The influence of stress on yield, abortion and seed size of French dwarf beans (*Phaseolus vulgaris* L.)

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Abstract

Dwarf beans *(Phaseolus vulgaris* L.) cv. Prosperity were grown on a Templeton silt loam to determine the effect of the mother plant on seed yield and quality. The trial was organized as a randomized complete block design. The treatments were a 2 x 2 x 2 factorial combination of two levels of husbandry (low plant density, high fertiliser, irrigation and full light [LC], and high plant density, no fertiliser, no irrigation and shaded [HC]); two levels of leaf removal (nil removed, 100% removed) and two levels of pod removal (nil removed and 25% removed). The leaf and pod removal treatments were applied 15-20 days after flowering (DAF). Weekly sequential harvests started 19 days later and were continued until 74 DAF. The HC plants produced 2.5 times more seeds, both in weight and in numbers, than did the LC plants. Plant density is thought to have been the most influential husbandry factor. Total dry weight (TDW) at 144 DAS was 60, 23 and 66% higher for the HC plots (3100 kg/ha), all pods (2300 kg/ha) and all leaves treatments (3200 kg/ha), compared to the LC plots, the no pods and the no leaves treatments respectively. Pod abortion rate increased over time in all treatments. Leaf removal increased pod abortion from 24% to 44%, compared with the control of 29% at 144 DAS. This treatment also significantly reduced the seed yield from 141 g/m^2 for the control to 80 g/m^2. The thousand seed weight (TSW) of seeds harvested from plants without leaves was significantly reduced to 318 g seeds from a TSW of 388 g for the control. No difference was found in germination of the seed lots from the different treatments from two harvests, but seedling dry weight was significantly higher from seeds from plants with all their leaves compared to the defoliated plants.

Additional key words: *degree days, growth curves, source/sink ratio, intraplant competition*

Introduction

New Zealand recently has attracted the interest of vegetable seed companies from the Northern Hemisphere because the ability to produce seed in the counter season creates the possibility of a safeguard against crop failures and reduces the need for big seed stocks. French dwarf beans (*Phaseolus vulgaris* L.) have been grown in New Zealand for about 10 years and because of the temperate climate, reliable agricultural infrastructure and relative freedom from the bacterial pathogens *Pseudomonas syringe* pv. *phaseolicola* (Burk.) and *Xanthomonas campestris* pv. *phaseoli* (Smith), good results were initially expected. Originally the crops were grown in Marlborough where the climatic conditions are not dissimilar to the traditional growing areas of the United States and Europe. While reasonable seed yields were achieved, seed germination and vigour was only mediocre (McKenzie *et al.*, 1991). Bean seed production has now moved to Canterbury and quality of the seed has reduced even further, with germination of freshly harvested seed falling to an unacceptable level of below 80% (Guy, 1996). This has happened to many cultivars irrespective of sowing date.

There has been no in depth study of the suitability of the Canterbury climate for the growing of dwarf beans for seed. However, this has been done for sweet corn (*Zea mays* L), which is a crop with similar climatic requirements to dwarf beans. Because sweet corn production was found to be marginal (Wilson and Salinger, 1994) it was recommended that only early sowing (late October) of early maturing cultivars which would be able to accumulate enough degree days before 30 April would have a reasonable chance of success.

While sweet corn is harvested fresh, bean seed has to be harvested at a low moisture percentage. Good drying conditions at harvest are therefor essential, making a harvest after April 15 very difficult. A crop is only grown successfully if besides a high yield the quality of the seed is also satisfactory.

Seed quality is very hard to quantify. Germination tests (ISTA, 1985) are universally used for predicting likely field emergence. They have the disadvantage that the seed is only tested under optimum conditions, and no distinction is being made between strong and weak seedlings (Copeland and McDonald, 1995). To get an indication of the potential for rapid and uniform emergence and development of normal seedlings under a wide range of field conditions, the term seed vigour was introduced (Perry, 1978). Several methods of testing for vigour have been suggested over the years but as yet, only the electro conductivity test (ISTA, 1995) for garden peas has been internationally endorsed. However, the general concept of seed vigour has been internationally accepted, together with a number of factors that influence it. The impact of seed age and storage conditions of beans on seed vigour was clearly illustrated by Pandey (1989). The condition of the testa and its effect on vigour was first reported by Powell and Matthews (1979, 1980) in peas. Both these important factors are affected by the handling of the seed after harvest maturity, and can easily be adjusted through careful harvesting (Jones, 1978; Siddique *et al.*, 1987; Smith, 1988) and storage.

