The effect of plant population on dry matter accumulation, yield and yield components of four grain legumes

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Abstract

The effect of population density on dry matter (DM) accumulation over time, and grain yield and its components of four grain legumes was examined in a field experiment in the 1998-99 season. The four legumes were sown at four different populations viz. lentils cv. Rajah (15, 150, 300 and 600 plants/m^2), desi chickpeas (5, 50, 100 and 200 plants/m^2), peas cv. Beacon and lupins cv. Fest (10, 100, 200 and 400 plants/m^2). The experiment was a split plot design with three replications. The trial was sown on 30 October 1998 and the species were harvested on different dates depending on their physiological maturity. Lupins produced the most DM (878 g/m^2) and DM was less affected by population than the other species. Lentil DM was highly dependent upon population and ranged from 186 to 513 g/m^2 at the lowest and highest population. Chickpeas and pea DM were also affected by population. Chickpeas produced from 430 - 869 g DM/m^2 as population increased and peas from 292 - 670 g DM/m^2. Lupins grain yield was least affected by population, being 323 and 434 g/m^2 at the lowest and highest populations. Lentil seed yield had a higher dependency on population than the other species and it was 91 and 304 g/m^2 at the low and the highest populations. In chickpea HI was affected more by population than in the other three species. It was 0.31 and 0.63 at the lowest and the highest population, respectively. The species by population interaction showed that in all four species, the mean seed weight, pods per plant and seeds per pod were inversely related to plant density.

Additional key words: Cicer arietinum, *grain yield, harvest index,* Lens culinaris, Lupinus angustifolius, Pisum sativum, *total dry matter.*

Introduction

Most grain legumes are reasonably plastic in their response to changing plant density, the main effect of variation in plant population being on pods per plant, which tends to be inversely related to plant population (Hodgson and Blackman, 1956; Newton, 1979; McKenzie *et al.*, 1986). Other yield components such as seeds per pod and mean seed weight are usually less affected (Ishag, 1973; McKenzie *et al.*, 1986), or are resistant to change in plant population (Hodgson and Blackman, 1956; Newton and Hill, 1977; Thompson and Taylor, 1977).

The harvest index (HI) of a crop depends on the ratio between total dry matter and seed yield and may vary due to variability of yield components (Wilson, 1987). Hay (1995) reported that HI values of modern cultivars of grain legumes fall in the range of 0.40-0.60. However, Husain *et al.* (1988) and McKenzie and Hill (1990) reported HI in grain legumes which varied from 0-0.60. Crop HI among pea (*Pisum sativum* L.) genotypes in Canterbury ranged from 0.53-0.62 (Moot, 1993). Individual plant HI in lentils (*Lens culinaris* Medik) ranged from 0.01-0.60 (Kirthisinghe, 1986), and from 0.25-0.59 in three lentil cultivars (Pandey, 1980).

One of the problems faced by grain legume growers around the world is variability in HI. Previous work in Canterbury (Hernandez, 1986; McKenzie and Hill, 1991; Moot, 1993) has shown that environmental and soil conditions can have a great effect on both yield and yield components. Growing season (Saxena *et al;* 1990; Poma and Fiore, 1990), plant population (El-sharraq and Naurai, 1983; Singh *et al.*, 1988), and genotype x location (Srivastava *et al.*, 1990) may all be reasons for yield component variability.

This paper considers the relationship between legume populations and yield. The objective was to relate differences in seed yield among four grain legume species to differences in the seed yield components, and to determine if seed yield was related to HI variability in these grain legumes.

