Technical Bulletins

Maine Agricultural and Forest Experiment Station

12-1-1997

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ISSN 1070–1524

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Technical Bulletin 167

December 1997

MAINE AGRICULTURAL AND FOREST EXPERIMENT STATION
University of Maine

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ACKNOWLEDGMENTS

This study was supported by funds from United States Department of Agriculture (USDA) award no. 91–3414-5904 to the University of Maine Potato Cropping Systems Project; USDA award no. 43-8417–3-256 (vetch germplasm evaluation); USDA Hatch Project ME08818 (evaluation of legume cover crops); the Jessie Smith Noyes Foundation (student support in Sustainable Agriculture); and the University of Maine Association of Graduate Students (graduate student research). J.-L. Jannink was supported by a National Science Foundation Graduate Research Fellowship during part of the study. Warm thanks are expressed to J. Abbott, M. Brown, R. Cook, G. Dickey, F. Drummond, L. Ferris, E. Gallandt, W. Halteman, T. Molloy, G. Porter, J. Sisson, and J. Umphrey for their assistance.

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ABSTRACT

Research Question

A survey of green manuring practices in New England and New York identified the need for a leguminous species that could be established late in the season after an early vegetable or field crop harvest. Hairy vetch (*Vicia villosa* Roth) has shown promise in filling this niche in states south of Maine. One experiment presented here sought to evaluate management practices for hairy vetch in Maine: appropriate planting date, use of companion crop, and growth on two soils differing in drainage. Two additional experiments sought to determine whether variability for winter hardiness exists among germplasm available commercially or from gene banks.

Literature Summary

Hairy vetch is a winter annual legume noted for its winter hardiness and productivity as a forage and winter annual green manure. Information relating to three aspects of managing hairy vetch as a winter annual legume in Maine is needed: planting date, intercropping with a cereal, and growth on different soils. The ability to plant vetch late (i.e., after 1 September in Maine) would facilitate its incorporation into cropping systems. Intercropped cereal/legume green manures have shown improved winter survival of the legume, greater total biomass production, greater weed suppression, and allowed reduced nitrate leaching relative to a sole-cropped legume. Hairy vetch's performance on different soils has not been studied although naturalized, uncultivated vetch is primarily found on well drained soils. Information is also lacking on the extent of genetic variability in winter hardiness among hairy vetch available commercially or from gene banks. Historical records indicate that hairier types of hairy vetch may be more winter hardy.

Study Description

Experiment 1, planted in 1990 and 1991 in central Maine, evaluated effects of planting date (mid-August vs. early September), companion crop (none vs. rye [*Secale cereale* L.] vs. oat [*Avena sativa* L.]) and soil types (a well drained Nicholville very fine sandy loam [coarse-silty, mixed, frigid, Aquic Haplorthods] and a somewhat poorly drained Boothbay silt loam [fine-silty, mixed, frigid, Aquic Dystric Eutrochrepts]). Dry weights of crops and weeds and plant above-ground nitrogen content were measured in October

and May. Experiment 2, planted in 1992 and 1993, evaluated effects of location (Presque Isle vs. Stillwater, ME) and a rye companion crop on winter survival of hairy vetch from six commercial sources. Planting occurred in early August in Presque Isle and late August in Stillwater. Hairy vetch plants within subplots were counted in September. Surviving hairy vetch plants were counted and hairy vetch spring biomass measured the following May. Experiment 3, planted in 1993 in Presque Isle and Stillwater, ME, evaluated growth and winter survival of 65 accessions available from three gene banks. Plants in single-row plots were counted in September and again the following May. Stem lengths were measured in mid-October and mid-June.

Applied Questions

What management practices are appropriate for use of hairy vetch as a winter annual green manure in Maine?

Hairy vetch was most productive when planted mid-August on the well drained soil. The inclusion of a rye companion crop led to greater weed suppression and stability of green manure yield relative to sole-cropped hairy vetch.

Does variability in winter hardiness exist among hairy vetch germplasm available commercially or from gene banks?

Yes. Hairy vetch available commercially in the USA is of two types, hairy and smooth. The hairy type of hairy vetch was found to be more winter hardy than the smooth type. Variability in winter hardiness among and within accessions available from gene banks was also found. Nevertheless, hairy vetch commercially available in the USA compared favorably to the best gene bank accessions.

Recommendations

Results from this research indicate that hairy vetch presently available does not overwinter reliably in central or northern Maine. When it does overwinter, the hairy vetch dry weights observed indicate that, for the mid- to late May harvest date considered, nitrogen contribution of hairy vetch to a hairy vetch and rye intercrop would be low. The profitability of adding hairy vetch to a rye cover crop is therefore questionable.

Further study is needed to determine if continued hairy vetch growth in the spring would improve its economic viability. Optimal seeding rates of rye that would maximize its benefits as a companion crop yet minimize its negative impact on hairy vetch growth also need to be investigated. Finally, research to determine the feasibility of selecting hairy vetch genotypes of greater winter hardiness should be conducted.