More difficult to quantify is the impact of the environment on the seed before physiological maturity, and between physiological maturity and harvest maturity. Most studies undertaken to assess the influence of the environment on the bean plant have focused on the effect on yield and yield components and not on the quality of seed produced. The main objective of this study was therefore to determine if extreme environmental conditions would cause the mother plant to produce seed of a lower quality, and if so, why?

Because quality can not be seen as separate from yield and yield components, these parameters were measured as well. This created an opportunity to evaluate the overall suitability of Canterbury for the growing of bean seed, and to obtain some idea about beneficial alternative crop husbandry methods.

Materials and Methods

The trial was sown on a Templeton silt loam (New Zealand Soil Bureau, 1968) near Lincoln University in Canterbury, New Zealand. The preceding crop had been kale (*Brassica oleracea* L.) and the soil fertility was high in available nitrogen (353 kg/ha) and medium in phosphorus (25 µg/ml) and potasium (0.65 meq/100g). It was planted as a 2x2x2 factorial randomized complete block design with four replicates. French dwarf bean (*Phaseolus vulgaris* L.), cv Prosperity was used . This cultivar has a long growing season (134 days in Idaho), is medium tall, produces seeds with a thousand seed weight (TSW) of 350 g and has a white testa. The crop was sown with a cone seeder in 15 cm rows on 29 November 1996 after soil incorporation of 800 g a.i./ha of trifluralin. Plots were 10 m long and 4.2 m wide with equally wide guard plots between irrigated and non-irrigated plots.

Two levels of crop husbandry were initially planned to produce crops under high competition levels (HC) and low competition levels (LC). HC consisted of an actual plant density of 82 plants/m^2, no irrigation, no fertiliser and was grown under 48% shade cloth which was erected at mid flowering at 70 days after sowing (DAS). The second level of crop husbandry, LC, had an actual plant density of 15 plants/m^2, trickle irrigation to keep the crop above 50% of field capacity, 320 kg /ha of Cropmaster 15 fertiliser (15-10-10-8) pre-plant, 100 kg of urea (46% N) at flowering, and was grown in full sunlight. Due to climate and high background soil fertility, the fertility and irrigation had no effect. Only plant density was of importance.

Factor two was leaving all pods on the plants or removing randomly 25% of the pods per plant. Factor three was leaving all leaves on the plant or removing all of them. These two factors were applied at mid-pod-filling (91-98 DAS). Further weed control consisted of two application of bentazone, one of 380g a.i./ha on 24 December and one of 580 g a.i./ha on 2 January 1997. After that in low density plots, hand weeding was done to control mainly field pansy (*Viola arvensis* L.) and wireweed (*Polygonum aviculare* L.). The LC plots were irrigated to field capacity on 16 and 24 February and 21 March 1997. Soil moisture was measured by time domain reflectometry (Model 6050X1, Soil Moisture Equipment Corp., Ca., USA) with fixed rods at 150 mm and 300 mm depth with four measuring points per husbandry level randomly allocated over the whole experimental field. Sequential harvesting was done from randomized sub-plots from 87 DAS. From HC plots, 0.438 m^2 and from the LC plots, 2.00 m^2 was harvested weekly. All plants were hand pulled and measured for total biomass, total number and weight of pods, number and weight of big pods (over 100 mm), number and weight of small pods, and number of aborted pods. Approximately 90% of the big pods were dried back slowly at a constant temperature of 25°C to 14% seed moisture.

