Competition studies in four grain legumes

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Abstract

In 1999/2000, the relationship of individual plants was studied in four grain legumes: chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), narrow-leafed lupin (*Lupinus angustifolius*) and field pea (*Pisum sativum*). The influence of neighbouring plants was assessed in populations of 10, 100 and 400 plants/m^2, and sowing depths of 2, 5 and 10 cm. A central plant, surrounded by four other measured plants, was treated with nitrogen (N) to create additional environmental diversity. There was a strong linear relationship ($R^2 > 0.90$) between seed weight/plant (SWT) and plant weight (PWT). Both mean SWT and PWT fell as plant population increased from 10 to 400 plants/m^2. The effect on individual plant harvest index (PHI) was also examined. The relationship between PHI and PWT tended to be asymptotic. In all four species, N treated plants performed better than the surrounding plants. In all cases, plants to the north had the least reduction in yield, plants to the east and west had intermediate values, and plants to the south had the lowest yields, particularly at the higher plant populations.

Media summary

Nitrogen application consistently increased seed weight/plant and plant weight but adversely affected neighbouring plants, particularly those located to the south of the treated plants. These results show factors that induce plant-to-plant variability can reduce yields in grain legume crops.

Key words

Asymptotic relationship, competition, individual plant studies, minimum plant weight, principal axis model, sowing depth.

Introduction

Under favourable conditions grain legumes can produce high seed yields. However, average yields are generally low due to poor yield stability within and between sites and seasons (Heath?& Hebblethwaite, 1985). In field pea (*Pisum sativum*), seed yield differences among genotypes have been associated with variability in plant harvest index (PHI) of individual plants in a crop (Ambrose & Hedley, 1984).

In this study, we extended the principal axis model (PAM) used by Moot (1997) to describe inter-plant competition in a field pea crop, to four grain legumes with different growth habits – chickpea, lentil, narrow-leafed lupin and field pea. Moot (1997) proposed the PAM, which consisted of a principal axis and an ellipse, to describe the relationship between seed weight/plant (SWT) and total dry weight (PWT), and the variability in the relationship, as the basis of differences in crop yields. Our underlying hypothesis was that crop management practices and selection for morphological traits that minimise plant-to-plant variability and/or the number of small plants in a crop should lead to increased crop yield. To create variability within crops, an experiment was designed to generate interplant competition through different plant populations, sowing depths and N application. From this, the effects on neighbouring plants and the population as a whole were investigated.

Materials and methods

The experiment was sown in at the Lincoln University Research Farm, Canterbury (43^o 38′ S) in 1999/2000. It was a split-split-split plot design with three replicates. Four grain legumes (chickpea, lentil, narrow-leafed lupin and field pea) were main plots, three plant populations (10, 100 and 400 plants/m^2) were sub-plots and three sowing depths (2, 5 and 10 cm) were sub-sub-plots. Plots were hand sown, at equidistant spacing in each population. Seed was sown 'on the square' at 31.5 ? 31.5 cm, 10 ? 10 cm and 5 ? 5 cm to give the desired plant populations.

Thirty-five days after sowing (DAS) a further split in the design was established. Nitrogen (N, as urea, 46 % N) was added to five tagged plants (N_x) in each sub-sub-plot. A rate equivalent to 100 kg N ha^{-1} was applied to ensure a response and consequently enhance interplant competition. Each plant's immediate neighbour to the north (N^{th}_x), south (S^{th}_x), east (E_x) and west (W_x) was tagged to investigate the influence of the central N treated plant on its four surrounding neighbour plants.

Measurements

At crop maturity, the 25 individual plants per sub-sub-plot were cut at ground level and oven dried at 70^o C. For each plant the PWT and SWT were recorded. Plant harvest index, i.e. the seed yield of each plant divided by total dry matter (TDM) of each plant, was calculated. There were a total of 2,700 plants.

Statistical analyses

All variates were analysed using the SYSTAT 9 for Windows statistical package. Initially the four-way interaction term was added to the random effects error term of the full split-split-split plot analysis. For all measured variables (SWT, PWT and PHI) the analysis showed that sowing depth, as a main effect and in the two and three way interactions, was not significant. However, many two-way interactions that involved species were significant.