INTRODUCTION

Concern about the production costs and environmental effects of synthetic fertilizer has led to increased interest in alternative ways of providing nitrogen fertility to farming systems, including the use of legumes grown as green manures (Reganold et al. 1990). Legumes can be used to occupy niches within a cropping system otherwise unused in time or space to simultaneously provide fertility, reduce soil erosion, improve soil physical properties (MacRae and Mehuys 1985; McVay et al. 1989; Smith et al. 1987) and reduce weed populations (Gliessman 1987; Teasdale and Daughtry 1993). To use legumes more effectively, information is needed on their adaptation to specific cropping system niches in different climatic regions (Knight 1987; Smith et al. 1987; Zachariassen and Power 1991).

A survey of green manuring practices in New England and New York identified the need for a leguminous species that could be established late in the season after an early vegetable or field crop harvest (Schonbeck 1988). Currently, common winter cover crops in the northeastern USA are rye (*Secale cereale* L.) and oat (*Avena sativa* L.) (Schonbeck 1988). Hairy vetch (*Vicia villosa* Roth) is a winter annual legume noted for its winter hardiness and northern range of adaptation (Aarssen et al. 1986; Duke 1981; Henson and Schoth 1955; Herman 1960). To evaluate the potential of hairy vetch to fill the proposed niche, appropriate management practices for its use and variability in its winter hardiness need to be determined.

Although hairy vetch has been studied in Maine as a spring-planted green manure (Jannink et al. 1996; Terman 1949), the only published information available on its use in the state as a winter annual green manure was from a single location in southern Maine (Schonbeck et al. 1993). In states south of Maine, hairy vetch has been planted at various dates, from late September in Maryland (Teasdale and Daughtry 1993) to late August in Massachusetts (Schonbeck et al. 1993) to mid-August in New York (Mohler and Teasdale 1993; Sarrantonio and Scott 1988). While the ability to plant hairy vetch late (i.e., after 1 September in Maine) would facilitate its incorporation into cropping systems, information is needed on whether this practice would reduce its productivity.

The multiple functions required of a green manure may be fulfilled most effectively by a legume intercropped with a cereal (Gliessman 1987). Potential benefits of intercropping hairy vetch with a cereal include improved winter survival of the legume (Smith 1981), reduction of nitrogen (N) loss due to nitrate leaching

(Shipley et al. 1992), increased total biomass production (Holderbaum et al. 1990; Schonbeck et al. 1993; Stivers and Shennan 1991; Sullivan et al. 1991), and weed suppression due to increased total crop density and diversity (Liebman and Dyck 1993). Thus, it is important to evaluate hairy vetch in both sole-crop and intercrop systems.

Little work has been done to characterize winter hardiness of different strains of hairy vetch. Five subspecies are recognized within *V. villosa* (Ball 1968); at least two subspecies (*V. villosa* subsp. *villosa* and *V. villosa* subsp. *varia* [Host] Corbiere) have been introduced from the Old World to North America where they occur as naturalized plants (Gunn 1970). These two subspecies are distinguished in part by relative degrees of hairiness on stems and leaves (Ball 1968). *Vicia villosa* subsp. *varia* ranges from glabrous to less hairy than *V. villosa* subsp. *villosa* and has in the past been referred to as smooth vetch (Allkin et al. 1986; Henson and Schoth 1955).

Historical records indicate that there may have been some regional differentiation in the type of hairy vetch produced in the United States (Henson and Schoth 1955). Herman (1960) states that 95% of the hairy vetch seed produced in Oregon was of a smooth type (*V. villosa* var. *glabrescens* Koch, synonymous with *V. villosa* subsp. *varia* [Allkin et al. 1986]). In contrast, Madison hairy vetch is a more hairy strain of hairy vetch (Henson and Schoth 1955) that was selected in Nebraska from seed brought by eastern European settlers at the turn of the century (J.F. Power, pers. comm.). Henson and Schoth (1955) report that the more hairy type of hairy vetch appears to be more winter hardy. In addition, Gunn (1970) indicates that smooth type hairy vetch is more prevalent in the southern United States and suggests this may be due to temperature adaptation. However, since there have been no recent seed certification programs for these hairy vetches, the parentage of commercially available hairy vetch is unknown.

The research presented here describes a set of three different experiments that sought to establish appropriate management practices for hairy vetch in Maine, and to determine whether variability for winter hardiness exists among germplasm available commercially or from gene banks. Specific objectives of the first experiment were to evaluate effects of planting date (mid-August vs. early September) and companion crop (none vs. rye vs. oat) on crop and weed dry weight and total above-ground N content in the fall and spring, at two sites differing in drainage (well vs. somewhat poorly drained). In a second experiment, the winter hardiness of hairy vetch from six commercial sources and the effect of a rye companion crop on hardiness were evaluated as indicated by percent winter survival and spring dry weight of hairy vetch. In a third experiment, 69 *V. villosa* accessions from three gene banks were evaluated for winter hardiness, vigor (as measured by stem length), flowering date, and seed production. Winter hardiness, growth potential, and flowering phenology are important descriptors for the selection of parental lines in the development of a winter hardy annual green manure (Owsley et al. 1989).