Seeds were cleaned with a Westtrup air screen machine with an 8 mm round hole top screen and a 3.75 mm slotted hole bottom screen. They were then stored at 5°C (±0.2°C) at a constant relative humidity of 45% (± 2%), until tested. The balance of the big pods were opened, the seeds were removed, counted and weighed for fresh weight (FW). Together with all other plant material, the pods and seeds were dried at 80°C until constant weight to establish the dry weight (DW) of all yield components. The seed moisture content and thousand seed weight (TSW; seed at 14% moisture) were calculated. At 147 DAS a heavy frost killed all surviving plants. Final harvest was at 151 DAS for HC and 157 DAS for LC. After all the harvested seed was carefully dried, some lots were tested for germination (short roll at 25°C in light, with only one count after nine days). As a test for seed vigour the seedling dry weight of the normal seedlings was established after drying at 80°C for a minimum of 24 hours (International Seed Testing Association, 1995). At this stage only seed lots harvested on 1 April (123 DAS) and at final harvest (151 DAS for HC plots and 157 DAS for LC plots), were tested. All results were analyzed by ANOVA and mean separation was done by Standard Error of the Mean (SEM). Generalized logistic curves were fitted to DW and TSW data over time.

Results

The 270 mm of rainfall which fell during the growing season and a lower than average temperature reduced the need for irrigation which was applied only three times during the season (Fig. 1). For a period of 30 days, the soil moisture in HC was under 50% of field capacity but stayed above wilting point, while LC stayed over 50% of field capacity for the length of the growing season.

Accumulation of total dry weight (TDW) in the HC plots was greater at 11 $g/m^2/d$, than the peak growth of 7.5 $g/m^2/d$ from the LC plots (Fig. 2). Harvest maturity (HM) in HC plots was reached at 145 DAS which was approximately 30 days earlier than in the LC plots which did not reach harvest maturity because of a 2.1°C frost on 17 April.

When only the plots with all leaves and all pods were considered, the maximum seed yield increment of the HC crop (7.4 $g/m^2/d$) was more than twice that of the LC crop (3.1 $g/m^2/d$), (Fig. 3), producing final seed DW yields of 293 g/m^2 and 152 g/m^2 respectively. Average seed moisture fell from 79% for LC and 78 % for HC at 88 DAS to 45 and 27% respectively at 144 DAS. When the whole experiment is taken into account, the total seed DW (g/m^2) was considerably lower (Tables 1 and 2). Initially only the factors husbandry and pod removal caused significant differences in the number of pods per plant (Table 1). At 144 DAS however (Table 2) leaf removal also significantly reduced pod number per plant through an increase in pod abortion over time from 1.2% at 109 DAS to 15.6% at 144 DAS. The 80% higher abortion rate found in the HC plants compared with the LC plants in the early stages of development was reduced to an increment of only 26% by 144 DAS (Table 1 and 2).

The number of seeds per pod was initially strongly influenced by all treatments. By first harvest (109 DAS),

