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ALTERNATIVE CROPS

Agronomic Potential of Narrow-Leafed and White Lupins in the Inland Pacific Northwest

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ABSTRACT

For economic and environmental reasons, there is need for alternative crops to rotate with winter wheat (*Triticum aestivum* L.) in the inland Pacific Northwest (PNW). White (*Lupinus albus* L.) and narrow-leafed (*Lupinus angustifolius* L.) lupins were evaluated as potential alternative grain crops under PNW conditions. Maximum grain yield of white lupin was 2128 kg ha^{-1}; however, yields were unstable, and cultivars matured later and were more prone to disease than narrow-leafed lupin. Narrow-leafed lupin had a yield potential of 2000 kg ha^{-1}. Early sowing was the most important agronomic factor tested for maximizing yield of narrow-leafed lupin, with greatest yields associated with sowing during the third week of March. Yield loss due to delayed sowing ranged from 5.8 kg ha^{-1} d^{-1} under dry conditions to as much as 60 kg ha^{-1} d^{-1} in more favorable conditions. In 2000, delaying sowing from 21 March to 17 April coincided with a reduction in soil water storage of 5.3 cm in the upper 1 m soil layer. Most of this evaporative loss occurred in the upper 50 cm layer, considerably reducing crop water availability. Crude protein content of grain also declined with delayed sowing. Maximum water use efficiency for grain production under our conditions was 6 kg ha^{-1} grain mm^{-1} water use. Mean harvest loss ranged from 24 to 62% of hand-harvested yields, suggesting this will be a potential production constraint. Our results suggest good agronomic potential for narrow-leafed lupin in the PNW. Agronomic challenges and market potential are discussed.

The winter wheat–summer fallow cropping systems that dominate the inland PNW are viewed by many as increasingly economically unsustainable. They are also seen as environmentally unsustainable because dust and field burning reduce air quality, and runoff reduces stream quality and destroys endangered salmonid (*Salmo* and *Oncorhynbchus* spp.) habitat (Duff et al., 1995).

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The summer fallow component of the cropping system, which depends on several tillage operations on the silt loam soils, is at the root of many of the environmental problems and, arguably, economic ones as well since no crop is produced one out of every 2 yr. To improve the sustainability of these systems, there is need for alternative rotation crops in lieu of summer fallow.

The inland PNW climate has been classified as midlatitude semiarid, or "Interior Mediterranean" using the Köppen method (Ramig, 1988, citing Critchfield, 1966) because 70% of the 250 to 450 mm of annual precipitation is received during winter months. Spring weather rapidly transitions from cold and wet to hot and dry (Payne et al., 2001). Therefore, potential alternative spring crops need to tolerate cold temperatures during early growth stages, when there is sufficient moisture for germination, and to escape or tolerate high temperatures, high evaporative demand, and drought during later growth stages when rain is increasingly improbable.

Lupinus is a genus of self- or cross-pollinating, mostly indeterminate plant species indigenous to diverse geographic regions. Virgil noticed the benefits of rotating wheat with lupin more than 2000 yr ago (Gladstones, 1998). White lupin was domesticated in Germany during World War I in response to a need for high-protein pulse crops adapted to temperate conditions. More recently, narrow-leafed lupin was domesticated in semiarid southern Australia (see Cowling et al., 1998, for review) where it is grown during the winter and spring months. For both narrow-leafed and white lupin species, domestication efforts have centered on low alkaloid content, early flowering, reduced pod shattering, and soft seeds (Cowling et al., 1998). Cowling (2001) provides a list of alternative taxonomic nomenclature and common names for lupin.

Advantages of growing lupins in wheat-based cropping systems include increased yield of the following wheat crop (Cox, 1998; Gregory, 1998), contribution of N and organic matter to soils, and the ability to directly feed lupin grain on-farm to poultry, cattle, and sheep due to

Abbreviations: PNW, Pacific Northwest.

the absence of alkaloids or trypsin inhibitors (Edwards and van Barneveld, 1998).