MATERIALS AND METHODS

Experiment 1: Winter Hardiness of Hairy Vetch in Response to Planting Date, Companion Crop, and Soil Type

Management and sampling

In 1990 and 1991, hairy vetch (unnamed cultivars of the smooth type; see Appendix) was seeded on two dates and two sites at the Maine Agricultural Experiment Station farm, Stillwater, ME. The planting dates were 14 August and 4 September 1990 and 14 August and 3 September 1991. The soil types of the sites were a well drained Nicholville very fine sandy loam (coarse-silty, mixed, frigid, Aquic Haplorthods) and a somewhat poorly drained Boothbay silt loam (fine-silty, mixed, frigid, Aquic Dystric Eutrochrepts). Soil fertility data are presented in Table 1 and were obtained as follows: pH in a 1:1 soil:water slurry; organic matter by loss on ignition; P

Table 1. Soil texture and fertility of the two fields used in Experiment 1.

	---------- Soil series ----------			
	Nicholville		Boothbay	
	---------- Year ----------			
Soil property	1990–91	1991–92	1990–91	1991–92
sand (%)	64	64	42	42
silt (%)	27	26	45	46
clay (%)	9	10	13	12
pH	6.3	6.4	6.2	6.0
CEC (me kg^{-1})	100	141	135	94
Organic matter (%)	7.0	7.0	6.5	6.0
P (mg kg^{-1})	4.3	7.5	6.5	6.5
K (mg kg^{-1})	103	148	56	36
Mg (mg kg^{-1})	134	140	291	207
Ca (mg kg^{-1})	1390	3080	1960	1530

using a Bray P1 extractant and inductively coupled plasma emission spectroscopy (ICPES); K using a pH 7.0 1N ammonium acetate extractant and ICPES.

Plots were 1.4 m $\times$ 9.1 m long, consisting of eight rows spaced 0.18 m apart. Hairy vetch was inoculated with *Rhizobium* and planted with a drill at 45 kg ha^{-1} either alone or with oat or rye planted within the same rows at 108 and 125 kg ha^{-1}, respectively. No weed control was performed. At each site, treatments were planted in a completely randomized design with four replications. In the 1991 planting, three plots were eliminated due to poor plant emergence related to previous field history.

Plots were sampled once in the fall (22–25 October 1990 and 21–23 October 1991) and once the following spring (22 May 1991 and 26 May 1992). All vegetation within two 0.125 m^2 quadrats was clipped and sorted to hairy vetch, companion crop (when present) and weeds. Vegetation was dried for several days at 70°C and weighed. Dried plant material was bulked by plot, ground with a Willey mill and analyzed for N content using a micro-Kjeldahl technique.

Data analysis

Analysis of variance (ANOVA) was performed using the General Linear Model routine of SYSTAT 5.2.1 (Wilkinson et al. 1992). Site, planting date, and companion crop were treated as fixed effects; year was treated as a random effect. When the interaction between year and a fixed effect was significant at α=0.05, the fixed effect was tested against that interaction, otherwise it was tested against the residual. Analyses using raw data (X) and $\log_e(X+1)$, $(X+0.5)^{½}$ transformations (Steel and Torrie 1980) were performed. The analysis presented was chosen according to its ability to homogenize variances, normalize the residual distribution and remove outliers.

Experiment 2: Winter Hardiness of Selected Hairy Vetch Cultivars in Northern and Central Maine

Management and sampling

In 1992 and 1993, hairy vetch from six commercial sources (unnamed cultivars; see Appendix) was planted at the Maine Agricultural Experiment Station farms in Stillwater and Presque Isle, ME. New seed was obtained each year from the same sources. Hairy vetch from each commercial source is designated an accession below. In Stillwater the soil types were a somewhat poorly drained Lamoine silt loam (fine, illitic, nonacid, frigid, Aeric

Epiaquepts) in 1992 and a somewhat poorly drained Boothbay silt loam (fine, silty, mixed, frigid, Aquic Dystric Eutrochrepts) in 1993. In Presque Isle, the soil type both years was a well drained Caribou gravelly loam (coarse, loamy, mixed, frigid, Typic Haplorthods). Soil pH was 6.4 in both years in Stillwater and 5.2 and 5.7 in 1992 and 1993, respectively, in Presque Isle. Soil in Presque Isle was limed with 2000 kg ha^{-1} $CaCO_3$ equivalent (ground to 50% through 100 mesh) prior to planting in 1992.

Planting dates were 26 August 1992 and 23 August 1993 in Stillwater and 7 August 1992 and 6 August 1993 in Presque Isle. Hairy vetch was inoculated as in Experiment 1. Plots were 1.4 m $\times$ 4.0 m in 1992 and 1.4 m $\times$ 5.2 m in 1993. In 1993 in Stillwater, plots were irrigated immediately after planting and again one week after planting because of dry soil conditions. In 1992, seeding rates were adjusted by accession according to seed weight and percent germination for a target density of 105 plants m^{-2} (the seeding rate ranged from 30 to 45 kg ha^{-1}). In 1993, all accessions were planted at 45 kg ha^{-1}.

