Nitrogen distribution in four grain legumes

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(Revised MS received 8 July 2004)

SUMMARY

The partitioning of above ground nitrogen (N) in chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), lupin (*Lupinus angustifolius*) and pea (*Pisum sativum*) at crop maturity was investigated. The plants were grown at different plant populations and sowing depths in 1998/99 and 1999/2000 in Canterbury, New Zealand. In all four legumes the N concentration was highest in seed (29–36 mg/g N) followed by senescent leaves. The lowest N concentration was in stems. Lupin had the highest seed N yield at 16.82 and 19.29 g/m² followed by chickpea at 10.26 and 13.10 g/m², in 1998/99 and 1999/2000, respectively. Lentil had the lowest N concentrations and yield. The distribution of N to all legume plant parts increased as population increased up to twice the optimum and 400 plants/m² in 1998/99 and 1999/2000, respectively. Over all plant populations, the nitrogen harvest index (NHI) was stable in each of the four species across the two seasons. However, the NHI changed with changes in plant population and sowing depth. The N accumulation efficiency (E_N) was highest in lentil at 0.024 and 0.027 g N/g DM and lowest in chickpea at 0.018 and 0.021 g N/g DM in 1998/99 and 1999/2000, respectively. The NHI and the crop harvest index (CHI) were correlated and both were strongly associated with seed yield. Thus, NHI might be useful as a selection criterion to improve seed yield in grain legumes.

INTRODUCTION

The performance of various legume species in terms of their biomass production and nitrogen (N) yield varies considerably among legume species and years (Schulz *et al.* 1999). In the field, N accumulation in grain legumes results from symbiotic N fixation and from N uptake from both soil and fertilizer (Chapman & Muchow 1985). Nitrogen concentration varies among different plant parts (Spaeth & Sinclair 1983). In the seed, leaves and stems of soybean (*Glycine max*), N concentrations were 42.3, 9.4 and 4.7 mg/g respectively (Streeter 1978). At harvest maturity, N concentrations in stems of peanut (*Arachis hypogaea*), soybean and pigeon pea (*Cajanus cajan*) were between 10 and 20 mg/g, while in the seed the N concentrations were 50, 68 and 35 mg/g, respectively (de Vries *et al.* 1989).

Data on the N concentration of senescent legume leaves are scarce. However, in Australia, Bushby & Lawn (1992) reported that the N concentration in senescent leaves of three mungbean (*Vigna radiata*)

genotypes was 11.3, 9.4 and 14.3 mg/g. This represented 4.4, 12.9 and 9.6% of total plant N in the three genotypes, respectively. Muchow *et al.* (1993a) reported that the amount of seed N in soybean at maturity was greater than in mungbean and cowpea (*Vigna unguiculata*), and this was associated with a higher nitrogen harvest index (NHI). Muchow *et al.* (1993a) also reported that soybean, at maturity, had a higher N accumulation efficiency (E_N ; 0.035 g/g) than mungbean (0.025 g/g) and cowpea (0.023 g/g). Newton & Hill (1981) compared the NHIs of *Vicia faba* cultivars Daffa and Maris Bead, and concluded that Maris Bead consistently partitioned more N to seed than Daffa over plant populations and seasons. The NHI values of mungbean genotypes ranged from 0.65 to 0.90 (Bushby & Lawn 1992).

In the present work four grain legumes were grown at different plant populations and sowing depths to investigate their nitrogen distribution at final harvest. This was done to assess whether:

- (1) Species differences in NHI were consistent over plant populations, sowing depths and growing seasons.
- (2) The NHI of legumes was associated with their yield and the CHI.

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- (3) The NHI was sufficiently consistent to be a viable trait for use in plant selection.

MATERIALS AND METHODS

Site and soil characteristics

The experiments were sown at the Horticultural Research Area in 1998/99 and at the Henley Research Farm in 1999/2000. Both sites are at Lincoln University, Canterbury, New Zealand (latitude 43°39' S, longitude 172°28' E). The soil is a Wakanui silt loam soil (Hewitt 1992). A Chinese cabbage (*Brassica pekinensis*) crop had been grown in the previous season to the 1998/99 experiment, and the Henley site, used in 1999/2000, was previously in perennial ryegrass (*Lolium perenne*). A Ministry of Agriculture and Fisheries (MAF) soil quick test was done in each season to determine soil available nutrient levels (Table 1).

