Seed production in narrow-leafed lupins (*Lupinus angustifolius* L.).

J. P. Millner[1], Khalid Mahmood Tahir[1], and C. Black[2]
[1]Institute of Natural Resources, Massey University, Palmerston North
[2]Forestcover Seeds, Williams and Kettle Ltd., Feilding

Abstract

Seed production of two *Lupinus angustifolius* cultivars, Aupouri and Forestcover, selected for use in post harvest oversowing in *Pinus radiata* plantations, and a standard cultivar of unknown origin, were compared. The effects of cultivar and sowing date on growth, seed yield, yield components and seed quality were measured in a trial established at Massey University on 9 September (early) and 9 October (late), 2002. Growth was similar in all three cultivars but Aupouri was slightly earlier maturing. All three cultivars displayed indeterminate flowering. The mean number of pod bearing branches per plant ranged from 4.6 to 5.4. Aupouri (4,016 kg/ha) produced significantly less ($P<0.05$) seed than Forestcover (4,902 kg/ha) and the Standard cultivar (5,282 kg/ha). This was mostly due to the lower mean seed weight in Aupouri, 161 g/1000 seeds, compared to 174 and 182 g/1000 seeds for the Standard cultivar and Forestcover respectively. Sowing date had little effect on seed yield, averaging 4,772 kg/ha and 4,694 kg/ha for the early and late sowing respectively. Germination testing revealed high hard seed content in Aupouri (67 %) whereas hard seed content in the other cultivars was negligible. Sowing date had no effect on hard seed content. There were no sowing date x cultivar interactions for any of the seed yield, yield component and seed quality characteristics that were measured. The seed of both Aupouri and Forestcover had high alkaloid content.

***Additional key words*:** cultivar, sowing date, seed yield, yield components, germination, hard seed.

Introduction

Narrow-leafed or blue lupin (*Lupinus angustifolius* L.) cultivars have been utilised in New Zealand as both a green manure crop and forage crop with the area planted peaking in the 1950's at about 4,000 ha (Claridge 1972). Initially they were mainly sown as a green manure crop because of their ability to fix substantial amounts of atmospheric nitrogen (Burtt & Hill, 1981; McKenzie and Hill, 1984) and high alkaloid content of old bitter cultivars, particularly of lupanine and hydroxylupanine (Anokhina *et al.,* 1980). The latter generally made them unpalatable to stock and poisonous if consumed in large quantities (Williams 1984). Although the introduction of sweet low alkaloid cultivars increased their use as a forage crop, the area sown declined markedly mostly because the need for green manure crops declined as well as the development of more productive greenfeed crops (Claridge, 1972). Lupin seed was assessed as a potential source of protein concentrate for animal feed in New Zealand. Under good management seed yields of 3.0-4.5 t/ha can be achieved containing up to 30 % protein. However difficulties, such as yield variability and problems with weed control (Withers, 1975), have meant that other grain legumes, particularly field peas (*Pisum sativum*) and imported soya beans (*Glycine max*) are the preferred source of protein concentrates in New Zealand (Hill, 1989). Important cultivars included Uniwhite, selected for reduced pod shattering as well as Unicrop (early maturing) and Uniharvest (late maturing) released in the late 1960's and early 1970's, all of Australian origin (Farrington, 1974). Whereas early cultivars had high hard seed content, later cultivars mostly had thin seed coats (Williams, 1984).