White lupin was first introduced into the southeastern USA during the 1930s as a plowdown green manure (Meronuck et al., 1991). Production peaked in the 1950s and then declined due to reduction of seed supply, loss of government support, availability of N fertilizer, freeze damage, and disease pressure. Despite recent renewed interest in white lupin in North America (Putnam et al., 1992, 1993; Noffsinger and van Santen, 1995; Faluyi et al., 1997; Kearney, 1999; Reeves et al., 1999), it remains a very minor crop. We know of no published studies on white lupin in the inland PNW, but local farmers and researchers at Oregon State University and Washington State University have occasionally experimented with the crop. In most cases, efforts were abandoned due to yield instability and pod disease tentatively attributed to the bacteria genus *Erwinia*. However, newer cultivars in Australia have been selected for increased yield stability and disease resistance (Cowling et al., 1998).

To our knowledge, there have been no studies on the agronomic feasibility of narrow-leafed lupin in the PNW, but there exists a potential market. Regionally, there has been recent expansion of the dairy industry, which demands reliable sources of high quality protein. Currently, one-half of the lactating dairy cows in the region are fed imported canola (*Brassica napus*) meal from Canada, and approximately 60% are fed soybean [*Glycine max* (L.) Merr.] meal grown in the Midwest (Mowery and Spain, 1999). Comparisons for milk production and quality between cows consuming lupin-based diets and cows consuming soybean-based diets have been variable (May et al., 1993; Moss et al., 1999; Singh et al., 1991) but provide evidence that lupin might be substituted as a high quality protein source, with the added advantage that no extrusion or processing is required. There is also international market potential; approximately 75% of the 1 000 000 t of lupin annually produced in Australia is exported to markets in Asia, including Korea, Japan, and Indonesia, and to Europe and South Africa (Cox, 1998), mostly as a protein supplement to ruminant and monogastric animal feeds. Many of these countries already import soft white wheat from the inland PNW.

Growing conditions of the inland PNW differ in important ways from those of southern Australia. Average temperature and growing season rainfall of the two regions are similar, but lupin is sown under conditions of decreasing temperature and daylength in southern Australia, whereas in the inland PNW, they would be sown under conditions of increasing temperature and daylength.

The objective of this study was to evaluate agronomic potential of white and narrow-leafed lupin for wheat-based cropping systems of the inland PNW.

MATERIALS AND METHODS

Experiments in this study consisted of three agronomic trials: (i) an experiment comparing narrow-leafed and white lupin cultivars at two sites during 2 yr, (ii) an experiment comparing yield of five early maturing narrow-leafed lupin cultivars sown at three dates and three sowing rates under no-till conditions at three sites, and (iii) an experiment comparing yield and water use of two narrow-leafed lupin cultivars sown at three dates, also under no-till conditions. Soils at all sites were classified as coarse, silty, mixed mesic Typic Haploxerolls (Smiley et al., 1993). Those at Moro and Pendleton were of the Walla Walla series (Rasmussen and Smiley, 1994).

Experiment 1

In 1998 and 1999, four public narrow-leafed lupin cultivars—'Merrit', 'Yorrel', 'Chittick', and 'Danja'—and four public white lupin cultivars—'Kiev Mutant', 'L2085', 'Ultra', and 'L1047'—were grown at Oregon State University Columbia Basin Agricultural Research Center stations near Pendleton (45 43 N, 118 W; elev. 454 m) and Moro (45 29 N, 120 30 W; elev. 561 m). Mean annual precipitation at Pendleton is approximately 420 mm, of which 70% is generally received between 1 September and 11 April. Mean annual precipitation at Moro is 280 mm with similar seasonal distribution.

The experimental design was a randomized complete block with four replications. In 1998, individual plot size at both sites was 1.5 by 5.2 m. In 1999, plot size was 1.5 by 5.8 m.