Experimental design

In 1998/99 the design was a split-plot randomized block. The four grain legume species chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), narrow-leaved lupin (*Lupinus angustifolius*) and field pea (*Pisum sativum*) were main plots. Subplots were four plant populations, one-tenth of the optimum population, the optimum population, twice the optimum population and four times the optimum population. Optimum plant populations (determined from recommended commercial sowing rates) were taken as 50 plants/m² for chickpea, 150 plants/m² for lentil, 100 plants/m² for narrow-leaved lupin and 100 plants/m² for field pea. There were three replicates. The trial was sown on 30 October 1998. Seed was sown at 4–5 cm depth using a tractor-driven cone seeder in rows 15 cm apart.

In 1999/2000 the design was a split-split plot design. The trial had the same four legumes as main plots. Subplots were three plant populations: 10, 100 and 400 plants/m². Three sowing depths (2, 5 and 10 cm) were sub-subplots. There were three replicates. The plots were hand sown, one replicate per 2 days between 19 and 24 October 1999 in equidistant arrangements. Sowing was on the square at 31.5 × 31.5 cm, 10 × 10 cm and 5 × 5 cm.

Full details of crop husbandry in the 2 years are contained in Ayaz (2001).

Sampling and measurements

At maturity when 95% of all plants were brown, five plants were taken from the central rows of each sub or sub-subplot as the final harvest. The plants were cut to ground level and separated into seed and straw (stem + petioles + pod walls). Senesced leaves were collected from the ground of the harvested area and

Table 1. Ministry of Agriculture and Fisheries soil quick test for 0–30 cm depth for the Horticultural Research Area (1998/99) and the Henley Research Farm (1999/2000) of Lincoln University, Canterbury. Ca, K, P, Mg, Na and S and NH₄⁺, NO₃⁻ are expressed as µg/g soil, and total N (TN) and C as mg/g

Season	pH	Ca	K	P	Mg	Na	S	C	NH ₄ ⁺	NO ₃ ⁻	TN
1998/1999	5.4	7	8	27	16	5	9	24	–	1	2
1999/2000	5.8	10	9	12	28	8	9	–	5	<1	3

Fig. 1. Climate data for 1998/99 (□, ●) and 1999/2000 (▨, ■) growing seasons and long-term means (▤, ▲) for Lincoln University, Canterbury, New Zealand. Long-term means for rainfall and temperature 1944–99 and for solar radiation 1975–99.

were bagged separately. All plant material was chopped and oven dried at 70 °C for 48 h in a forced draught oven. Samples were ground in a Cyclotech mill to pass through a 0.5 mm screen for N analysis. Senescent leaves, straw and seed samples were analysed for their N concentration by the Kjeldahl method.

The nitrogen harvest index (NHI) was calculated as the amount of N in seed as a proportion of total aboveground plant N. The N accumulation efficiency (E_N) was determined for each legume species as the ratio between net aboveground N and the net total

Table 2. *The effect of legume species and plant population on the N concentration of seed, straw (stem + petioles + pod walls), and senesced leaves at final harvest in Canterbury, 1998/1999*

Treatments	N at final harvest (mg/g DM)		
	Seed	Straw	Senesced leaf
Species (S)			
Chickpea	26.6	5.5	18.3
Lentil	30.4	8.5	17.5
Lupin	43.2	4.3	16.0
Pea	29.0	14.2	28.6
S.E.	1.27	0.97	1.44
Population (P)			
0.1 × optimum	30.5	8.3	19.7
1.0 × optimum	30.2	8.4	19.7
2.0 × optimum	35.3	8.0	21.0
4.0 × optimum	33.3	7.7	20.0
S.E.	1.42	0.57	0.91
CV %	15.2	24.2	15.7
Sign. interactions	ns	ns	ns

dry matter (TDM) at final harvest (Chapman & Muchow 1985; Muchow *et al.* 1993*b*).