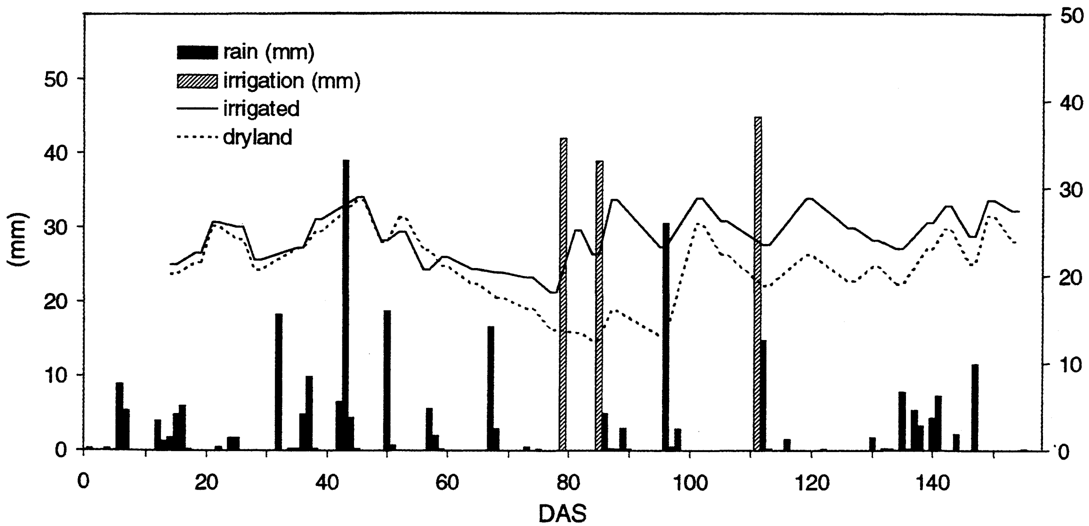

Figure 1. Soil moisture % v/v in irrigated and dry plots (solid and broken lines, respectively) during the growing season with daily rainfall and irrigation levels (vertical bars).

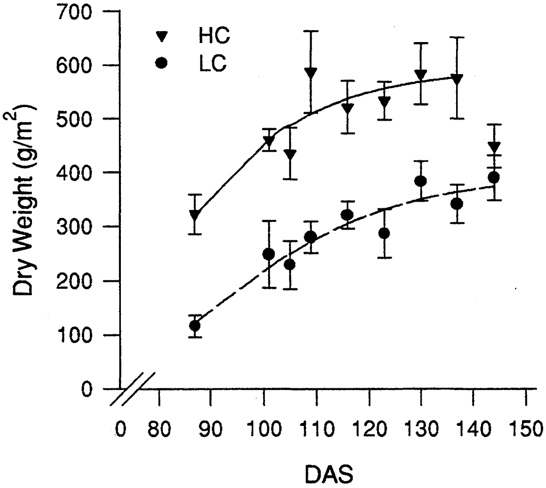

Figure 2. Accumulation of total dry weight of French dwarf beans over time. The error bars represent ± SEM.

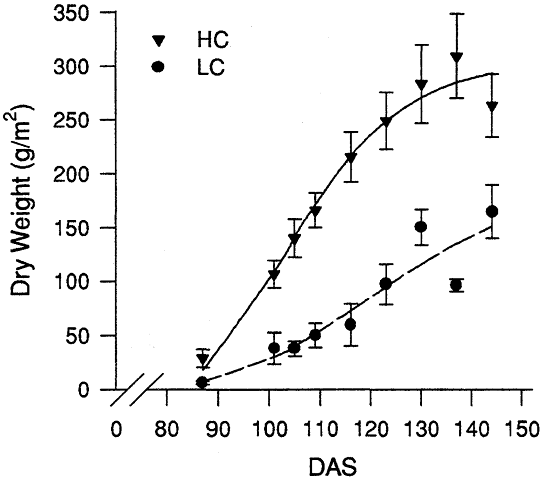

Figure 3. Accumulation of seed dry weight of French dwarf beans over time. The error bars represent ± SEM.

Table 1. The effects of crop husbandry, source and sink reduction on yield and yield components of *Phaseolus vulgaris* cv. Prosperity, at 109 DAS. (ns, non-significant; *, p≤0.05; **, p≤0.01).

	total DW (g/m^2)	plants/m^2	pods per plant	aborted (%)	seeds per pod	TSW (g)	Seed DW (g/m^2)
Husbandry (h)							
high competition	400.7	81.9	4.9	30.1	2.83	252	140.1
low competition	171.4	13.8	9.7	16.7	3.19	140	35.1
significance	**	**	**	**	**	**	**
Pods (p)							
75% of pods	237.8	44.1	6.0	22.7	2.86	203	66.1
all pods	334.3	51.7	8.5	24.1	3.16	190	109.1
significance	**	ns	**	ns	*	ns	**
Leaves (l)							
no leaves	198.6	50.6	7.1	24.0	2.62	189	73.1
all leaves	373.5	45.2	7.5	22.8	3.40	203	102.1
significance	**	ns	ns	ns	**	ns	*
SEM	17.11	3.52	0.42	1.28	0.088	9.6	7.73
CV %	23.9	29.4	23.0	21.8	11.7	19.6	35.3
significant interaction				h x l**	p x l**		h x p*

the HC plants, the plants with only 75% of the pods and the plants without leaves had 11, 9 and 23% less seeds per pod respectively, with an average of 3.01 seeds/pod. By 144 DAS there were no significant differences and the average number of seeds per pod was down to 2.86, probably due to seed abortion.