In 1998, plots were sown on 28 April at Pendleton and 27 April at Moro. In 1999, plots were sown on 30 March at Pendleton and 1 April at Moro. In both years, seeds were sown into tilled ground from which winter wheat had been harvested the previous summer. In both years and at both sites, sowing rate was 86 seeds m^{-2} using a Hege 55[1] (Hege Maschinen GmbH, Domäne Hohebuch, Waldenburg, Germany) plot drill with double-disc openers spaced 15 cm apart. Seeds were treated with benzene hexachloride (1,2,3,4,5,6-hexachloro cyclohexane) at a rate of 0.85 g kg^{-1} seed and carboxin (5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxamide) at a rate of 4.1 g kg^{-1} seed. Seeds were inoculated with *Bradyrhizobium* sp. (*Lupinus*) before sowing.

Granular fertilizer 16–20–0–14 (N–P–K–S) was applied before sowing at a rate of 112 kg ha^{-1}. Ethalfluralin [*N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4- (trifluoromethyl) benzenamine] was applied preplant in liquid form at a rate of 0.84 kg a.i. ha^{-1} and incorporated with a cultivator into the upper 5 cm of soil. Metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] was broadcast preemergence at a rate of 0.28 kg a.i. ha^{-1}.

In 1998, soil samples were taken with an auger at 30-cm intervals to a depth of 1.2 m in three of the four replications for each cultivar at plant emergence and again after harvest to calculate change in profile water storage during the growing season. The change in water storage and rainfall data was used to calculate crop water use (crop transpiration plus evaporation from the soil surface) during the growing season. When calculating crop water use, drainage from the root zone and runoff were assumed to be negligible (Payne et al., 2001; Chen and Payne, 2001). Water use efficiency was calculated from yield divided by crop water use. Samples were hand-harvested at maturity from one randomly chosen 1-m^2 area within the plot, including any grain on the ground.

Experiment 2

Five narrow-leafed lupin cultivars were sown under no-till conditions at three sites on three dates, using three sowing rates. A randomized complete block experimental design with four replications was used with a split-split plot restriction on treatment arrangement. Main plots were sowing date, subplots

[1] Mention of trade names does not constitute an endorsement.

were sowing rates (112, 168, and 224 kg seeds ha^{-1}), and sub-subplots were cultivar, including one public cultivar (Merrit) and four Plant Breeders Rights–protected cultivars (‘Belara’, ‘Kalya’, ‘Tallerack’, and ‘Tanjil’). The 100-seed weight for these cultivars was 14.8 g for Merrit, 14.4 g for Tanjil, 13.2 g for Kalya, 15.0 g for Belara, and 13.8 g for Tallerack. Sub-subplot dimensions were 3.1 by 31 m. A John Deere 1560 no-till drill, fitted with 18 single disc openers spaced 17.5 cm apart, was used. Seeds were sown to moisture at 2.5 to 3.5 cm.

Experimental fields were near Helix, Condon, and Lexington, OR. Mean annual precipitation is 400 mm at Helix, 300 at Condon, and 250 mm at Lexington. At the Helix site, lupin was sown on 2 April, 23 April, and 10 May 1999. At the Lexington site, sowing dates were 31 March, 20 April, and 8 May 1999. At the Condon site, seeding dates were 8 April, 29 April, and 14 May 1999. Lupin was sown into wheat stubble at the Helix and Lexington sites and into barley stubble at the Condon site.

Ethalfluralin was applied presowing, at a rate of 0.84 kg a.i. ha^{-1}, with a GANDY spreader (GANDY Co., Owatonna, MN), using a 10% granular formulation to reduce adherence of herbicide to surface residue. Metribuzin was broadcast-applied postsowing, pre-emergence at a rate of 0.28 kg a.i. ha^{-1}. Incorporation was not possible due to no-till conditions. *Bradyrhizobium* sp. (*Lupinus*) inoculant was mixed with seeds in the drill box. Starter liquid fertilizer was applied with seed as a 1:1 mix of thiosol and polyphos solution, equivalent to 16.8 kg N ha^{-1}, 11.2 kg P ha^{-1}, and 20.2 kg S ha^{-1}. Plots were harvested using a Hege 140 plot combine (1.5-m header) and by hand from a randomly chosen area of 1 m^2, including any seed on the ground. Harvest loss was calculated from the equation [(hand-harvest yield $-$ combined yield)/hand-harvest yield] $\times$ 100, with yield expressed on a per unit area basis.