Results

The regression between SWT and PWT (Figure 1 a-c) was positive, linear and strong (R^2?>?0.92) for all species by population combinations (Table 1). All models produced a negative SWT-axis intercept and as a consequence a minimum plant weight (MPW) was calculated for each model (Table 1). The MPW changed with population, being lowest at the highest population for each species and ranging from 0.40 g/plant for lentil at 400 plants/m^2 to 16.38 g/plant for narrow-leafed lupin at 10 plants/m^2.

Generally the relationship between PHI and PWT was asymptotic. The lowest PHI values were from the smallest plants in each population. The asymptotic trend was strongest at 400 plants/m^2 for each species (Figure 1 d-f) and there was a clear indication that these small, low PHI plants were disproportionately located to the south of the N treated plant in each crop. Conversely, the largest plants with a high PHI had generally been treated with N (Figure 1 d-f).

Table 1. Parameters from the principal axis model (PAM) analyses of individual plant seed weight (SWT) against plant weight (PWT) from four grain legumes sown at three plant populations in 1999/2000.

Legume species	Population (plants/m^2)	Regression and derived parameters			
		Intercept (g)	Gradient	R^2	MPW* (g)
Chickpea	10	-6.877 (0.559)	0.515 (0.010)	0.94	11.18
	100	-1.882 (0.063)	0.585 (0.008)	0.97	3.22

	400	-0.252 (0.034)	0.503 (0.009)	0.93	0.50
Lentil	10	-2.543 (0.253)	0.528 (0.010)	0.92	4.82
	100	-0.430 (0.054)	0.610 (0.010)	0.94	0.71
	400	-0.276 (0.025)	0.698 (0.014)	0.93	0.40
Lupin	10	-8.368 (0.837)	0.511 (0.009)	0.94	16.38
	100	-1.318 (0.100)	0.600 (0.010)	0.95	2.20
	400	-0.500 (0.039)	0.653 (0.013)	0.94	0.77
Pea	10	-3.316 (0.387)	0.550 (0.011)	0.93	6.03
	100	-1.210 (0.073)	0.678 (0.010)	0.96	1.78
	400	-0.253 (0.040)	0.611 (0.012)	0.95	0.41

*Minimum plant weight (MPW = -a/b); all intercepts and gradients were highly significant (P?< 0.01); values in parentheses are the S.E.

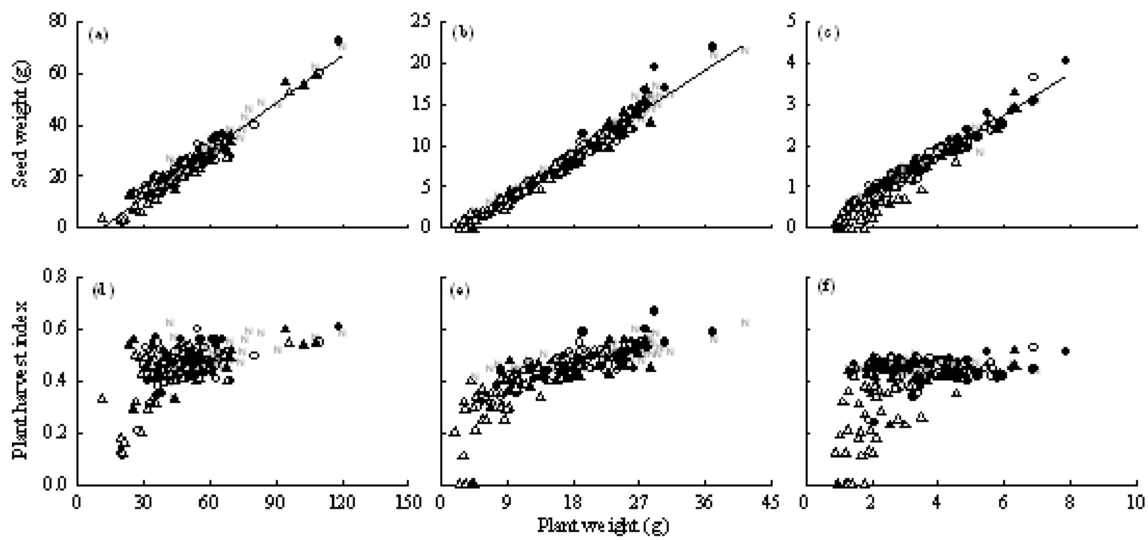

Figure 1. The relationship between plant weight and seed weight (a-c), and plant weight and plant harvest index (d–f) of chickpea sown at three plant populations in Canterbury, 1999/2000. (a, d) 10

plants/m^2, (b, e) 100 plants/m^2, (c, f) 400 plants/m^2. (●)?Northern plant, (○) Eastern plant, (▲) Western plant, (∆) Southern plant, (N) Central plant (+ N).