More recently there has been renewed interest in using narrow-leafed lupins as a source of shelter and nitrogen in coastal North Island sand country *Pinus radiata* plantations. The soils in these plantations are free draining, prone to wind erosion and of low fertility, particularly nitrogen (Gadgil, 1976). Up until the late 1980's the tree lupin (*Lupinus arboreus*) was an important nitrogen source in these soils and helped prevent erosion of mobile sand dunes. However the arrival of lupin blight (*Colletotrichum gloeosporioides*) has resulted in greatly reduced tree lupin populations and vigour (Dick, 1994). Consequently lupin nitrogen fixation has been greatly reduced, forcing forest managers to apply nitrogen fertilisers to ensure acceptable growth rates in young trees (Maclaren, 1993). This resulted in increased growing costs and potential environmental problems associated with the use of nitrogen fertilisers, such as nitrate leaching. Alternative legume species have been trialed as replacements for tree lupin, including *Lotus, Melilotus* and *Trifolium* species (Gadgil *et al.*, 1999), but none have proved to be as effective as tree lupin. However, narrow-leafed lupin has shown potential as an alternative legume for sand country. Pearse (1958) noted their ability to establish quickly, grow vigorously and reseed on loose windblown sand. Recent trials with narrow-leafed lupin oversown on cut-over sites in Aupouri forest, Northland, have had good success (P. Tolliday pers. comm.). In 2003 two cultivars were granted plant variety protection (Williams and Kettle Ltd.) and released for use in this role, namely Aupouri and Forestcover (Anon., 2004). Aupouri has good potential to produce self-sustaining populations because of a high level of hard seed, an important characteristic of tree lupins, (Dick, 1994). Although some cultivars of narrow-leafed lupin are susceptible to lupin blight (Frencel, 1998) both new cultivars have shown a very high degree of resistance. Originally selected by the Institute for Crop and Food Research at Palmerston North from a collection of lines held by the West Australian Department of Agriculture for resistance to lupin blight (Cowling *et al.,* 1999), both cultivars have been further selected for resistance to blight and their ability to establish quickly and persist after oversowing. They also have a low, (Forestcover), and a high, (Aupouri), hard seed content.

Narrow-leafed lupins are often spring sown but may be autumn sown in parts of the world where the early onset of high temperatures and moisture stress limit production, for example in Western Australia (Williams, 1984). In New Zealand, growing conditions in late spring and early summer are good in most areas and good yields from spring sowing can be expected. However late sowing can result in crops suffering from delayed maturity, late harvesting and reduced yields (Withers 1975). Reduced yields result from shortened flowering duration and consequently the production of fewer main stem pods (Withers *et al.,* 1974). Claridge (1972) recommended autumn sowing to avoid the risk of delayed maturity and late harvest.

Delayed maturity was a problem for both Forestcover and Aupouri seed crops sown in late October 2001 in the Manawatu. Ripening did not occur until the following April with resulting wind damage, high pod losses, pod shattering, weed ingress and reduced yield.

Seed production is an important aspect of new cultivar development. Adequate supplies of seed at an appropriate cost and quality are essential for the successful commercialisation of new cultivars (Lancashire 1985).

Information on the growth, seed yield and seed quality of new cultivars is therefore important. Growth, maturity, seed yield, seed yield components and seed quality of Aupouri, Forestcover and a locally sourced blue lupin of unknown origin sown at two spring sowing dates were compared.

Methodology

A trial was established on the Frewens block of the Pasture and Crop Research Unit at Massey University, Palmerston North comparing three narrow leafed lupin cultivars (Table 1) at two sowing dates in a factorial, fully randomised complete block design with four replications. The standard cultivar was obtained locally but its agronomic characteristics are unknown. Both Aupouri and Forestcover are susceptible to pod shattering. Sowing dates were 9 September and 9 October, 2002.

Table 1. Descriptions of the *Lupinus angustifolius* culivars grown.

	Flower colour	Stem anthocyanin	Grain bitterness	Growth habit	Grain colour
Cultivar					
Aupouri	Violet	High	Bitter	Indeterminate	Mottled brown
Standard	Blue	Moderate	-	Indeterminate	Mottled grey
Forestcover	Pink	Low	Bitter	Indeterminate	Mottled grey

Plots of 5 x 1.35 m were drilled into a cultivated seedbed using a cone plot seeder. Rows were 15 cm apart. The sowing rate of each cultivar was adjusted to take into account seed size and germination with the aim of establishing 120 plants/m^2 in all plots. Seed was treated with Apron XL® fungicide (350g/kg metalaxyl), applied at 100ml/100kg of seed to control damping-off diseases. Seed was not innoculated with Rhizobium as previous research (Withers 1976) and local experience suggested that a response to inoculation was unlikely. Aupouri seed was scarified with coarse sandpaper prior to sowing and treating because of high hard seed. Weed control was achieved with a pre-plant application of trifluralin (0.8kg ai/ha) and some hand hoeing at about 15 cm crop height to control black nightshade (*Solanum nigrum*) and spurrey (*Spergula arvensis*) seedlings not adequately controlled by herbicide.