Experiment 3

In 2000, the narrow-leafed lupin cultivars Merrit and Kalya were sown on three dates into winter wheat stubble at the Columbia Basin Agricultural Research Center near Pendleton, using a John Deere 1560 no-till drill. A randomized complete block experimental design with four replications was used with a split-plot restriction on treatment arrangement, with sowing date (21 March, 31 March, and 17 April 2000) as main plots and cultivar as subplots. Subplot size was 3.1 by 22.9 m. A 10% granular ethalfluralin formulation was applied presowing at a rate of 0.84 kg a.i. ha^{-1} using the GANDY spreader. Lupin was sown at a rate of 168 kg seeds ha^{-1}. Before sowing, lupin seeds were inoculated with *Bradyrhizobium* spp. (*Lupinus*) by mixing inoculant slurry with seeds in the drill box. Starter liquid fertilizer was applied at a distance of 13 to 25 mm from the seeds as a 1:1 mix of thiosol (ammonium sulfate) and polyphos (ammonium polyphosphate) solution equivalent to 16.8 kg N ha^{-1}, 11.2 kg P ha^{-1}, and 20.2 kg S ha^{-1}. After sowing, metribuzin was broadcast-applied on the soil surface at a rate of 0.28 kg a.i. ha^{-1}. Plots were harvested with a Hege 140 combine. Grain from combined samples was sampled from each plot and its N content determined using the automated combustion method described by Sheldrick (1986). The N content was multiplied by a factor of 6.25 to obtain crude protein content.

One neutron probe access tube was installed in the center of each subplot, and soil moisture content was measured weekly using a field-calibrated CPN model 503 neutron probe (Campbell Scientific, Nuclear Corp., Pacheco, CA). Probe calibration was described by Payne et al. (2001).

Table 1. Results of ANOVA for combined analysis of year, site, and cultivar on yield of narrow-leafed and white lupin in east Oregon.

Source	Sum of squares	df	F ratio	P
Site (S)	2.20×10^{5}	1	14.8	0.000
Year (Y)	4.23×10^{7}	1	2.85E 03	0.000
Cultivar (V)	5.88×10^{6}	7	56.5	0.000
S × Y	1.96×10^{6}	1	1.32E 02	0.000
S × V	8.08×10^{5}	7	7.77	0.000
Y × V	7.21×10^{6}	7	69.3	0.000
S × Y × V	2.34×10^{5}	7	2.25	0.036
Error	1.42×10^{6}	96		

Statistics

All statistical analyses were made using the GLM module of SYSTAT version 10.2 (SYSTAT Software, Inc., Richmond, CA). For Exp. 1, a preliminary analysis of variance was made for the combined data set using site, year, and cultivar as fixed effects in a factorial model. Analysis of variance was then made for individual sites for each year using a randomized complete block design. For Exp. 2 and 3, analysis of variance was made as described by the SYSTAT manual for split-plot designs. This includes different error terms for “between-plot” and “within-plot” effects. Mean separations were made using Tukey’s hsd test.

RESULTS

Experiment 1

Overwinter (1 September to 31 March) precipitation in 1997–1998 was 263 mm at Pendleton and 197 mm at Moro; spring (1 April to 31 July) precipitation was 130 mm at Pendleton and 112 mm at Moro. Overwinter rainfall in 1998–1999 was 338 mm at Pendleton and 185 mm at Moro; spring precipitation was 83 mm at Pendleton and only 21 mm at Moro.

A combined ANOVA revealed that all main effects (site, year, and cultivar) were significant ($P < 0.0001$) (Table 1). Because all two-way interactive effects ($P < 0.0001$) and the three-way interactive effect ($P < 0.05$) were also significant, we present mean yields and mean separation among cultivars for individual sites and years (Table 2).

In 1998, yield for all white lupin cultivars was extremely low ($<$90 kg ha^{-1}) at both Moro and Pendleton

Table 2. Least square means of narrow-leafed and white lupin yield grown near Moro and Pendleton, OR, in 1998 and 1999.