Discussion

Increasing plant population and applying N produced interplant variability in the four grain legumes grown but sowing depth was of little importance. Increased plant population was inversely related to mean PWT and SWT in each species as found in pea genotypes by Moot (1997). The disproportionately low conversion of assimilates to SWT plants located to the south of N treated plants was probably due to shade. This reduced their PHI, and consequently the small plant populations had both a reduced mean PHI and crop harvest index (CHI). The more intense the shade (e.g. in southern plants), the greater the reduction in PWT and SWT of the legume species. This observation is consistent with work by Liyanage & McWilliam (1981) on mungbean (*Vigna radiata*). It is also consistent with the notions of increased random leaf overlapping and penumbral shading among neighbouring plants. This shading increases with green area index (GAI) at higher populations. Consequently, with continued leaf expansion, the plant-to-plant variability in DM accumulation and seed yield/plant increased with population density (Ayaz, 2001).

The PAM analyses indicated that, for each species and at each population, there was a strong linear relationship between SWT and PWT (Figure 1 a-c). The stability of this relationship, despite the 40-fold change in plant population and the contrasting growth habits of these four species, support its use as the basis for the PAM. A simple linear relationship between SWT and PWT has been reported in maize (*Zea mays*) (Gardner & Gardner, 1983), sorghum (*Sorghum bicolor*) (Prihar & Stewart, 1991) and field pea (Moot, 1997). The SWT-axis intercept was negative for all treatment combinations of the four legumes and three plant populations. Consequently it was possible to estimate a minimum plant weight (MPW) from the PAM (Table 1). The highest calculated MPW for each species was in plants sown at 10 plants/m^2. Moot *et al*. (1997) reported a similar conclusion and showed this resulted from an increased number of barren branches at low populations. Further, legumes that had larger seeds also had higher MPWs.

The results indicate that at populations of 10 plants/m^2 the range of PWT values were beyond the initial linear phase of the asymptotic relationship and consequently variability in PHI values was low. However, the relationship is explained in the highly competitive plants, sown at high plant populations (100 to 400 plants/m^2) where competition was intensified by the N treated plant (Figure 1 e-f). As plant population increased, interplant competition increased and there was greater plant-to-plant variability in PHI values. Increased populations also resulted in a trend towards an asymptotic relationship. This was evident in all four legumes at 100 and 400 plants/m^2 (the trend of all species was similar, therefore only chickpea results are given). At the high populations, the majority of the plants in each species had high PHI values but low PHI values were associated with smaller plants (Hedley & Ambrose, 1985; Moot *et al.,* 1997). These smaller plants were the result of the intense competition from the central N treated plant on the plant located to its south (Figure 1). A further increase from the relationship between PHI and PWT is that at higher plant populations than tested, PHI variability would increase due to lower PWT values and a more distinct asymptotic relationship would be expected at higher populations than those tested in this trial. The results of this study suggest a similar approach could be adopted for chickpea, lentil and narrow-leafed lupin.

The asymptotic relationship between PHI and PWT was the key for interpreting the differences in PHI values among crops. The slope of the principal axis was the asymptote of this association when the SWT-axis intercept was negative. There was a clear indication that these smallest, low PHI plants were disproportionately the southerly plants while the larger plants, with a high PHI, were N treated (Figure 1). These findings confirm the assumption of Moot (1993) that small plants have low PHIs. Overall, the observations confirm our hypothesis that crop management practices or the selection of morphological traits that minimise variability and the number of small plants in a crop, should lead to increased crop yield and stability. Thus, these results agree with concept of a weak competitor as the basis for a crop ideotype (Donald 1968) and justify the use of PAM to select appropriate phenotypes (Moot, 1993).

Conclusions

- As plant populations increased, greater variability was found in PWT, SWT and PHI values.
- Nitrogen application consistently increased PWT and SWT but adversely affected neighbouring plants, particularly those located to the south of the treated plant.
- The PAM was a useful tool for describing the relationship between SWT and PWT values for the four grain legumes studied, even when there were significant changes in the distribution of these values.

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