Materials and Methods

The experiment was conducted at the Horticultural Research Area, Lincoln University Canterbury during 1998-99. The four legume species [lentils, chickpeas (*Cicer arietinum* L.), peas and lupins (*Lupinus angustifolius* L.)] were main plots and each was sown at four populations (subplot). The populations used were 0.1x optimum, 1x optimum, 2x optimum and 4x optimum. Optimum plant populations were 50/m^2 for chickpeas, 150/m^2 for lentils and 100/m^2 for peas and lupins. All species were sown on 30 October 1998 in rows 15 cm apart and 4 cm deep with a plot-drill. Seed was treated with Apron 70SD. Before sowing the field was cultivated by ploughing, harrowing and rolling to produce the seed bed. A pre-sowing spray of Treflan, pre-emergence spray of Bladex (cynazine) and post-emergence spray of Metribuzine were applied, with further weed control achieved by hand weeding. All plots were irrigated as and when required and no fertilizer was applied. The experiment was therefore a split plot design with three replicates. The four species were harvested when they were physiologically mature at 91, 112, 126 and 133 days after sowing for peas, lentils, chickpeas and lupins, respectively. Maturity was defined as the point at which more than 90% of the plants within a species had completely lost their green colour.

Dry matter accumulation was measured by taking 0.2 m^2 samples randomly cut from each sub-plot at weekly intervals from 28 days after sowing. Samples were oven dried to constant weight and weighed. Yields and HI were calculated from a 2 m^2 sample (0.5 m^2 at four places from each sub-plot) harvested from the central rows of each sub-plot at harvest maturity. Plants were cut to ground level, bagged, air dried and threshed in a Kurtpelz stationary thresher. Five randomly selected plants from each sub-plot were used for the yield component measurements (pods per plant, seeds per pod, mean seed weight). Data recorded were analysed statistically using SYSTAT. Mean separation was done using Fisher's protected LSD.

Results

Yield

Total dry matter (TDM) depended upon both species and plant population (Table 1). Among the four species, highest mean TDM production over all populations was 878 g/m^2 in lupins followed by chickpeas with 701 g/m^2. Increasing plant population increased TDM production in lentils and lupins but the highest population of chickpeas and peas had reduced TDM production (Table 2). For lentils and lupins the lowest TDM (186 g/m^2 in lentils and 771 g/m^2 in lupins) was recorded at the low plant density (15 and 10 plants/m^2, respectively) and the highest TDM (513 and 971 g/m^2) was produced at the highest plant population (600 and 400 plants/m^2) (Table 2). In chickpeas and peas the lowest TDM yields (430 and 292 g/m^2, respectively) were also recorded at the low populations (5 and 10 plants/m^2), but the greatest TDM (869 and 670 g/m^2) was produced at 100 and 200 plants/m^2 respectively.

Seed yield was also affected significantly ($p<0.001$) by both species and population, and their interaction. Chickpeas and lupins yielded more than lentils and peas (Table 1). The interaction of species by population showed that only lentils and lupins had increased seed yield (from 91-304 and 323-434 g/m^2 respectively) as population increased from 15-600 and 10-400 plants/m^2, respectively (Table 2). Chickpeas and peas produced the highest seed yield (541 and 365 g/m^2) when sown at 100 and 200 plants/m^2, respectively. At the highest plant density seed yield of both species declined.

Table 1. Seed yield, total dry matter (DM) and harvest index (HI) of four legume species at four different plant populations at final harvest.

	Seed yield (g/m^2)	Total DM (g/m^2)	HI
Legume species			
Chickpeas	384	701	0.52
Lentils	244	418	0.57
Lupins	386	878	0.44
Peas	286	532	0.53
Significance	p<0.001	p<0.001	p<0.001
Population			
Low	173	420	0.43
Medium	340	664	0.52
High	403	738	0.55
Very high	384	708	0.55
S.E.	9.7	8.3	0.01
Significance	p<0.001	p<0.001	p<0.001
CV %	5.1	4.5	6.0
Interaction significance	p<0.001	p<0.001	p<0.001

Harvest index was also affected significantly ($p<0.001$) by both species and population. Averaged over all populations the highest HI (0.57) was recorded in lentils and the lowest (0.44) was in lupins (Table 1). Harvest index for the four species increased between the low and medium populations (Table 2), but only for chickpeas was there any further increase as population increased. The greatest HI (0.62 and 0.63) was recorded in chickpeas sown at the high (100 plants/m^2) and very high populations (200 plants/m^2), respectively (Table 2).