Measurements

The following measurements were taken.

Plant population at establishment and flowering;
Flowering date (when 50 % of plants had a main stem with flowers);
Main stem and branch pods/plant;
Seeds/pod (main stem and branch);
Combine seed yield;
1000 seed weight from both hand and machine harvest samples;
Germination;
Hard seed content

Rainfall and temperature data collected by AgResearch, about 1.5 km from the trial site, were used as a record of seasonal weather during crop growth.

Sampling for plant population and time to 50 % flowering was from four 1m row lengths in each plot excluding the outside row in all cases. All other crop sampling was undertaken by randomly selecting four plants per plot. Sampling for yield components and harvest index was carried out separately for each sowing date and was initiated when most pods in all plots had begun to change colour. Colour change was first evident in the Aupouri plots. Final seed yield was measured using a F. Walter & H. Wintersteiger small combine plot harvester. Seed yield is reported at 14 % moisture. The time of final harvest was dependant on the weather. A forecast of wet or windy conditions triggered harvesting to minimise pre-harvest losses, particularly from pod shattering and pod drop, which was evident in all plots. The first plots were harvested on 13 February and the last on 10 March. Seed weight was measured by counting, drying, and weighing 5 x 100 seed sub samples. A further seed sub sample was taken and submitted to Seed Technology Services, Massey University, to determine germination, after pre-chilling at 5 ^{0}C for 4 days, and the proportion of hard seed. In addition 200 seed samples of Aupouri and Forestcover were subject to a stain test using a solution of 14g of potassium iodide and 10g of iodine in 100 ml of distilled water to indicate their alkaloid content. Seeds were split and immersed in the solution for 10 seconds, rinsed with distilled water and the split surfaces visually assessed for brown staining. Staining indicated a high alkaloid content. ANOVA was carried out utilising the GLM procedure of the SAS software system. The least squares means option was specified for reporting of treatment means. Reported least squares means followed by a different letter are significantly different.Correlation analysis and analysis of covariance revealed no significant plant density effect on seed yields, consequently all treatment means are presented without adjustment for plant population.

Results

Crop growth

As a result of a cool spring maximum seedling emergence did not occur until 4 and 3 weeks after sowing for the September and October sowing respectively. The September 2002 to February 2003 period was cool, particularly November and October which, atypically, was cooler than September (Table 2). Rainfall was near normal during the spring and early summer but conditions became quite dry by late summer.

Table 2. Mean monthly temperature (°C) and rainfall (mm) over the 2002/03 season compared with the long term mean

	Month					
	Sept	Oct	Nov	Dec	Jan	Feb
2002/03						
Temperature	10.2	9.8	11.7	15.1	15.9	16.3
Rainfall	99.4	67.6	45.4	84.8	19.8	23.4
Long term mean						
Temperature	10.7	12.5	14.2	16.0	17.4	17.6
Rainfall	76.2	87.0	78.0	86.1	76.5	80.7

Long term means: (AgResearch Palmerston North, 1928 to1997)

There were no significant cultivar x sowing date interactions so only main effects are reported. Establishment was lower than anticipated, particularly in Aupouri. Final plant populations averaged over both sowing dates were 94 plants/m^2, 110 plants/m^2 and 109 plants/m^2 for Aupouri, the Standard and Forestcover respectively. Sowing date had little effect on plant density, however by flowering, plant populations had declined in all cultivars to 90 pl/m^2, 95 pl/m^2 and 96 pl/m^2 respectively. Apart from some minor rabbit browsing during the trial and some weed growth, which was controlled by hand hoeing, there were no serious pest or disease problems. The formation of root nodules appeared to be good in all plots.

There was a small but significant cultivar difference in time to 50 % flowering (Table 3). Forestcover flowered slightly earlier than the other two cultivars. Although chronological time to flowering was greater with the early sowing, when expressed in thermal time, 902 ^{0}C days and 898 ^{0}C days for the early and late sowing respectively, there was no difference. By maturity the situation had changed with earlier senescence and a lower seed moisture content in Aupouri (Table 8).