Two accessions, one originating from Oregon (Accession 2) and one from Nebraska (Accession 5), were chosen to be planted both with and without 63 kg ha^{-1} of rye. The total of eight treatments (four accessions without rye plus two accessions with and without rye) were planted in a randomized complete block design at both sites.

On 19 September 1992 and 17 September 1993 in Stillwater, and 30 August 1992 and 1 September 1993 in Presque Isle, a 1.0 m^2 area containing the central four rows of each plot was marked off using flags and hairy vetch plants were counted in this area. In mid-May the following spring (14 May 1993 and 19 May 1994 in Stillwater, and 24 May 1993 and 30 May 1994 in Presque Isle), the number of surviving plants in this flagged area was counted and above-ground material of hairy vetch harvested. Percent survival was calculated as the ratio between the plant count in the fall to the count in the spring. Harvested hairy vetch biomass was dried and weighed.

Accessions were characterized for seed weight, hard-seededness and seedling hairiness. Seed weights were determined by weighing six random samples of fifty seeds from each accession each year. Percent hard seed was determined on replicated sets of 25 seeds (three and four replications in 1992 and 1993, respectively). Seeds were germinated on wet paper towels and those remaining unimbibed after ten days were considered hard (Donnelly 1971).

Seedling hairiness was evaluated in the summer of 1994. In early June, remnant seed from each accession and each year was planted in a completely randomized design in a tray in the greenhouse. Seedlings were watered regularly with tap water and given no supplemental lighting. Seedling hairiness was assessed six weeks after germination. The last fully expanded leaf on the longest stem of each seedling was removed and the number of visible hairs on the rachis between the first and second pair of leaflets was counted under a dissecting microscope.

Data analysis

Analysis of covariance (ANCOVA) was performed on percent winter survival and hairy vetch dry weight using the population density in the fall (plants · m^{-2}) as covariate to remove density dependent effects (e.g., density dependent mortality). In all cases, a test of homogeneity of slopes indicated no interaction between treatments and the covariate (Wilkinson et al. 1992:298). To normalize residuals, percent survival was arcsine($X^{½}$) transformed and hairy vetch dry weight was $\log_e(X+1)$ transformed. Year and site effects were tested against the mean square for blocks nested within year and site.

Two separate analyses were performed on the field data collected. The first analysis tested for differences in winter hardiness between hairy vetch accessions and included data from all sole-cropped hairy vetch plots. A factorial model with three way classification was used, with data from two years (random effect), two locations (fixed effect), and six accessions (fixed effect). The second analysis tested for main and interaction effects of rye companion crop. To avoid confounding effects due to the rye companion crop with differences among accessions, the second analysis included only data from plots containing those accessions planted with and without rye (Accessions 2 and 5). A factorial model with four way classification was used, a “with or without rye” effect (fixed) being added to effects described for the first analysis. Differences among accessions for the three seed or seedling traits that were assessed were analyzed by an ANOVA on, respectively, untransformed seed weights, arcsine($X^{½}$) transformed percent hard seed, and $X^{½}$ transformed hair counts.

Experiment 3: Evaluation of Hairy Vetch Germplasm for Winter Hardiness

Management and sampling

Sixty-five accessions originating from a total of 21 countries were planted. Fifty-seven accessions were obtained from the National Plant Germplasm System (NPGS) of the United States

Department of Agriculture—55 of which were from the Plant Introduction (PI) collection at the Western Regional Plant Introduction Station and two from the National Seed Storage Laboratory (NSSL)—and seven from the Polish National Department of Genetic Resources (PNDGR) , and one collected by J.-L. Jannink in Maine. Hairy vetch accessions from four commercial sources—three in the United States and one in Germany—were included to compare hardiness of commercially available germplasm to that of gene bank germplasm. The germplasm trial was planted at the same two locations as Experiment 2, Stillwater and Presque Isle, ME. Accessions were inoculated with *Rhizobium* and planted on 5 August 1993 in Presque Isle on a well drained Caribou gravelly loam (coarse, loamy, mixed, frigid, Typic Haplorthods) and a duplicate planting was made on 23 August 1993 in Stillwater, ME, on a somewhat poorly drained Boothbay silt loam (fine, silty, mixed, frigid, Aquic Dystric Eutrochrepts). Plantings were single 3 m rows spaced 0.81 m apart. Two seeds were planted every 0.15 m. Rows of accessions with sufficient seed were replicated twice. Plots were irrigated once after planting and again a week later. Populations in each row were counted and thinned to a maximum of 20 plants per row. Because of low germination in some accessions, mean number of plants per row by accession ranged from 6 to 20 across all replicated accessions.