Climate

From October 1998 to April 1999, the weather was dry and the rainfall was about 40% less than the long-term average (Fig. 1). The mean temperature and solar radiation were higher than the long-term average by 5% and 7%, respectively, from January to March 1999. In the second year the rainfall was about 90% of the long-term average (385 mm). The mean monthly maximum temperatures in December 1999 and January 2000 were lower at 18.9 and 19.5 °C, respectively, than the long-term average values of 21.3 and 22.6 °C, respectively (Fig. 1). Solar radiation from December 1999 to March 2000 was about 10% higher than the long-term mean.

Statistical analysis

All variates were analysed using analysis of variance. The statistical package used was Genstat. Standard errors (S.E.), coefficients of variation (CV as a %) and the correlation coefficient (*r*) were also calculated.

RESULTS

Nitrogen concentration and its partitioning

The N concentration of seed, straw and senesced leaves of the four legumes species is shown in Tables 2 and 3. The N concentration of seed, straw and

Table 3. *The effect of legume species, plant population and sowing depth on the N concentration in seed, straw (stem + petioles + pod walls), and senesced leaves at final harvest in Canterbury, 1999/2000*

Treatments	N at final harvest (mg/g DM)		
	Seed	Straw	Senesced leaf
Species (S)			
Chickpea	29.4	8.1	20.3
Lentil	34.5	14.3	14.6
Lupin	36.2	7.9	7.5
Pea	31.7	17.3	23.3
S.E.	0.19	0.17	0.29
Population (P)			
10 plants/m ²	33.5	11.6	16.1
100 plants/m ²	32.0	12.0	16.5
400 plants/m ²	33.5	12.1	16.7
S.E.	3.0	0.23	0.17
Depth (D)			
2 cm	32.5	11.9	16.6
5 cm	32.9	12.1	16.6
10 cm	33.4	11.7	16.0
S.E.	0.11	0.22	0.20
CV %	1.9	11.3	7.4
Sign. interactions	ns	ns	ns

senesced leaves varied significantly ($P < 0.001$) among the legume species. However, there were no significant interactions in either season.

In all four legumes, the seed N concentration was highest followed by the N level in senesced leaves. The lowest N concentration was in the straw. Narrow-leaved lupin had the highest seed N concentration in both 1998/99 and 1999/2000. Chickpea seed had the lowest N concentration in both years. Narrow-leaved lupin straw had a lower N concentration than straw from the other three species. The N concentration in field pea straw was the highest compared with the other species in both years. The N concentration of the senesced leaves varied from 16 mg/g in narrow-leaved lupin to 28.6 mg/g in field pea in 1998/99 and from 7.5 mg/g in narrow-leaved lupin to 23.3 mg/g in field pea in 1999/2000. In the second year, plants sown at 10 cm depth had higher seed N concentrations than plants from the shallower sowings.

Nitrogen yield and partitioning

The N yield of seed, straw and senesced leaves varied significantly ($P < 0.001$) among the legumes (Tables 4 and 5). Narrow-leaved lupin produced the most seed N in both years, followed by chickpea. Lentil produced the lowest seed N in both years.

In 1998/99 the amount of N partitioned to straw at final harvest was not consistent among species

Table 4. *The effect of legume species and plant population on yield of N in seed, straw (stem + petioles + pod walls), and senesced leaves, N accumulation efficiency (E_N) and nitrogen harvest index (NHI) at final harvest in Canterbury, 1998/1999*

Treatments	N yield at final harvest (g/m ²)				E_N (g/g)	NHI
	Seed	Straw	Senesced leaf	Total		
Species (S)						
Chickpea	10.26	1.29	1.56	13.11	0.018	0.75
Lentil	7.58	1.01	0.99	9.57	0.025	0.78
Lupin	16.82	1.72	1.46	20.02	0.022	0.84
Pea	8.46	2.46	2.04	12.96	0.024	0.64
S.E.	0.529	0.174	0.235	0.714	0.0011	0.017
Population (P)						
0.1 × optimum	5.72	1.31	0.92	7.95	0.019	0.68
1.0 × optimum	10.31	1.73	1.57	13.61	0.021	0.75
2.0 × optimum	14.13	1.78	1.87	17.78	0.024	0.80
4.0 × optimum	12.96	1.66	1.70	16.32	0.023	0.78
S.E.	0.580	0.122	0.096	0.651	0.001	0.009
CV %	18.6	26.1	21.9	16.2	13.6	4.5
Sign. interactions	ns	S × P ($P < 0.05$)	ns	ns	ns	ns