There were no cultivar height differences but late sowing increased plant height by almost 20 cm. (Table 3).

Table 3. Plant height at 50 % flowering, days and thermal time (base 0^{o}C) between planting and 50 % flowering

	Height(cm)	Days to 50% Flowering	Thermal time to 50% Flowering
Cultivar			
Aupouri	75.9	78.7 a	907 a
Standard	79.8	78.6 a	904 a
Forestcover	76.2	77.4 b	889 b
Sowing date			
September	67.3 b	84.4 a	902
October	87.2 a	72.1 b	898

Table 4 . Branch and pod formation in three cultivars of *Lupinus angustifolius*.

	Branch/plant	Branch pod/plant	Main stem pod/plant	Total pod/plant
Cultivar				
Aupouri	5.4	11.4b	7.7a	19.1
Standard	4.6	12.8a	5.9b	18.7
Forestcover	5.2	14.8a	4.9b	19.7
Sowing date				
September	5.4	18.3a	5.9	24.2a
October	4.7	7.6b	6.5	14.1b

Yield and yield components

Seed yields were good, Aupouri produced 4,016 kg/ha, which was significantly (P<0.05) less than the Standard cultivar, 5,282 kg/ha and Forestcover, 4,902 kg/ha (Table 5). Forestcover appeared to have a lower harvest index than the other two cultivars but this was the result of a low harvest index in the September sowing, one replicate of which was lost, and was not significant. Sowing date had no effect on harvest index.

Table 5. The seed yield and harvest index of three cultivars of *Lupinus angustifoliu*

	Yield(kg/ha)	Harvest index
Cultivar		
Aupouri	4,016 b	0.46
Standard	5,282 a	0.45
Forestcover	4,902 a	0.39
Sowing date		
September	4,772	0.44
October	4,694	0.43

All three cultivars had an indeterminate flowering pattern. This resulted in flowers being present over three to four weeks. Branching was not influenced by cultivar or sowing date (Table 4). Total pod number/plant was not influenced by cultivar but time of sowing had a strong influence: early sown plants produced on average 72 % more pods/plant than later sown plants. This was because fewer branch pods were produced. The proportion of main stem and branch pods was influenced by both cultivar and sowing date. Aupouri plants produced significantly fewer branch pods but had more main stem pods than the other two cultivars. There were significantly more branch pods than main stem pods (P < 0.005), except at the late sowing. Differences were least in Aupouri (3.7 pods/plant), significantly lower than in the Standard cultivar (P= 0.05) and Forestcover (P= 0.001), which had 6.9 and 9.8 more branch pods than main stem pod/plant respectively. The seed/pod was not influenced by either cultivar or sowing date (Table 6). There were generally more seeds in main stem pods than in branch pods, (P < 0.05), the exception being Forestcover. There were no significant treatment effects on the difference between seed/pod in main stem and branch pods.

Analysis of the seed weight of seed collected prior to final harvest revealed no significant treatment effects. Seed from main stem pods was significantly heavier than that from branch pods in all treatments (P < 0.001). Among cultivars, the difference in main stem and branch seed weight was significantly less in Aupouri than in the other two cultivars (P< 0.05). Sowing date was also significant (P < 0.0001). Machine harvest 1000 seed weights were less than those from the pre-harvest hand samples. Mean cultivar seed weights were 161.2, 173.9 and 181.9 g/1000 seeds for Aupouri, the Standard cultivar and Forestcover respectively, all differences were significant (P<0.01) (Table 7). Early sowing also gave significantly heavier seed than late sowing.

Table 6. The mean number of seeds/pod in branch pods and main stem pods on three cultivars of *Lupinus angustifolius*.

	Seed/Branch pod	Seed/main stem pod	Mean seed/pod
Cultivar			
Aupouri	3.8	4.5	4.1
Standard	4.0	4.5	4.2
Forestcover	4.1	4.8	4.3
Sowing date			
September	4.0	4.5	4.1
October	4.0	4.7	4.3

Table 7 . The1000 seed weight (g) from pre harvest and machine harvest seed of three cultivars of *Lupinus angustifolius*.