Yield components

Average seed weight (206 mg) and pods/plant (101) over all the populations were greater in chickpeas than the other three species (Table 3). In all species there was a tendency for the mean seed weight, pods/plant and seeds/pod to decrease as density increased (Table 4). The interaction of population by species showed that chickpeas produced the highest (216 mg) and lowest (191 mg) seed weights when sown at the lowest and highest densities (Table 4). Lentils produced their maximum seed weight of 55 mg in the low population, and this changed little with increasing population.

In a similar way the number of seeds per pod and pods per plant were inversely related to plant population. The number of pods per plant decreased with increasing population (Table 4). Chickpeas consistently had more pods over the whole range of populations than did the lentils, lupins and peas.

The number of seeds per pod decreased as plant population increased (Table 4), though differences were not always significant. Maximum seed number per pod (5.8) was recorded in peas at the lowest population (10 plants/m^2).

Table 2. The interaction between legume species and plant population for total dry matter, seed yield and harvest index at final harvest.

Legume	Population: Low	Medium	High	V. high
Total dry matter (g/m^2)				
Chickpeas	430	757	869	748
Lentils	186	476	497	513
Lupins	771	857	913	971
Peas	292	565	670	600
S.E.		16.6		
Significance		$p<0.001$		
Seed yield (g/m^2)				
Chickpeas	133	391	541	369
Lentils	91	284	297	304
Lupins	323	377	410	434
Peas	143	308	365	329
S.E.		9.66		
Significance		$p<0.001$		
Harvest index				
Chickpeas	0.31	0.51	0.62	0.63
Lentils	0.49	0.60	0.60	0.59
Lupins	0.42	0.44	0.45	045
Peas	0.49	0.54	0.55	0.55
S.E.		0.02		
Significance		$p<0.001$		

Dry matter accumulation over time

Averaged over all populations lupins had accumulated 622 total DM g/m^2 by physiological maturity at 133 days after sowing (DAS)(Fig. 1). This was followed by chickpeas with 480 g/m^2 at 121 DAS, lentils with 356 g/m^2 at 112 DAS, and peas 469 g/m^2 at 91 DAS.

Table 3. Seed weight, pods/plant and seeds/pod at final harvest of four legume species at four different plant populations.

	Mean seed weight (mg)	Number of pods/plant	Number of seeds/pod
Legume species			
Chickpeas	206	101	1.4
Lentils	52	42	1.3
Lupins	172	19	4.3
Peas	159	9	5.0
Significance	$p<0.001$	$p<0.001$	$p<0.05$
Population			
Low	153	98	3.3
Medium	150	35	3.0
High	148	24	2.9
Very high	138	14	2.8
S.E.	14.8	4.5	0.1
Significance	$p<0.05$	$p<0.01$	$p<0.05$
CV %	1.43	5.07	10.60

Table 4. The interaction between legume species and plant population for yield components.

Legume	Population Low	Medium	High	V. high
Mean seed weight (mg)				
Chickpeas	216	215	201	191
Lentils	55	53	51	50
Lupins	176	173	170	166
Peas	175	166	155	140
S.E.		8.9		
Significance		$p<0.05$		
Seed per pod				
Chickpeas	1.5	1.4	1.4	1.2
Lentils	1.4	1.3	1.2	1.1
Lupins	4.5	4.3	4.1	4.0
Peas	5.8	5.1	4.9	4.6
S.E.		0.2		
Significance		$p<0.05$		
Pods per plant				
Chickpeas	221	87	63	34
Lentils	94	35	22	16
Lupins	54	10	6	4
Peas	27	6	3	3
S.E.		9.2		
Significance		$p<0.001$		

Discussion

DM Yield

There was marked variability in yields and harvest indices among species and plant populations. The highest total DM was recorded in lupins followed by chickpeas. El-sharraq and Naurai (1983) reported similar trends. The differences in total dry matter production between species can be explained on the basis of intercepted radiation and increasing canopy closure (data not shown), plus the fact that erect leaves use light more efficiently than lax leaves because smaller leaf angles reduce light saturation (Wilson, 1960). High plant populations close their canopies quickly and hence intercept more sunlight more rapidly than do low populations (McKenzie and Hill, 1991). This results in early rapid growth rates, which can be sustained if the crops have adequate soil moisture and fertility. Only in the lupins, which had a very long growth duration, did the low population manage to yield as much as the higher populations.