The number of plants successfully established after thinning was counted and the longest stems were measured on each of five randomly chosen plants per replication on 2 October 1993 in Presque Isle and 18 October 1993 in Stillwater. Plants surviving to 19 May 1994 in Presque Isle and 22 May 1994 in Stillwater were counted within each row and percent winter survival calculated. In Presque Isle only five individual plants out of the whole trial survived the winter, so data collection was discontinued after the May sampling date. At the Stillwater location, the lengths of the longest stems on each of five randomly picked plants per replication were measured on 10 June 1994. Date of flowering onset (10% of plants in a row bearing open flowers) and full flowering (90% of plants in a row bearing open flowers) were recorded. Flowering date is the mean of these two dates given in days after 1 June 1994. On 1 August 1994 in Stillwater, all plants from each row were threshed, the bulked seed weighed, and seed production per plant calculated. Seed weights were measured on seed received from the original sources by weighing 100 seed of each accession.

Data analysis

Due to the virtual lack of winter survival of the germplasm in Presque Isle, data reported here is from the Stillwater location only. Information from the original seed sources was used to classify accessions according to subspecies and geographic origin. These classifications were used to perform two ANOVA on each variable described above. In the first ANOVA, accessions were considered random effects nested within subspecies and the accession-within-subspecies effect was used as the error term to test the subspecies effect. In the second ANOVA, accessions were considered random effects within geographic origin and the accession-within-origin effect used as the error term to test the origin effect. Percent winter survival was arcsine($X^{½}$) transformed prior to analysis (Steel and Torrie 1980); other variables were not transformed. Nine accessions were classified as *V. villosa* subsp. *villosa* by the NPGS but displayed sharply serrate stipules and mucronate leaflets and therefore did not conform to morphological descriptions of the taxon (Herman 1960). These accessions were not included in the analyses.

RESULTS & DISCUSSION

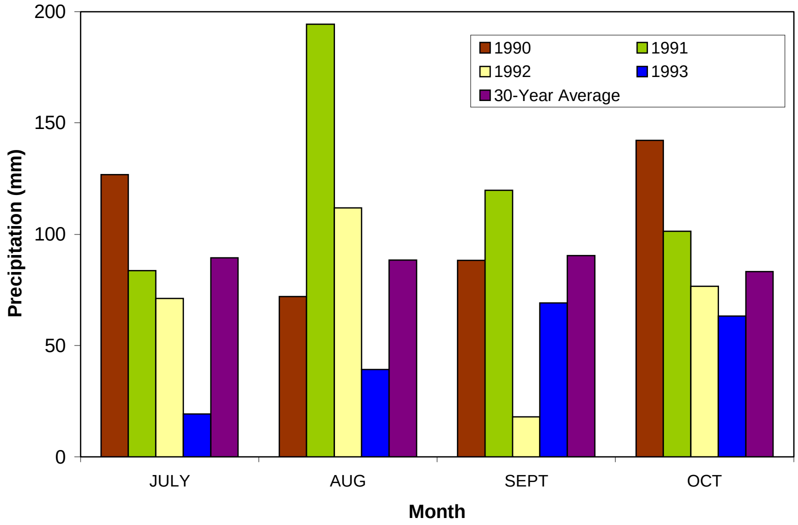
Weather Conditions

In 1993 in Stillwater soil moisture was judged inadequate for hairy vetch establishment as a result of low rainfall in July and August of that year (Figure 1a). In the absence of irrigation, such dry periods prior to appropriate planting dates may restrict the use of hairy vetch as a winter annual.

Experiment 1

Fall growth

Several higher order interactions between management treatments and year affected hairy vetch dry weight production in the fall (Table 2). The biological and practical importance of these interactions is unclear. In contrast, important main effects of treatments were also observed. Hairy vetch dry weight was greater on the well-drained soil (Nicholville) than the poorly drained one (Boothbay). Hairy vetch is sensitive to soil drainage (Aarssen et al. 1986) and this sensitivity may have caused the difference in its growth between sites. Other factors possibly confounded with the difference in drainage between sites were soil fertility (Table 1) and



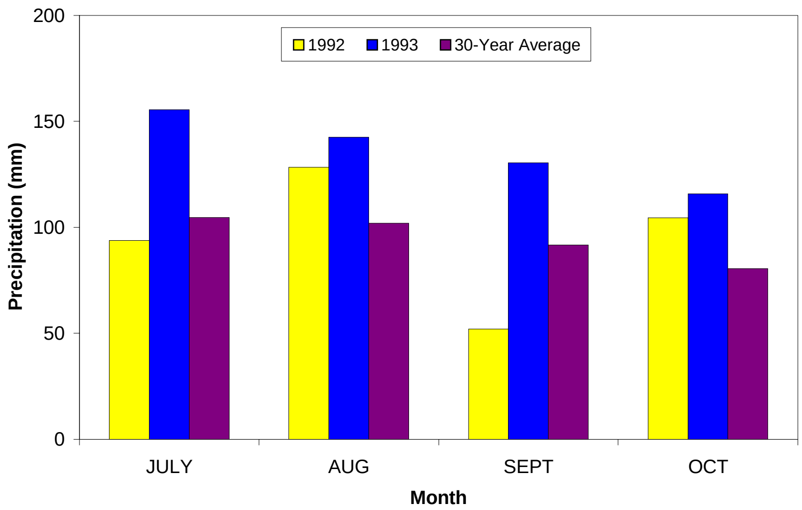


Figure 1. Monthly precipitation at the Stillwater (a) and Presque Isle (b) study sites before and during the establishment periods of the experiments. Due to equipment failure, precipitation for Stillwater in August and September 1991 are as reported for Orono, approx. 5 km from the study site.

microclimate. It is therefore impossible to attribute a site effect on any response variable to a precise cause.