Table 5. *The effect of legume species, plant population and sowing depth on yield of N in seed, straw (stem + petioles + pod walls), and senesced leaves, N accumulation efficiency (E_N) and nitrogen harvest index (NHI) at final harvest in Canterbury, 1999/2000*

Treatments	N yield at final harvest (g/m ²)				E_N (g/g)	NHI
	Seed	Straw	Senesced leaf	Total		
Species (S)						
Chickpea	13.10	2.01	1.90	17.00	0.021	0.75
Lentil	9.76	1.66	0.87	12.29	0.027	0.78
Lupin	19.29	2.47	1.02	22.78	0.023	0.84
Pea	11.44	3.21	1.39	16.03	0.026	0.69
S.E.	0.409	0.165	0.108	0.354	0.0003	0.010
Population (P)						
10 plants/m ²	7.80	1.87	0.80	10.47	0.023	0.72
100 plants/m ²	13.49	2.54	1.38	17.40	0.024	0.77
400 plants/m ²	18.91	2.60	1.70	23.21	0.026	0.80
S.E.	1.18	0.061	0.036	1.17	0.0002	0.017
Depth (D)						
2 cm	12.78	2.34	1.28	16.40	0.024	0.75
5 cm	13.43	2.40	1.32	17.14	0.024	0.76
10 cm	13.98	2.27	1.28	17.53	0.025	0.78
S.E.	0.089	0.046	0.019	0.102	0.0002	0.002
CV %	4.0	11.7	8.7	3.6	3.8	2.0
Sign. interactions	ns	S × P ($P < 0.001$)	S × P ($P < 0.001$)	ns	ns	ns

(Fig. 2a). The straw N yield in chickpea decreased as plant population increased. In contrast, in narrow-leaved lupin straw N yield increased as plant population increased up to four times the optimum. The

other two species had variable responses to changed plant population.

In 1999/2000, the N yields from straw in field pea and lentil increased from one-tenth the optimum to

Fig. 2. Straw nitrogen yield in 1998/99 (a), and straw (b) and senescent leaf N yields in 1999/2000 (c) of four grain legumes sown at different plant populations in Canterbury.

four times the optimum but was unchanged in narrow-leaved lupin. Straw N increased in chickpea up to twice the optimum population and then plateaued at the highest population (Fig. 2b). In the second year, all four species had a marked increase in the N yield from senescent leaves with increased plant population (Fig. 2c).

All four species showed marked variation in their total N yield at final harvest (Tables 4 and 5). In both seasons, narrow-leaved lupin gave the highest amount of total N. The lowest total N yield was from lentil in both years. Increasing sowing depth from 2 to 10 cm increased total N yields slightly (Table 5). There were no significant interactions. Overall, crops in the second season contained about 20% more N than in the first season.

Nitrogen accumulation efficiency

The calculated N accumulation efficiency (E_N) at final harvest is shown in Tables 4 and 5. The E_N was highest in lentil and was lowest in chickpea. In the first season, as plant population increased E_N increased by 20% (Table 4). However, in the second year there was only a 13% increase in E_N as plant population increased (Table 4). Again there were no significant interactions. However, increased sowing depth slightly increased E_N from 0.024 to 0.025 g N/g DM.