	Branch pod*	Main stem pod*	Final harvest
Cultivar			
Aupouri	188	219	161 c
Standard	183	236	174 b
Forestcover	177	240	182 a
Sowing date			
September	172	239	176 a
October	193	224	168 b

Seed quality

Germination was good in both the Standard line (88.2 %) and Forestcover (87.8 %). This was significantly higher than in Aupouri (24.9 %). However virtually all of this difference was due to a much higher proportion of hard seed in Aupouri, 67.3 % compared with 5.0 % and 1.7 % for the Standard and Forestcover respectively. This assumes that the hard seed was mostly viable, however, viability was not determined. Sowing date had no influence on germination or the proportion of hard seed. The assessment of the alkaloid content of Aupouri and Forestcover revealed that both cultivars had a high alkaloid content. All seeds of both cultivars were strongly stained by the iodide/iodine solution indicating a high alkaloid content.

Discussion

Below average temperatures in the 2002/2003 season probably caused slow seedling emergence (Herbert and Hill, 1977a) and increased the time to flowering (Perry and Poole, 1975) in this trial. Conversely the low rainfall in January and February 2003 may have advanced crop maturity because of moisture stress (Withers, 1974). Lucas *et al.* (1976) found that irrigation delayed maturity by up to 5 weeks in a Canterbury trial that received three times the January and February rainfall of the current study.

Cultivar differences in time to flowering, about 1 day, were negligible. Lucas *et al.* (1976) found differences in the sowing to flowering period between early (Unicrop) and late (Uniharvest) cultivars of up to three weeks from spring sowing. Sowing date differences in thermal time from sowing to flowering in this study was minimal. Other research has found that time to flowering is reliably explained by models that include average temperature and day length between sowing and flowering (Reader *et al.,* 1995). Harvest maturity was achieved by mid February in the early sowing, and by mid March for the late sowing. This highlights the problem of seed ripening extending into early autumn due to late sowing, increasing the risk of prolonged ripening and delayed harvest (Withers, 1975; Lucas *et al.,* 1976).

The seed yields achieved were high when compared with typical commercial crop yields (Claridge, 1972; Withers, 1974). However some researchers have achieved yields of over 6,000 kg/ha (Lucas *et al.*, 1976; Herbert and Hill, 1978b) albeit from hand rather than machine harvested samples. The yield potential of Aupouri appears to be lower than the other two cultivars, probably due to its lower seed weight. Ripening in Aupouri appeared to be more rapid than in the other two cultivars and this is supported by the seed moisture data from the pre-harvest samples (Table 8). If this is a result of a shorter seed fill period rather than a quicker seed dry-down this might explain lower seed weight in Aupouri. There were no cultivar differences in the total pod/plant and seed/pod but Aupouri did have fewer branch pods and more main stem pods than the other cultivars. Although seed development was not measured in this study, previous work has shown that seed filling occurs almost concurrently in all pods (Perry, 1975; Herbert and Hill, 1978a; Dracup and Kirby, 1996).

Table 8 . The seed moisture content (%) of *Lupinus angustifolius* seed collected from branch and main stem pods on10 February (early sowing) and 28 February (late sowing), 2003.

	10 February		28 February	
	Branch	Main stem	Branch	Main stem
Cultivar				
Aupouri	52.0	40.0	54.0	49.0
Standard	65.0	56.0	57.0	58.0
Forestcover	66.0	53.0	63.0	56.0

Table 9 Germination (%) and the proportion of hard seed (%) in three cultivars of *Lupinus angustifolius*.

	Germination	Hard seed
Cultivar		
Aupouri	24.9 b	67.3 a
Standard	88.2 a	5.0 b
Forestcover	87.8 a	1.7 b
Sowing date		
September	68.4	26.5
October	65.6	22.8

Previous work examining the effect of sowing rates on yield found yield differences were primarily affected by pod number per unit area (Lucas *et al.*, 1976; Herbert, 1978). Although there were differences in the number and proportion of main stem and branch pods, in this study the total pod number per plant was not influenced by the cultivar but late sowing did produce fewer branch pods. Consideration of all the yield component data suggests that the contribution of branch pods to the total yield was at least equal that of main stem pods. Herbert and Hill (1978b) found that the contribution of branch pods to total yield varied with plant density and irrigation. It was greatest under irrigation and low plant density when almost 80 % of total yield was produced by branch pods. In contrast, a high plant density without irrigation resulted in only 12 % of total seed yield being produced on branch pods.