Planting in mid-August versus early September allowed much greater fall growth of hairy vetch (Table 2). Both companion crops severely reduced fall hairy vetch growth, and oat significantly more than rye (Table 2). Oat produced more fall dry weight than rye, though the difference between companion crops was greater on the Nicholville than the Boothbay site, leading to a site by companion crop interaction (Table 2). A site by year interaction also affected companion crop growth: companion crops produced more growth on the somewhat poorly drained than the well drained soil in 1990 when August and September precipitation were below their 30-year average; the reverse was true in 1991 when August and September precipitation were above average (Figure 1).

Weed dry weight in the fall was affected by companion crop and by interactions between companion crop and other management treatments (Table 2). The oat and hairy vetch mixture suppressed weeds more than either rye plus hairy vetch or hairy vetch alone. Site by companion crop and planting date by companion crop interactions show that the benefit of planting oat to suppress weeds increased in environments with greater weed pressure: the difference in weed growth between the oat plus hairy vetch treatment and other treatments was greater on the Boothbay than the Nicholville site and for the mid-August than the early September planting (Table 2). The cause of interactions between site and planting date and year are not clear. The fields used in 1990 and 1991 for the Nicholville site were not adjacent and had different histories. Difference in seed bank or in germination conditions between these sites may have resulted in the interactions observed.

Above-ground N accumulated was lower in cover crops planted in early September than mid-August (Table 2). The effect of planting date, however, was not equal among all companion crop treatments, leading to interactions. Sole-cropped hairy vetch suffered a much greater decrease in above-ground N than either mixture when planted at the later relative to the earlier date. The difference between mixtures and sole-cropped hairy vetch was greater in 1990 than in 1991, leading to a year by planting date by companion crop interaction. The interaction between planting date and companion crop may result from the higher overall planting rates of the mixtures than of sole-cropped hairy vetch: this higher planting rate allowed greater growth to the mixtures during the short period before winter after an early September planting. The difference in above-ground N between mid-August and early Sep-

Table 2. Effects of year, planting date, companion crop, and site (Nicholville [Nichol.] vs. Boothbay [Booth.]) on hairy vetch, companion crop, and weed dry weight (DW), and above-ground nitrogen (N) in October.

			Vetch DW		Comp. Crop DW		Weed DW		Above-ground N	
			Soil Series of Site							
Year	Plant Date	Companion Crop	Nichol.	Booth.	Nichol.	Booth.	Nichol.	Booth.	Nichol.	Booth.
			kg · ha^{-1}							
1990	14 Aug.	None	1790	1100	—	—	371	450	92	69
1990	14 Aug.	Oat	580	190	3130	3150	85	13	88	69
1990	14 Aug.	Rye	880	530	1520	1790	246	38	95	82
1990	4 Sept.	None	150	310	—	—	169	171	12	19
1990	4 Sept.	Oat	110	110	1180	1070	63	29	57	46
1990	4 Sept.	Rye	240	180	230	600	154	41	23	33
1991	14 Aug.	None	1870	830	—	—	94	401	101	57
1991	14 Aug.	Oat	90	360	4360	2720	9	23	127	62
1991	14 Aug.	Rye	1290	480	1230	640	75	294	111	52
1991	3 Sept.	None	160	90	—	—	4	13	7	6
1991	3 Sept.	Oat	150	60	1010	590	9	2	46	21
1991	3 Sept.	Rye	130	90	910	710	6	5	45	29

Table 2. Continued.

ANOVA Effects	Transform†:	$\log_e(X+1)$	$(X+0.5)^{½}$	$\log_e(X+1)$	$(X+0.5)^{½}$
Year (Y)		**	NS	***	NS
Site (S)		**	NS	NS	NS
Planting Date (D)		***	NS	NS	***
Companion Crop (C)		***	***	***	***
S*D		NS	NS	NS	***
S*C		NS	*	**	NS
D*C		NS	NS	***	NS
S*D*C		NS	NS	NS	NS
Y*S		NS	***	***	***
Y*D		NS	*	***	NS
Y*C		NS	NS	NS	NS
Y*S*D		**	NS	**	NS
Y*S*C		*	NS	NS	NS
Y*D*C		NS	***	NS	**
Y*S*D*C		**	NS	NS	NS
CV (%)		14.8	11.2	34.8	13.5

†. Analyses were performed using these data transformations; back-transformed means are shown in the table.
NS, *, **, *** indicate not significant, and significant with $P < 0.05$, 0.01, and 0.001, respectively.

tember-planted green manures was less on the Boothbay than the Nicholville site, leading to a site by planting date interaction (Table 2), the cause of which is unclear. Finally, above-ground N was affected by a year by site interaction parallel to that observed on companion crop growth: above-ground N was equal across both sites in 1990, but was less on the Boothbay than the Nicholville site in 1991, a year of above average August and September precipitation (Figure 1).