Table 6. Senesced leaf DM production (g/m²) of the four legume species at final harvest in Canterbury, 1998/99 and 1999/2000

1998/99		1999/2000	
Species (S)		Species	
Chickpea	90	Chickpea	103
Lentil	59	Lentil	68
Lupin	100	Lupin	149
Pea	76	Pea	75
S.E.	8.3	S.E.	12.5
Population (P)		Population (P)	
0.1 × optimum	29	10 plants/m²	58
1.0 × optimum	85	100 plants/m²	101
2.0 × optimum	101	400 plants/m²	138
4.0 × optimum	100		
S.E.	1.6	S.E.	1.4
		Depth (D)	
		2 cm	97
		5 cm	98
		10 cm	101
		S.E.	0.23
CV %	7.3	CV %	1.6
Sign. interactions	S × P ($P < 0.01$)		S × P ($P < 0.01$)

Nitrogen harvest index

In the four legume species, the NHI varied from 0.64–0.84 in 1998/99 and from 0.69–0.84 in 1999/2000 (Tables 4 and 5). Narrow-leaved lupin had the highest NHI at 0.84 in both seasons. In both years, the NHI increased with plant population. It was comparatively stable in 1999/2000 with higher values than in the first year. Increased sowing depth increased the NHI by 4% (Table 5).

Senesced leaves

In both seasons the amount of senesced leaf increased as plant population increased. In 1998/99, senesced leaves increased as population density increased from one-tenth of the optimum to twice the optimum. However, further population increases did not affect the dry matter production of senesced leaves (Table 6). In 1999/2000, senesced leaf TDM increased from 58 to 138 g/m² as plant population increased from 10 to 400 plants/m² (Table 6). In both seasons there were significant species by population interactions which showed that as population increased senesced leaf nitrogen increased for all species.

Relationships between seed yield and TDM, and between seed N and total plant N

There was a significant linear relationship ($P < 0.001$) between seed yield and TDM production at maturity

Fig. 3. The relationships between total dry matter and seed yield (a–d) and seed nitrogen and above-ground nitrogen (e–h) at final harvest of four grain legumes sown at four plant populations (●) in 1998/99, and three plant populations (▲) and three sowing depths (△) in 1999/2000. The fitted equations are (i) 1998/99 and (ii) 1999/2000.

for each species (R^2 of at least >0.96) (Fig. 3a–d). Similarly, there was a significant linear ($P < 0.001$) relationship between seed N and net aboveground N (including senesced leaf N) (Fig. 3e–h). There were also positive correlations between NHI and the crop harvest index (CHI). Both parameters were also positively correlated with seed yield and TDM (Table 7).

DISCUSSION

In the present study, plant N concentration varied among the four grain legumes and in their seed, straw and senesced leaves. This variation possibly indicates different rates of N translocation from vegetative parts to seed in the different species. Spaeth & Sinclair (1983) considered that N accumulation in both seed and whole plants varied among soybean cultivars and indicated there were different rates of N translocation from vegetative tissues to seed.

The N concentration of legume species or their cultivars can be affected by symbiotic N fixation. This process ceases at leaf senescence, because of lack of assimilate supply to nodules, thus total plant N would stop increasing before final harvest while translocation of N to seed was still occurring (Newton & Hill 1981). In all four species seed N concentration was higher than in the other plant parts. All four species had partitioned most of their N to seed by crop maturity. Burton *et al.* (1979) and Schulz *et al.* (1999) previously reported the highest proportion of N was located in seed in a range of grain legumes.

During the final stages of plant development, N moves from leaves, primarily to the seeds, at rates faster than it is deposited (Hanway 1976). This movement will be followed by reduced physiological activity and eventual leaf senescence and abscission (Burton *et al.* 1979).

The N concentration, averaged over both seasons, in senesced leaves was 26.0, 19.3, 16.1 and 11.8 mg/g for field pea, chickpea, lentil and narrow-leaved lupin, respectively. Variation in N concentration in senesced mungbean cultivar leaves was 9.4, 11.3 and 14.3 mg/g for CPI 106032, Satin and ACC 41, respectively (Bushby & Lawn 1992). Averaged over both seasons, the contribution of the N of the senesced leaves of the four legume species ranged from 20% in lupin to 35% in chickpea and pea of the total plant N (excluding root N). This is clearly a substantial loss of nitrogen from the plant system. A loss of N with senescence was also reported in mungbean genotypes in Australia (Bushby & Lawn 1992). The fraction of vegetative biomass and N partitioning to plant parts varies among legume species (Newton & Hill 1981; Bushby & Lawn 1992). Burton *et al.* (1979) reported in soybean, at maturity, 70% of the total N was in pods, 8% in straw and 22% in leaves.