Table 2. The effects of crop husbandry, source and sink reduction on yield and yield components of *Phaseolus vulgaris* cv. Prosperity, at 144 DAS. (ns, non-significant; *, p≤0.05; **, p≤0.01).

	total DW (g/m^2)	plants/m^2	pods per plant	aborted (%)	seeds per pod	TSW (g)	Seed DW (g/m^2)
Husbandry (h)							
high competition	311.3	88.9	4.2	40.8	2.86	338	151.3
low competition	194.6	18.7	10.8	32.3	2.86	367	69.7
significance	**	**	**	*	ns	*	**
Pods (p)							
75% of pods	226.8	53.7	6.6	37.7	2.87	362	91.1
all pods	279.1	53.9	8.5	35.3	2.85	343	129.9
significance	**	ns	**	ns	ns	ns	**
Leaves (l)							
no leaves	189.9	58.5	6.5	44.3	2.61	318	79.9
all leaves	316.0	49.0	8.5	28.7	3.11	388	141.1
significance	**	ns	**	**	ns	**	**
SEM	11.7	1.59	0.35	2.7	0.187	8.9	5.39
CV %	18.5	11.8	18.7	29.8	26.2	10.1	19.5
significant interaction	-	-	h x l** p x l*	h x p**	-	-	p x l**

At 144 DAS the TSW of the seed from the HC plants was 8% less (p = 0.036) than that from the LC plants. When generalized logistic curves were fitted to the data (Fig. 4), it was found that the number of days needed to reach the point of inflection as well as the duration of crop growth, were longer for LC crops (p<0.001 and p=0.034 respectively). This resulted in a higher predicted final thousand seed weight (395 g against 367 g with p= 0.025). This shows that the differences in seed DW/m^2 found between the two husbandry levels (Fig. 3) was not only caused by the extra numbers of seeds per m^2, but also partly by the higher TSW.

Pod removal did not affect TSW but leaf removal lowered TSW by 18% (p <0.001) at 144 DAS (Table 2). A generalized logistic curve fitted to these data (Fig. 5), shows a considerable reduction in seed growth through leaf removal. Highly significant differences in the maximum TSW were predicted for the two levels of treatment (351 g for complete leaf removal and 411 g for plants with all the leaves with p<0.001). The duration of seed growth however, stayed the same.

Combined with the difference in plant population the above yield components gave significant differences in seed yield among all the treatments. The seed DW yield of the HC plots at first harvest (109 DAS) was 140 g/m^2 (Table 1), which was 300% higher than the seed DW yield of the LC plots (35 g/m^2). At 144 DAS however the difference was down to 116% (Table 2). Similarly, removing no pods gave a 65% higher yield (109 g/m^2) than removing 25% of pods (66 g/m^2) at 109 DAS while the difference was reduced to 43% (130 g/m^2 compared to 91 g/m^2) at 144 DAS. This trend in reduced differences over time was reversed with leaf removal. The 40% higher yield of the all leaf treatments increased to 76% (141 against 80 g/m^2). An interaction (p= 0.01) between the pod and leaf treatments showed no difference in seed DW/m^2 between plants with 75% of the pods and plants with all the pods when all leaves were removed. With no leaf removal however, removing pods gave a 39% decrease in yield. Very similar trends were found for the total DW produced and the number of seeds produced.

The germination percentage of all seed lots from both harvests averaged only 83%, probably due to the frost and to the fact that all seeds were used irrespective of seed infection or size. There were no differences between any of the treatments. However, there was a significant difference in seedling dry weights. The all leaf treatment had a 22% higher seedling dry weight (p = 0.008) compared with the no leaf treatments which averaged at 0.11 g per seedling (Fig. 6).