	Yield			
	Moro		Pendleton	
Cultivar	1998	1999	1998	1999
	kg ha^{-1}			
Narrow leafed				
Merrit	1386a†	1301a	873a	1366ac
Chittick	35b	1470a	2b	1806bd
Danja	637c	1400a	40b	1547ab
Yorrel	786c	1268a	547c	1771b
White				
L1047	87b	964b	0b	1077c
L2085	62b	1398a	0b	1761b
Ultra	32b	1040b	0b	1485ab
Kiev Mutant	58b	1455a	8b	2128d
SE	61	69	39	70

† Means within the same column without a letter in common differ at $p < 0.05$ using Tukey’s hsd.

(Table 2). All white lupin cultivars flowered near 25 June, long after rains had ceased, and when temperature and evaporative demand are high (Payne et al., 2001). Plants produced very few pods, a common effect of water stress in white lupin (Withers, 1979). Of the very few pods that formed, most exuded a white foam that suggested bacterial fermentation following invasion by larvae of any number of moth species (W. Cowling, personal communication, 2002). We did not identify any specific species, but Sweetingham et al. (1998) mention that mirid (*Lygus* spp.) had been recorded as a significant pest in white lupin experimental plots at Washington State University. In Australia, white lupin is more prone to this fermentation than narrow-leafed lupin.

Among the narrow-leafed lupin cultivars, yield was greatest for Merrit and least for Chittick at both sites. Yield among narrow-leafed cultivars corresponded directly to earliness of flowering date. At Moro, Merrit flowered on 13 June, Yorrel and Danja on 16 June, and Chittick on 25 June. Flowering dates were nearly identical at Pendleton, indicating that narrow-leafed lupins required only 50 to 60 d to flower. This represents a much shorter vegetative growth period and earlier flowering compared with narrow-leafed lupins grown under Australian conditions. Dracup and Kirby (1996), for example, give a range of 75 to 98 d to flowering for the narrow-leafed lupin cultivar Gungurru when sown on 29 April. In general, this crop will develop and mature faster in the inland PNW than in Australia because of photoperiod response to the longer daylength experienced during the cropping season. Rate of development is hastened by increasing temperature (up to an optimum) and daylength (Dracup and Kirby, 1996). In 1999, when sowing dates were approximately 4 wk earlier than in 1998, yield of white lupin was comparable to that of narrow-leafed lupin (Table 2). At Moro, the white lupin cultivars L2085 and Kiev Mutant had similar yields to narrow-leafed lupin of 1400 kg ha^{1}, whereas L1047 and Ultra had yields of 1000 kg ha^{1}. There were no differences among narrow-leafed cultivars at Moro; however, at Pendleton, the narrow-leafed cultivars Chittick and Yorrel had greater yields than Merrit, which appeared to have a poorer stand than the other cultivars. Danja's yield was similar to Merrit's. Seed for cultivars other than Merrit were certified and purchased directly from seed dealers in Australia. We speculate that poorer stands of Merrit in 1999 were due to reduced seed quality caused by an unknown combination of seed damage from harvesting and suboptimal storage conditions (Perry et al., 1998). The white lupin cultivar Kiev Mutant had significantly greater yield than all white and narrow-leafed lupin cultivars in Pendleton except the latest-maturing narrow-leafed cultivar, Chittick.

Experiment 2

Yields from combining were extremely low in this experiment due to pronounced drought at the experimental sites (Fig. 1). Crops failed for the second and third seedings at Lexington and for the third seeding at Condon. We therefore only made ANOVAs for individual sites; seeding date was not used as a factor at Lexington.

Because sites were remote and only visited monthly, rain gauges were not installed. Qualitative indicators of drought severity can be obtained from nearby weather stations and wheat yields of adjacent fields. Measurements from the rain gauge nearest to the Lexington site, which was 7 km away, indicated that total precipitation from 1 Sept. 1998 to 31 Aug. 1999 was 114 mm; wheat yields from fields adjacent to lupin plots were 300 kg ha^{1}. At the Moro station, which is 65 km from the Condon site, rainfall during this period was 206 mm, and wheat yields were 1200 kg ha^{1}. The Pendleton station, which normally receives 25 to 50 mm more rain than the Helix site due to its greater elevation, received 396 mm during this period, and wheat yields were about 3600 kg ha^{1}.