Spring growth

Although the mid-August planting date increased hairy vetch fall growth relative to the early September planting date, it did not consistently allow hairy vetch to survive the winter (Table 3). In 1991–92, hairy vetch winter-kill was practically complete: average temperatures of the coldest winter weeks were lower than in 1990–91 and occurred during periods of little snow cover (Table 4). These conditions appear to have been fatal to hairy vetch. Because of hairy vetch winter-kill in 1991–92, only data from May 1991 hairy vetch dry weight have been analyzed (Table 3). As expected, oat winter-killed in both years of the experiment, while rye survived.

Hairy vetch dry weight was affected by a three-way site by planting date by companion crop interaction (Table 3). Because this result was obtained in only one year, its robustness is unclear and it will not be discussed. The highly significant site and companion crop main effects are worth noting. Hairy vetch winter survival was greatly affected by site. Hairy vetch dry weight in May 1991 was 510 kg ha^{-1} on the well drained soil vs. 30 kg ha^{-1} on the somewhat poorly drained soil (means averaged across companion crop and planting date treatments). Both oat and rye decreased hairy vetch spring regrowth, oat significantly more so than rye (Table 3). In contrast to sole-cropped hairy vetch, hairy vetch planted with rye or oat produced more in the spring when planted in early September than mid-August, leading to a companion crop by planting date interaction (Table 3). A possible interpretation is that later planting reduced interference from the companion crop on hairy vetch, even though the beneficial effect of companion crop on hairy vetch winter survival was maintained (Smith 1981).

Evaluating the relative weed suppression of hairy vetch and companion crops is difficult because of high order interactions affecting May weed dry weight (i.e., significant Y*D*C and Y*S*D interactions; Table 3). However, the main effect of companion crop observed may be explained in part by the fact that hairy vetch alone consistently suppressed weeds the least (Table 3). High order

Table 3. Effects of year, planting date, companion crop, and site (Nicholville [Nichol.] vs. Boothbay [Booth.]) on hairy vetch, rye, and weed dry weight (DW), and above-ground nitrogen (N) in May.

			Vetch DW†		Rye DW		Weed DW		Above-ground N	
	Plant	Companion	Soil Series of Site							
Year	Date	Crop	Nichol.	Booth.	Nichol.	Booth.	Nichol.	Booth.	Nichol.	Booth.
			$kg \cdot ha^{-1}$							
1990	14 Aug.	None	1550	82	—	—	160	110	73	48
1990	14 Aug.	Oat	4	0	—	—	8	8	1	3
1990	14 Aug.	Rye	240	2	3730	1760	7	11	78	35
1990	4 Sept.	None	450	78	—	—	930	38	42	27
1990	4 Sept.	Oat	130	0	—	—	460	22	25	12
1990	4 Sept.	Rye	660	6	3470	1520	230	22	92	29
1991	14 Aug.	None	0	0	—	—	81	92	4	28
1991	14 Aug.	Oat	0	0	—	—	11	42	1	13
1991	14 Aug.	Rye	0	0	2730	770	15	66	56	34
1991	3 Sept.	None	0	0	—	—	14	40	1	16
1991	3 Sept.	Oat	0	0	—	—	34	17	3	7
1991	3 Sept.	Rye	0	0	4110	2330	0	2	59	39

Table 3. Continued.

ANOVA Effects	Transform†:	$\log_e(X+1)$	$(X+0.5)^{½}$	$\log_e(X+1)$	$(X+0.5)^{½}$
Year (Y)		—††	NS	***	***
Site (S)		***	***	NS	NS
Planting Date (D)		NS	NS	NS	NS
Companion Crop (C)		***	—	***	NS
S*D		NS	NS	NS	*
S*C		**	—	NS	NS
D*C		*	—	NS	NS
*D*C		*	—	NS	NS
Y*S		—	NS	***	***
Y*D		—	***	***	NS
Y*C		—	—	NS	***
Y*S*D		—	NS	*	NS
Y*S*C		—	—	NS	*
Y*D*C		—	—	*	**
Y*S*D*C		—	—	NS	NS
CV (%)		41.9	16.2	28.9	16.8

† Analyses were performed using these data transformations; back-transformed means are shown in the table.
†† Because vetch planted in 1991 winter-killed, ANOVA results are shown for data from the 1990 planting only.
NS, *, **, *** indicate not significant, and significant with $P < 0.05$, 0.01, and 0.001, respectively.