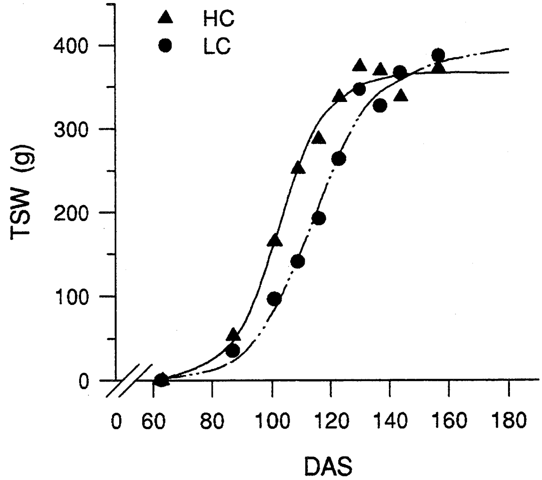

Figure 4. The influence of different crop densities on seed growth of French dwarf beans (lines = general logistic curve). Maximum TSW is 366 and 395g respectively, with P= 0.025. Point of inflection at 100 and 114 DAS respectively, with P<0.001.

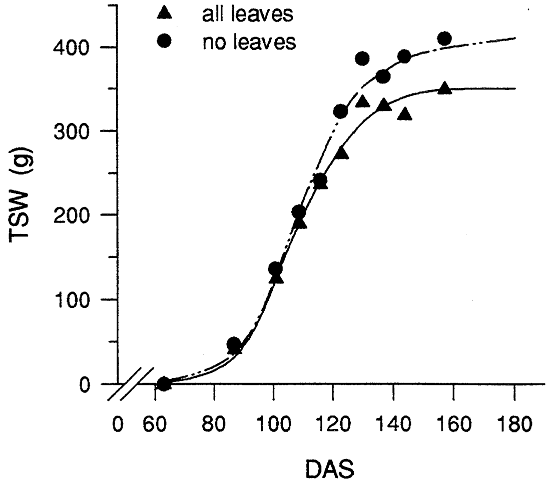

Figure 5. The influence of leaf removal on the rate of phenological development of a crop of French dwarf beans. (lines = general logistic curve). Maximum TSW is 351 and 411g respectively, with P< 0.001. Point of inflection at 105 and 110 DAS respectively, with P=0.031

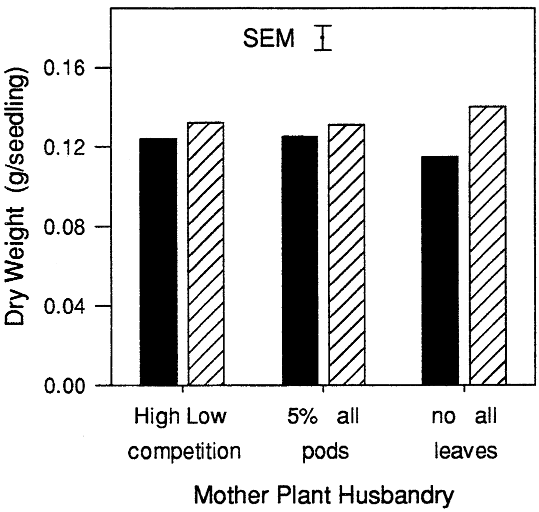

Figure 6. Dry weights of seedlings taken from standard germination tests of seed harvested at 151 DAS.

Discussion

Big differences in DW accumulation were found between the two husbandry levels with the HC plants outperforming the LC plants for total dry weight and seed yield. They also developed, and matured earlier (Fig. 4). This was in spite of the stress factors which had been applied to the HC plants. These factors however had less impact than was expected.

Non-irrigated crops experienced little water stress due to 270 mm of rainfall, which was well spread over the growing season (Fig. 1). As a result, the non-irrigated crops were only under water stress during the period of 8 February to the 24 February. In that period the LC crop was irrigated twice with 43 and 39 mm respectively.

Differences in fertiliser application did not have any effect due to the high soil fertility (available N: 353 kg/ha, P: 25 μg/ml, K: 0.65 me/100 g). Site selection was compromised due to inaccuracies concerning cropping history.