Species differences in total dry matter were more dependent on growth duration, with lupins and chickpeas having a much longer duration than peas and lentils. Again, this would result in greater amounts of intercepted radiation. It was also possible that there was a difference in the utilization coefficient (the ability of the crop to convert intercepted radiation into dry matter) between these species. This has been suggested by other workers at Lincoln where Zain *et al.* (1983) and Husain *et al.* (1988) reported utilization coefficients of 1.2 and 2.0-2.05 g DM/MJ PAR for field beans and peas, respectively.

Seed yield and its components

The effects of plant population on seed yield and its components were consistent with those reported by other workers (Hodgson and Blackman, 1956; Newton 1979; McKenzie *et al.* 1986), i.e., pods per plant and seeds per pod were less affected by population. The highest seed yield was produced in the high population, while the lowest was in the low population. Attiya (1985) reported that faba bean seed yield increased as population increased. Chickpeas produced more pods/plant and heavier seed than the other species. This might be due to fewer plants/m^2 (5-200) compared to the other species (which ranged from 10-600 plants/m^2). The results indicate that as intra-row spacing increased, branching increased, and vice versa. Maximum seeds per pod were recorded in all species sown at low populations and these declined with increase in planting densities. The highest number of seeds/pod were noted in peas and lupins. The reduction in the number of pods/plant, seeds/pod and seed weight at higher densities might be due to increased interplant competition. The results obtained agree with McKenzie *et al.* (1986) who also reported the same trend in pods/plant and seeds/pod with a population study on lentils. The results for pods/plant also agree with those of Hodgson & Blackman (1956), Newton (1979), and McKenzie and Hill (1995) who reported that the number of pods/plant decreased as plant population increased. Plants at higher populations might have lower crop photosynthesis as fewer young leaves are formed during the reproductive stage (Hernandez and Hill, 1985). Mean seed weight also decreased with the increasing populations. This agrees with Moot (1993) who reported a decline in the mean seed weight of pea genotypes with increased plant population. No yield component was related to variability in HI. Harvest index was variable over species and over populations (Table 4). There was