The high proportion of hard seed in Aupouri was expected, being an important attribute of this cultivar. The west coast North island sand country is typically moisture deficient for all of the year except the winter and early spring. To produce self-sustaining populations in such an environment a high proportion of hard seed is desirable to protect against false starts (Scott and Hampton, 1985). Hard seed content in lupins and other legumes is strongly genetically controlled but can be influenced by the environment, particularly during seed development. Hot and dry conditions generally result in higher hard seed content (Rolston 1978). The proportion of fresh ungerminated seed was generally low (< 4 % averaged across all samples) so if a similar proportion of non-viable seed in the hard seed component is assumed then viability in all cultivars was about 90 %. In addition to viability good performance in seed lots is also influenced by seed vigour, particularly in harsh environments (Hampton 1999). Oversowing results in seed lying on the soil surface where it is subject to extremes in temperature and moisture availability. Under these conditions high seed vigour is necessary if an acceptable rate of seedling establishment is to be achieved. While high viability can indicate high vigour in *Lupinus angustifolius* (Rowarth *et al.,* 1997) viability itself may not always be a reliable indicator of seed vigour (Hampton, 1999). The harvesting strategy used in this study, which involved harvesting at high grain moisture contents, has been shown to favour high vigour in grain legumes (Castillo *et al.*, 1992).

Conclusion

The agronomic characteristics of Aupouri and Forestcover were similar to that of the Standard cultivar indicating that current advice for lupin production in the North Island, that is early sowing and high sowing rates to reduce the risk of problems inherent with delayed harvest, are appropriate. The seed yield potential of Aupouri appears to be lower than that of Forestcover and the standard cultivar, suggesting that an upward adjustment of seed crop areas would be prudent. The results confirm the high proportion of hard seed in Aupouri.

References

Anonymous. 2004. *New Zealand Plant Variety Rights Journal No.* 96.

Anokhina, V. S., Kupstova, A. G., Kozlova, L. S. and Leonovich, I. A. 1980. Variation in content and composition of alkaloids in intervarietal lupin hybrids and the use of these characters in breeding and seed production. *Sel'skokhozyaistvennaya Biologiya* 15(1):111-115.

Burtt, E. S. and Hill G. D. 1981. Dry matter accumulation and nutritive value of lupins *Lupinus angustifolius* and their potential as a summer forage. *Proceedings of the Agronomy Society of New Zealand* 11:45-50.

Burgess, S. M.1986. The climate and weather of Manawatu. *New Zealand Meteorological Service* 115(18):47pp.

Castillo, A. G., Hampton, J. G. and Coolbear, P. 1992. Effect of time and method of harvest on seed vigour in garden peas. *Journal of Applied Seed Production* 10:31-36.

Claridge, J. H. 1972. Arable farm crops of New Zealand. DSIR in association with A. H. & D. W. Reed LTD. Wellington. 345pp.

Cowling, W. A., Buirchell, B. J., Sweetingham, M. W., Yang, H., Thomas, G., Lucket, D. J., Brown, A. G. P. and Hamblin, J. 1999. Anthracnose resistance in lupins - an innovative Australian research effort 1996-1998. In Lupin, An Ancient Crop for The New Millennium (eds. E. van Santeen, M. Wink, S. Weissmann and P. Romer). *Proceedings of the 9th International Lupin Conference*. 60-62.

Dick, M. A. 1994. Blight of *Lupinus arboreus* in New Zealand. *New Zealand Journal of Forestry Science* 24(1): 51-68.

Dracup, M. and Kirby, E. J. M. 1996. Pod and seed growth and development of narrow-leafed lupin in a water limited Mediterranean-type environment. *Field Crops Research* 48: 209-222.

Farrington, P. 1974. Grain legume crops: Their role on the world scene and in Australian agriculture. *The Journal of the Australian Institute of Agricultural Science* 40: 99-108.

Frencel, I. M. 1998. Report of first detection of anthracnose (*Colletotrichum gloeosporoides*) on lupins in Poland. *Plant Disease* 82(3):350.