Shade did affect plant growth. Samples taken from HC plants from outside the shaded area, returned yields which had 56% more seeds and 61% higher seed DW, compared with yields obtained under the shade. This corresponds with data found by Verghis (1996) in chickpeas (*Cicer arietinum* L.). The extra accumulation of DW was translated into extra seed produced but not into bigger seed. Taweekul (1997) however found that shading did significantly reduce the seed size in peas (*Pisum sativum* L.).

In spite of the shade, the HC plots still produced 50% more seed DM /m^2 than the LC plots. The shade cloth reduced the solar radiation by 48% but was not erected until 10 days after flowering, giving the HC plants ample opportunity to store assimilates. At 80 plants/m^2 these plants closed their canopy one week before flowering, while the LC plants never achieved canopy closure.

The main contribution to the differences between HC and LC plots came from the difference in plant density. The same trend has been already reported by Love *et al.* (1988), Russo and Perkins-Veazie (1992) and others before them, although a lack of consistency in the reaction of *Phaseolus vulgaris* to plant density has been reported (McKenzie *et al.*, 1991). The higher plant density is thought to increase the temperature in the crop due to reduced wind flow through the crop. This higher temperature sped up the phenological development. Much of the difference in yield found between the HC and LC crops can therefore be attributed to the difference in maturity. The frost at the end of the growing season, which only affected the much slower developing LC crops, did reduce yield even more by killing the plants before maximum TSW could be reached.

Similar to reports by Schaafsma and Ablett (1994), removal of all the leaves eventually caused a 24% reduction in pods per plant (Table 2). When only big pods were taken into consideration (data not shown) then the difference between the "all leaves" and "no leaves" treatments became more significant over time, indicating that the plants were trying to reduce the reproductive sink. This is confirmed by the increase in pod abortion over time. Not only was less assimilate available to fill existing pods, but some was being diverted to produce new leaves. Source reduction had more impact on the seeds per pod of LC plants than of the HC plants. Leaf reduction consistently had a greater influence on the LC plants for the number of seeds per pod for all but the first and the last harvest (data not shown). The expected big differences in pod abortion and seeds per pod between the husbandry levels were not found, probably due to the intra plant competition in the LC crop which compensated for the inter plant competition in the HC crop (Chanprasert *et al.*, 1989).

No differences in seeds per pod were found for any of the treatments at 144 DAS. The most important finding here was that the average number of seeds per pod was only 2.86, while the pods mostly had 6 ovules. It is not clear yet what caused this enormous loss of yield potential which is found in many grain legumes.

Few studies have been done on the influence of the source / sink ratio on the seed. In this study, severe reduction of the source significantly decreased the TSW as was found by Schaafsma and Ablett (1994) in beans and Hunter *et al.* (1991) and TeKrony *et al.* (1995) in maize. Hunter *et al.* (1991) did mention that maximum seed vigour was obtained earlier in time for the defoliated treatments. The implication of this could be that if seed vigour is measured at a certain stage after physiological maturity, the seed vigour of the defoliated treatments would be past their maximum and thus lower when compared to the non-defoliated treatments. TeKrony *et al.* (1995) however did not find lower vigour in the smaller seeds produced by the defoliated plants. Preliminary results in this study show that seed from defoliated plants indeed did have a significantly lower vigour.

The fact that high plant density affected TSW, as shown in Tables 1 and 2, must be taken into account when deciding about plant densities to achieve maximum yields.

Considering that the LC plants never reached harvest maturity (Fig. 2) it is likely that the TSW and possibly the seed vigour from the LC plots still had the potential to increase which could make the differences between seeds from the HC and LC plants even bigger than the measured values.

Conclusions

1. In Canterbury, it is possible to reach yields of 2200 kg/ha of acceptable quality.
2. Seed quality as shown by TSW was influenced by husbandry level and leaf removal, while seedling dry weight was only affected by leaf removal.
3. Under extreme conditions, plants reduce the size of the sink by aborting pods and seeds and also by limiting seed size which could compromise seed quality.
4. Besides the use of early maturing cultivars and moving the sowing dates forward, it is possible to bring forward the harvest of French dwarf beans by three weeks or more, through increasing plant density.

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