There were no statistical interactions between the three experimental factors at any of the sites. Despite drought conditions that ranged from moderate at Helix to disastrous at Lexington, yields showed similar response to cultivar at the three sites and to sowing date at Helix and Condon (Fig. 1). A prominent trend was yield decline with delayed sowing. At the Helix site, for example, when yield of all cultivars was pooled and mean yield divided by the number of days between the first and second sowing, the mean rate of yield decrease was 5.8 kg ha^{1} d^{1}. Additionally, at all sites, the cultivar Tallerack matured later and yielded less than the others. Finally, there was little to no response to increased sowing rate. Sowing rate response was statistically significant at Helix and Lexington, but the increase in yield was so small as to barely recover the additional seed used at the higher rate. It is possible that there would have been a greater yield response to sowing rate under more favorable rainfall conditions. In drought-prone areas of Australia, narrow-leafed lupin is typically sown at rates of 80 to 100 kg ha^{1} (Gregory, 1998; Dracup et al., 1998).

Mean harvest loss was 32% at Helix, 24% at Condon, and 62% at Lexington; median harvest loss was 35% at Helix, 54% at Condon, and 66% at Lexington. As severity of drought increased, plant stature decreased, making harvest more difficult. But even for taller plants, the stiff, rigid structure resulted in pod loss and shattering due to shaking by the cutter bar. Additionally, much of the cut material fell off the combine platform. Control of combine harvest loss is an important aspect of lupin management in Australia (Riethmuller and Blanchard, 1995) and is achieved with double-density knife guards to reduce shaking of the plant, extending the harvester platform, and assisted movement of material to the auger using air reels, vibrating mats, or platform sweeps. Preliminary experiments at the Pendleton station suggested that the use of a stripper header (Siemens et al., 2002), which is often used to combine no-till wheat, can also greatly reduce combine harvest loss.

Experiment 3

Overwinter rainfall at Pendleton in 1999–2000 was 379 mm; spring rainfall was 110 mm. Since there was

Fig. 1. Effects of sowing date (day of year), cultivar, and seeding rate on narrow-leafed lupin yield at three sites in eastern Oregon (Exp. 2). At the Helix site, date of sowing and sowing rate had significant (p 0.01) effects on yield; at the Condon site, date of sowing and variety had significant effects. At the Lexington site, where only the first sowing date was harvested, both sowing rate and cultivar had significant effects. Bars represent 1 SE and are calculated for individual sites because of the different number of harvests at each site.

no effect of cultivar on yield, and no interaction between cultivar and sowing date, data for the two cultivars are pooled in Fig. 2. Narrow-leafed lupin yields from the earliest planting were near 1900 kg ha^{-1} in this experiment, which was the greatest yield we observed for the cultivar Merrit. We believe that the favorable yields were due to a combination of favorable overwinter and especially spring rainfall, which is critical to yield of spring crops such as field pea (*Pisum sativum* L.) (Payne et al., 2000, 2001), and early planting. Similar to results from Exp. 2, delayed sowing was associated with a strong decrease in yield. Mean yield decreases between dates when all cultivars were pooled were 60 kg ha^{-1} d^{-1} when sowing was delayed from 21 to 31 March and 27 kg ha^{-1} d^{-1} when delayed from March to 17 April. Decreased protein content was also associated with delayed sowing (Fig. 2). These results confirm the importance of early sowing to lupin yield in the inland PNW and suggest that it is an important determinant of quality as well.

From 31 March to 17 April 2000, mean water storage in the upper 1-m profile declined from 31.5 to 26.2 cm (Fig. 3). This decline was very similar among planting dates and cultivars, suggesting that drying of the soil profile during the spring is largely controlled by weather patterns. Most of the moisture lost between the first and last planting date was stored in the upper 50-cm layer (Fig. 4), indicating that seedlings had less and less water available to them as planting was delayed. Given

Fig. 2. Yield and protein content of narrow-leafed lupin as a function of planting date near Pendleton, OR, in the year 2000. Lupin was planted on 21 March [day of year (DOY) 80], 31 March (DOY 90), and 17 April (DOY 117). Bars represent ± 1 SE.

the fact that most precipitation in this region is received during winter months, and the rapidly decreasing probability of rainfall during early spring months, seedling water availability would appear to be a primary reason to plant lupin as early as possible.