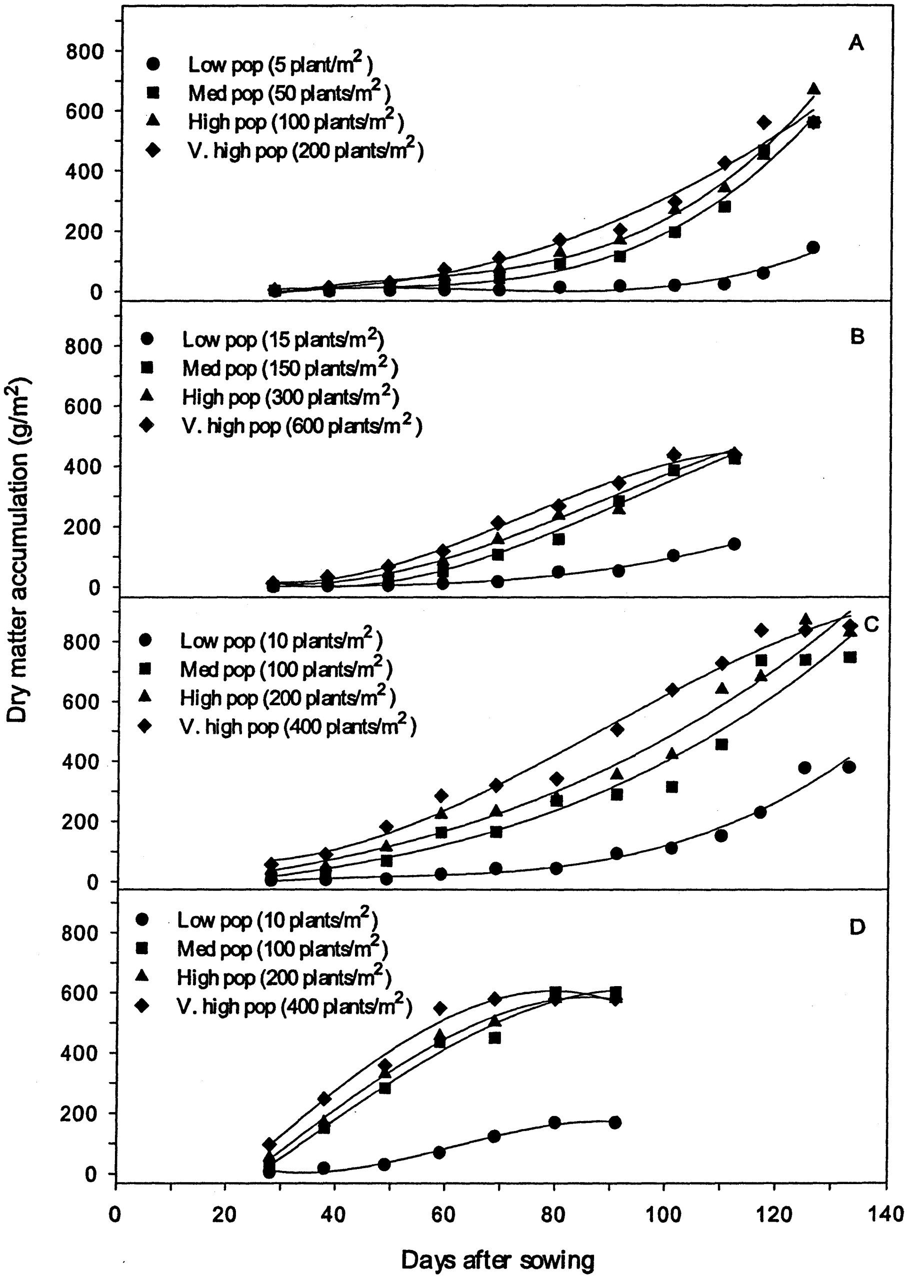

Figure1. Dry matter accumulation until physiological maturity for four legume species; (A) chickpeas, (B) lentils, (C) lupins and (D) peas, each at four population densities.

no relationship between plant populations and HI or between TDM and HI. This was probably due to the fact that the varying species had different potential levels of productivity. Hence a high or low TDM does not necessarily result in a high or low HI. The lack of a population response may have been due to the differences in the morphological responses of the four legume species, particularly branch number, which produces pod sites.

Dry matter accumulation

Dry matter accumulation over time increased with higher densities and varied in the four species but was higher in lupins compared with similar plant densities of other species. Initially DM was accumulated slowly followed by a rapid growth in medium to higher populations of chickpeas, lentils and lupins. Early in the growing season, when leaf area index was small, the fraction of radiation absorbed by the crops would have been small. This is usually the reason for slow crop growth (Attiya, 1985). Total DM/unit area increased with population at each sampling in all species and finally stopped with crop maturity. High total DM at the higher populations was the result of greater plant number per unit area, but DM/plant was decreased. Lupins accumulated the highest DM while lentils produced the least. Higher populations accumulated more DM as canopy closure was earlier at the high plant densities, resulting in greater interception from incoming solar radiation (McKenzie and Hill, 1991). Dry matter accumulation in the higher populations usually peaked earlier as at later stages competition occurred among individual plants and the higher plant number per unit area could not compensate for the reduction in DM/plant in higher populations (Herbert, 1977).

Conclusions

- Maximum seed yield was attained for all four species at high or very high populations.
- High or very high populations produced maximum total dry matter due to rapid early growth rates.
- Harvest index was not related to yield or yield components.

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