The N yield of the seed of the different legumes ranked: narrow-leaved lupin > chickpea > field pea > lentil. In straw it ranked: field pea > narrow-leaved lupin > chickpea > lentil. Schulz *et al.* (1999) reported that faba bean had the highest N seed yield while Persian clover (*Trifolium resupinatum*), a pasture legume, had the highest straw N yield.

Table 7. The correlation matrix between yield and nitrogen attributes in four grain legumes in Canterbury, 1998/99 and 1999/2000

	SY	TDM	Total N	E_N	NHI	CHI
Chickpea						1998/99
SY		0.973	0.969	0.942	0.925	0.977
TDM	0.987		0.978	0.930	0.857	0.912
Total N	0.916	0.894		0.982	0.835	0.903
E_N	0.293	0.215*	0.611		0.804	0.888
NHI	0.666	0.597	0.772	0.722		0.958
CHI	0.949	0.901	0.882	0.404	0.769	
	1999/2000					
Lentil						
SY		0.980	0.974	0.650	0.759	0.901
TDM	0.997		0.934	0.539	0.664	0.800
Total N	0.872	0.865		0.789	0.749	0.912
E_N	0.117 ^{ns}	0.142 ^{ns}	0.326		0.551	0.779
NHI	0.385	0.359	0.682	0.823		0.839
CHI	0.919	0.897	0.851	0.094 ^{ns}	0.556	
	1999/2000					
Lupin						
SY		0.919	0.708	0.506	0.619	0.630
TDM	0.982		0.702	0.457	0.484	0.273 ^{ns}
Total N	0.828	0.827		0.953	0.701	0.346*
E_N	0.597	0.579	0.930		0.693	0.338*
NHI	0.626	0.567	0.854	0.917		0.577
CHI	0.957	0.888	0.768	0.581	0.669	
	1999/2000					
Pea						
SY		0.983	0.920	0.453	0.633	0.644
TDM	0.995		0.946	0.469	0.534	0.500
Total N	0.867	0.857		0.715	0.465	0.436
E_N	0.418	0.401	0.797		0.146 ^{ns}	0.256 ^{ns}
NHI	0.660	0.645	0.900	0.931		0.747
CHI	0.943	0.910	0.796	0.360	0.604	
	1999/2000					

All values are highly significant ($P < 0.001$), unless indicated as significant * ($P < 0.05$) or ns = not significant. SY = seed yield, TDM = total dry matter, CHI = crop harvest index, E_N = nitrogen accumulation efficiency, NHI = nitrogen harvest index.

Narrow-leaved lupin was the most productive crop in terms of N yield and NHI (Tables 4 and 5). It contained more than 20 g N/m² in each season with the highest N content in the seed. Final seed N levels depend on the plant's ability to transfer N from vegetative tissues to the seed (Rattunde & Frey 1986; Ganeshan *et al.* 1998).

Species which produced high seed yields such as *Lupinus angustifolius* also had high seed N yields. Hill *et al.* (1977) also reported that the seed N concentration of *Lupinus angustifolius* was higher than in pea. This may be due to narrow-leaved lupin being the most effective species in the Canterbury environment for biological N fixation (Rhodes 1980; Ganeshan *et al.* 1998). Schulz *et al.* (1999) reported that in Nepal, faba bean was the most effective crop in terms of biological N fixation and fixed more than 200 kg N/ha, but lentil performed poorly.

All four legumes had higher N yields in 1999/2000 than in 1998/99. This was probably due to the higher

rainfall in 1999/2000 (Fig. 1). Schulz *et al.* (1999) reported similar results. The high N yield may also have been due to the higher TDM yields in the second trial as total N yield is a function of per cent N and the DM yield per unit area (Rhodes 1980) and there was little variation in N concentration over the 2 years.

