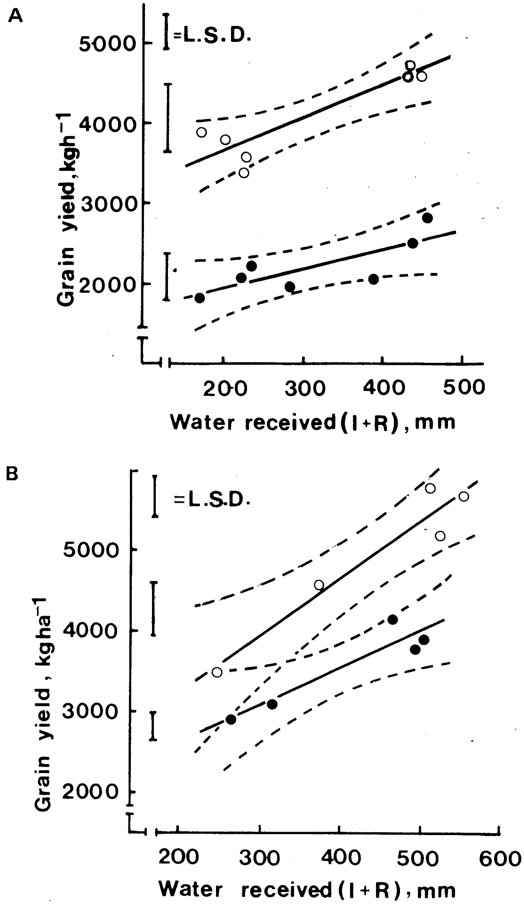


**Figure 3: The relation between total water received (Irrigation + rainfall) and grain yield. a. 1981/82 [0-autumn, Y = 2920 (±270) + 3.9 (±0.8)X, $R^2$ = 0.78 ● - spring, Y = 1490 (±272) + 2.4 (±0.8)X, $R^2$ = 0.55]. b. 1982/83 [0-autumn, Y = 1860 (±535) + 7.0 (±1.2)X, $R^2$ = 0.90. ● - spring, Y = 1750 (±441) + 4.5 (±1.1)X, $R^2$ = 0.81].**

**Response to irrigation**

Treatments which yielded significantly more than the unirrigated treatments gave an average response of about 5.6 kg/ha/mm of irrigation (Tables 2, 3); less than half the mean response reported by Penman (1970, 1971) on a sandy-loam soil in Central England. The reason for the smaller response in our experiments was perhaps environmental; the sandy soil in which Penman's crops were grown had an available water capacity of only 80 mm in the top 1 m - less than half the value for our silt-loam soil. The growth of the English crops was severely restricted when a potental soil moisture deficit of about 30 mm was reached (French and Legg, 1979). An average response of yield to irrigation of about 6.5 kg/ha/mm (calculated when the response of yield to irrigation was positive) can be obtained from French and Legg's (1979) data for three crops on a clay-loam soil at Rothamsted. The large response of yield to 200 mm irrigation during pod-fill in the 1982/83 spring-sown crop may be due to a positive interaction with rainfall during flowering (Fig. 2b) which moistened the rooting zone to about 35 cm at the start of flowering. Growth may therefore not have been restricted by moisture deficit before the start of pod growth.