Data plotted in Fig. 5 suggest that a maximum water use efficiency of approximately 6 to 7 kg ha^{-1} grain per millimeter of crop water use was asymptotically approached under conditions of maximum yield. The curve in Fig. 5 resembles Model C of Viets' (1962) classic paper that related yield to water use and water use efficiency. A value of 6 to 7 kg ha^{-1} grain per millimeter of crop water use would appear to be a reasonable goal for crop management and could serve to estimate yield potential from available water supply when estimating production or making fertilizer recommendations, similar to methods used for wheat and pea (e.g., Payne et al., 2001).

DISCUSSION

Our results suggest that yield instability remains a problem with white lupin. Although the very low yields obtained in 1998 at both Moro and Pendleton may have been partially due to late sowing date, disease susceptibility continues to be a serious production constraint. Our observations therefore are consistent with those made by many farmers in the area who had informally experimented with the crop.

Based on the highest yields in Fig. 5, obtained with

Fig. 3. Stored water in the upper 1-m soil profile as a function of day of year (DOY) in the year 2000 for narrow-leafed lupin planted on 21 March (DOY 80), 31 March (DOY 90), and 17 April (DOY 117) near Pendleton, OR. Closed symbols are for the cultivar Merrit; open symbols are for the cultivar Kalya. Bars represent ± 1 SE.

Fig. 4. Profile water distribution on the day of planting in the year 2000 for narrow-leafed lupin planted on 21 March (DOY 81), 31 March (DOY 91), and 17 April (DOY 118) near Pendleton, OR. Bars represent ± 1 SE.

Fig. 5. Water use efficiency (WUE) [grain yield/(crop transpiration evaporation from soil surface] as a function of yield for narrow-leafed lupin. The diamond symbols are from the 1998 Exp. 1, conducted at Moro and Pendleton. All other symbols are from the 2000 Exp. 3. Circles are for the 21 March planting date, squares for the 31 March planting date, and triangles for the 17 April seeding date. CH, DA, ME, YO, and KA represent the cultivars Chittick, Danja, Merrit, Yorrel, and Kalya, respectively.

early planting in 2000, our data suggest a yield potential (Evans, 1993) of more than 2000 kg ha^{1} and therefore good agronomic potential for narrow-leafed lupin. Our data point strongly to early sowing as the most important agronomic factor to obtaining acceptably high yield, protein content, and plant height because sowing delay is associated with diminishing rainfall, rapidly increasing temperature and evaporative demand, and declining soil moisture storage. Perry et al. (1998) state that time of sowing was a topic of extensive research in the early phase of the narrow-leafed lupin industry in Australia and that lupin yields declined more rapidly than cereals as the sowing date is delayed and the effective growing season reduced. Despite the opposite trends in temperature and daylength during the Australian and inland PNW growing seasons, our data also suggest that sowing at the first opportunity will be a critical management practice.

There are clearly important agronomic challenges to address before narrow-leafed lupin will be widely accepted in the inland PNW. In our view, the two greatest challenges are reducing harvest loss and the availability of an effective herbicide for weed control, particularly for no-till conditions.

While the technology to reduce combine harvest loss exists, an effective herbicide treatment for the inland PNW is still needed. Current environmental regulations in the USA restrict the use of herbicides applied to lupin in Australia and Canada, such as atrazine [6-chloro-N-ethyl-N -(1-methylethyl)-1,3,5-triazine-2,4-diamine] or simazine (6-chloro-N,N -diethyl-1,3,5-triazine-2,4-diamine). The lack of a label for an effective herbicide is a major obstacle to successful introduction of narrow-leafed lupin into the inland PNW. Yet its introduction as a replacement of fallow would have expected environmental benefits in terms of increased organic matter input, improved air quality, and reduced runoff.

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