The amount of N in seed, as a proportion of total above-ground biomass N (the nitrogen harvest index, NHI) (Bushby & Lawn 1992) was similar in chickpea, lentil and narrow-leaved lupin (mean of 0.79) in both seasons. However, NHI was lower in field pea (0.67). The high NHIs in the present study may have been due to the low non-seed N yields (Tables 4 and 5). Rhodes (1980) reported similar variation in the NHIs of pea and *Lupinus angustifolius*. The highest NHI was the result of less partitioning of N to stems and leaves of the narrow-leaved lupin. This suggests an efficient mobilization of N in straw and leaves to seed, particularly, in narrow-leaved lupin. Rhodes (1980)

reported high NHIs of 0.86 and 0.91 for pea and lupin, respectively, and this was found to be due to the low N concentrations in the pod walls, stem and leaves. The results of Farrington *et al.* (1977) and Streeter (1978) with *Lupinus angustifolius* and soybean support this hypothesis. The low NHI of pea in the present study may have been due to crop lodging as lodging in wheat (*Triticum aestivum*) has been reported to inhibit N partitioning, which reduced the NHI by 30% (Canvin 1976).

Generally, NHI increased with increased plant population. This has also been reported in *Vicia faba* by Newton & Hill (1981). This may have been due to a close relationship between the HI and the NHI (Table 7) as was also found in a range of grain legumes by Muchow *et al.* (1993b). A higher NHI may result from a greater depletion of the straw N reservoir. When this is combined with a greater proportion of seed in the plant more N is incorporated into the seed biomass (Löffler & Busch 1982). More efficient partitioning of N to the seed without changing the amount of carbohydrate accumulated in the seed would increase seed protein concentration but would not greatly change HI (May *et al.* 1991).

In the present work, there were strong positive correlations between NHI and seed yield in all four legume species as has been reported in wheat (Spratt & Gasser 1970; Halloran 1981), oats (*Avena sativa*) (Rattunde & Frey 1986) and cowpea, mung bean and soybean (Muchow *et al.* 1993b). Therefore, selecting for a high NHI in grain legumes may also increase seed yield (Rattunde & Frey 1986). Selection for NHI, in wheat, increased seed yield by 5 to 11% (Löffler & Busch 1982).

In the present work the NHI and the CHI were positively correlated (Table 7) and both were positively correlated with seed yield. Similar results have been reported in cereals (Löffler & Busch 1982; Rattunde & Frey 1986). Thus, selection for both CHI and NHI may lead to increased seed yield in grain legumes. Since the determination of NHI is more laborious and costly than the measurement of CHI, Löffler & Busch (1982) and Rattunde & Frey (1986) suggested that the close relationship between NHI

and CHI may allow CHI to be used as an alternative selection criterion.

The nitrogen accumulation efficiency (E_N) at final harvest differed among legume species, plant population and sowing depths (Tables 4 and 5). Among the four legumes, chickpea had the lowest E_N (0.018 and 0.021 g N/g DM). These values are similar to those of Chapman & Muchow (1985), and Muchow *et al.* (1993b) for soybean, cowpea and mungbean in Australia. The ranking of the species for their E_N is the reverse of that for their RUE in the present study (Ayaz 2001). This negative association between E_N and RUE can possibly be explained by differences among the species in their use of photosynthate for N fixing symbiosis (Minchin *et al.* 1981). Lentil may have a high capacity N fixing system that gave a high E_N , but a substantial proportion of photosynthate may have been used to support N fixation, with a concomitant reduction in DM production. This would give a lower conversion of intercepted radiation to DM. Similar results were reported for other grain legumes (Muchow *et al.* 1993b).

Both sowing depth and population had small, variable but significant effects on the E_N . The increase with increased sowing depth was probably due to greater moisture availability in the subsoil as reported for other grain legumes in Australia (Siddique & Loss 1999). Chapman & Muchow (1985) and de Vries *et al.* (1989) compared a range of grain legumes, and concluded that total N accumulated and estimated E_N generally decreased as water stress increased.

CONCLUSIONS

In spite of the wide variation in the degree of change in TDM and seed yield and N at final harvest, there were strong relationships between seed yield and total aboveground biomass at harvest maturity. Seed N and total aboveground N at final harvest were also strongly associated in all four legume species. The close correlations between NHI, CHI and seed yield mean that CHI can be used as a quick selection criterion for plant breeders searching for increased yield.

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