Gadgil, R. L. 1976. Nitrogen distribution in stands of Pinus radiata with and without lupin in the understorey. *New Zealand Journal of Forestry Science* 6(1):33-39.

Gadgil R. L., Douglas G. B. and Sandberg A. M. 1999. Screening of nitrogen-fixing plants for use in sand-dune revegetation in New Zealand. *New Zealand Journal of Forestry Science* 29 (1):64-84.

Hampton, J. G. 1999. Producing quality seed: the problem of seed vigour. *Agronomy Society of New Zealand Special Publication No.* 12:53-61.

Herbert, S. J. 1978. Plant density and irrigation studies on lupins. III. Seed - yield relationships of *Lupinus angustifolius* cv. Unicrop. *New Zealand Journal of Agricultural Research* 21:483-489.

Herbert, S. J. and Hill G. D. 1978a. Plant density and irrigation studies on lupins. I. Growth analysis of *Lupinus angustifolius* cv. WAU11B. *New Zealand Journal of Agricultural Research* 21:467-474.

Herbert, S. J. and Hill G. D. 1978b. Plant density and irrigation studies on lupins. II. Components of seed yield of *Lupinus angustifolius* cv. WAU11B. *New Zealand Journal of Agricultural Research* 21:475-481.

Hill, G. D. 1989. World production and trade in grain legumes. Grain Legumes National Symposium and Workshop. *Agronomy Society of New Zealand Special Publication No.* 7. 1-5.

Lancashire, J. A. 1985. Some factors affecting the rate of adoption of new herbage cultivars. Chapter 11. In Using Herbage Cultivars (eds. R. E. Burgess and J. L. Brock). New Zealand Grasslands Association, Palmerston North. *Grasslands Research and Practice series No.* 3:79-87.

Lucas, R. J., Pownall, D. B. and Herbert, S. J. 1976. October sown *Lupinus angustifolius* in Canterbury. *Proceedings of the Agronomy Society of New Zealand* 6:75-77.

Maclaren, J. P. 1993 . Radiata pine growers' manual. FRI, Rotorua. *Forest Research Institute Bulletin No.* 184. 140pp.

McKenzie, B. A. and Hill G. D. 1984. Nitrogen uptake and transfer from a spring sown lupin crop. *Proceedings of the Agronomy Society of New Zealand* 14:95-99.

Pearse, H. C. H. 1958. Stabilisation of sand drifts with blue lupins. *New Zealand Journal of Agriculture* 99:147-151.

Perry, M. W. 1975. Field environment studies on lupins. 2. The effect of time of planting on dry matter partition and yield components of *Lupinus angustifolius* L. *Australian Journal of Agricultural research* 26 (5):809-818.

Reader, M. A., Dracup, M. and Kirby, E. J. M. 1995. Time to flowering in narrow-leafed lupin. *Australian Journal of Agricultural research.*46(5):1063-1077.

Rolston, M. P. 1978. Water impermeable seed dormancy. *Botanical Review* 44:365-396.

Rowarth, J. S., Jones, A. V., Searle, H., Kelstrup, L. and Williams, P. H. 1997. Harvest date influence on field emergence and on laboratory indicators of quality in lupin (*Lupinus angustifolius* L.). *Proceedings of the Agronomy Society of New Zealand* 27:95-114.

Scott, D. J. and Hampton, J. G. 1985. Aspects of seed quality. In Producing Herbage Seeds. (eds. M. D. Hare and J. L. Brock). New Zealand Grasslands Association, Palmerston North. *Grassland Research and Practice Series No.* 2. 43-52.

Williams, W. 1984. Lupins in crop production. *Outlook on Agriculture*: 13 (2):69-76.

Withers, N. J., Baker, C. J. and Lynch, T. J. 1974. Some effects of date, rate and method of sowing on lupin seed yield. *Proceedings of the Agronomy Society of New Zealand* 4:4-48.

Withers, N. J. 1975. Growing lupins. Agronomy Department, Massey University.10pp.

Withers, N. J., McQueen, I. P. M. and Clark, K. W. 1976. A preliminary study of lupins on pumice soils. *Proceedings of the Agronomy Society of New Zealand* 6:71-73.