Unfortunately, our experiments were insuffcently precise to assess the response of yield to small amounts of irrigation and in addition, the effects of rainfall were confounded with those of irrigation. Even when the effects of rainfall during a period of irrigation were accounted for (Yn - Yo)/(I + R): the possibility remains that rainfall before and after the period of irrigation affected crop response. The relation between yield and total water received by the crops during the main growing period was therefore further examined. Neutron probe measurements showed that during 1 October to maturity in these growing seasons, none of the irrigation or rain water was lost to drainage. Fig. 3 shows that grain yields of our 4 crops of field beans were strongly dependent upon the amount of water received by the crops. However, the magnitude of response between sowings and seasons was associated with the size of absolute yields. Averaged over two seasons, the slopes for the autumn-sown crops were about 60% steeper than for the spring sowings. This is similar to the difference in absolute yield. Krogman *et al.* (1980) also reported that yields of spring-sown field beans were linearly dependent upon the amount of rainfall + irrigation in Canada. However, the magnitude of the response in their experiments, about 7 kg/ha/mm on a sandy-loam soil was about 55% greater than the average response 4.5 kg/ha/mm reported here. A comparable value of about 6.3 kg/ha/mm has been reported for wheat in Israel by Stanhill (1973). In our experiments, when mean response (slope of the lines in Fig. 3) is expressed as percent of the best irrigated yields, the response of yield to each mm of water applied was found to equal about 0.1% of the yield of the best irrigated crops. Thus in dry climates, where ΣEp is much larger than ΣR, it seems that crop yields are to a large extent dependent upon the quantity of water received. However, the positive intercepts of Fig. 3 imply that Y/(I + R) decreases steadily with increasing I + R (Tables 2, 3). The probable causes for this are: smaller use of soil water by the fully and late irrigated crops, and about 70% more soil evaporation from the fully irrigated crops than from unirrigated ones.

**Evidence for moisture sensitive periods**

Despite many irrigation experiments there is little agreement as to the presence of any moisture-sensitive periods in grain legumes. This is because of two major problems: difficulty in quantifying the degree of drought during the supposed 'sensitive-period' and lack of control over rainfall. Our work showed that response of yield to water supply did not vary markedly during different developmental phases although the efficiency (Y/(I + R)) declined with increasing I + R as explained above. The deviation of yield of the pod-set to maturity treatment of 1981/82 spring (Fig. 3a) from the response line was an exception and needs further investigation. Penman's (1962,1970) analyses of the response of field beans to irrigation did not support the idea of a 'moisture sensitive period' either before or after flowering. Subsequent analysis of Hebblethwaite (1982) also did not show any particularly sensitive period in field beans. French and Legg (1979) however showed that field bean yield was less affected by drought in July and August than earlier in the year. They suggested that this was because the crops developed a more extensive root system later in the year, rather than some particularly sensitive phase of growth. Our own observations showed that the spring-sown crops reached almost 70% of their rooting depth before the start of pod-fill and root growth at depth continued, albeit slowly, until crop maturity. However, Salter and Drew (1965) showed reduced root growth during flowering as one reason for particular sensitivity of *Pisum sativum* at this stage. El-Nadi's (1970) evidence for the existence of a moisture sensitive period for *Vicia faba* is weak as his results on yield/plot are not consistent with the yield obtained from the product of the yield components. In addition, as mentioned above, his results showed that the greater the amount of irrigation applied, the greater the yield. El-Nadi (1969, 1970) and Keatinge and Shaykwich (1977) emphasised the need for irrigation during early reproductive phase to ensure more flower production and pod-set; Sprent *et al.* (1977) and Farah (1981) showed the importance of post-flowering irrigation to retain more mature pods. In contrast, Jones (1963) found that early watering was necessary to obtain higher yield through early establishment and rapid growth of young seedlings. The results of pot experiments with *Vicia faba* done under mobile rain shelters outdoors (Meriaux, 1972) enables stress days (S.D.) to be calculated. [S.D. = n (1-E/$E_F$), where E and $E_F$ are the evaporation of partially irrigated and fully irrigated crops during a phase of development and n is the duration of the phase in days]. The result showed that field beans were equally sensitive to drought during all phases of development. Stansell and Smittle (1980) also showed that snap beans were equally susceptible to a 75 k Pa soil moisture stress during preflowering, flowering and post-flowering phases. It therefore appears that the evidence supporting the existence of moisture sensitive periods for field beans and other grain legumes is not as sound as many believe. There is a need for field experiments in which large plots can be sheltered from rain to provide firm an unequivocal evidence on this important question.

## CONCLUSIONS

These results confirmed that under Canterbury conditions (where average rainfall during October to January, about 225 mm, is much less than average potential evaporation of about 500 mm), irrigation is expected to increase the grain yield of both autumn and spring-sown crops of field beans by about 45%. Under these conditions, and within the precision of our experiments, we could not detect a 'moisture-senstive period' in field beans. Response to irrigation should therefore be similar irrespective of developmental phases of the crop at application *providing* that the water is needed.

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