Table 4. Average temperatures and snow cover during the coldest weeks in each winter month at the Experiment 1 location.†

	Month			
Year	December	January	February	March
1990–91				
Week centered on:	29 Dec.	24 Jan.	14 Feb.	7 Mar.
Temperature (°C)	-5.3	-13.5	-8.1	-1.5
Snow Cover (mm)	10	100	150	10
1991–92				
Week centered on:	19 Dec.	19 Jan.	9 Feb.	16 Mar.
Temperature (°C)	-9.6	-15.7	-10.6	-7.3
Snow Cover (mm)	0	10	280	0

†. Snow cover as reported by the Bangor International Airport, approx. 16 km from the experimental site.

interactions also affected May above-ground N content (i.e., significant Y*S*C and Y*D*C interactions; Table 3). An important factor entering into these interactions was the difference between years in hairy vetch winter survival as shown by the absence of hairy vetch from all treatments in May 1992. The hairy vetch winterkill in the second year of the experiment led to a year by companion crop interaction affecting May above-ground N. Whereas sole-cropped hairy vetch accumulated N equal to that of the hairy vetch-rye mixture in 1991, this was not the case in 1992 (Table 3). The hairy vetch-rye mixture consistently accumulated the most above-ground N, irrespective of year, site, or planting date, presumably because of the strong spring growth of rye (Table 3).

Experiment 2

Both parameters examined to evaluate winter hardiness (percent survival and spring dry weight) behaved similarly (Table 5). The more severe winter conditions at Presque Isle compared to Stillwater reduced both percent survival and spring dry weight (Table 5). The lower spring dry weight observed in 1993 relative to 1994 was not due to fewer growing degree days (GDD) accumulated prior to sampling in 1993: calculated using a 10°C base, 104 vs. 27 GDD were accumulated in Stillwater, and 45 vs. 39 were accumulated in Presque Isle, in 1993 vs. 1994, respectively. Data on percent survival and spring dry weight suggest the winter of 1992–93 was more severe.

Table 5. Effects of year, location, and accession on sole-cropped hairy vetch survival and spring dry weight.†

Accession††	----- Percent Survival ---		----- Spring Dry Weight -----	
	Stillwater	Presque Isle	Stillwater	Presque Isle
	---------- % ----------		--------- $kg \cdot ha^{-1}$ -------	
1	46	2	117	6
2	51	6	197	11
3	51	6	224	10
4	32	8	68	16
5	73	32	580	78
6	72	44	495	104
ANCOVA Effects				
Transform:	arcsine($X^{½}$)		$log_e(X+1)$	
Year	**		**	
Location	**		**	
Accession	***		***	
Covariate	NS		NS	
CV%	38%		47%	

†Analysis of covariance was performed using hairy vetch density the previous fall (plants · m^{-2}) as covariate. Back-transformed adjusted means are shown, averaged across years.
††Sources for germplasm are listed in the appendix.
No interactions were significant.
NS, **, *** indicate not significant, and significant with P < 0.01, and 0.001, respectively.

There were significant effects of both accession and rye companion crop on percent survival and spring dry weight (Tables 5 and 6). In the first analysis (examining differences in winter hardiness among six accessions planted alone) higher percent survival and spring dry weight were observed in two accessions relative to the four others (Table 5). Mature plants of these two hardier accessions were hairier and bore larger stipules than the other four accessions (pers. obs.). The difference in hairiness observed among mature plants was confirmed by an examination of seedling hairiness (Table 7) and suggests that Accessions 1 to 4 belong to *V. villosa* subsp. *varia* while Accessions 5 and 6 belong to *V. villosa* subsp. *villosa* (Ball 1968). The link between hairiness and winter hardiness observed in this study is also consistent with previous reports (Gunn 1970; Henson and Schoth 1955). Differences among accessions, however, were not consistent with accession location of origin (Table 7).

Differences among accessions for percent hard seed only roughly followed differences in seed weight and hairiness (Table 7). In addition, a significant year × accession interaction was found on

Table 6. Effects of year, location, accession, and rye companion crop on hairy vetch survival and spring dry weight.†

Accession††	Comp. Crop	---- Percent Survival --- Stillwater	Presque Isle	--- Spring Dry Weight --- Stillwater	Presque Isle
		------------- % ------------		---------- kg · ha^{-1} ----------	
2	None	60	4	254	8
2	Rye	72	3	311	4
5	None	76	28	630	67
5	Rye	88	45	524	113
ANCOVA Effects					
	Transform:	arcsine($X^{1/2}$)		$\log_e(X+1)$	
Year (Y)		**		**	
Location (L)		**		**	
Accession (A)		***		***	
Rye (R)		*		NS	
L x A		**		*	
Covariate		+		NS	
CV%		24%		33%	

†Analysis of covariance was performed using hairy vetch density the previous fall (plants · m^{-2}) as covariate. Back-transformed adjusted means are shown, averaged across years.
†† Sources for germplasm are listed in the appendix.
Interactions not shown were not significant.
NS, +, *, **, *** indicate not significant, and significant with P < 0.1, 0.05, 0.01, and 0.001, respectively.

percent hard seed (data not shown). This interaction may indicate maternal effects on percent hard seed that vary from year to year. It also raises the possibility that seed companies obtain their seed from different sources each year. While we were not able to eliminate this possibility through inquiry with the seed companies, consistency in other characteristics measured indicates at least consistency of accession subspecies.

In the second analysis (examining the effect of rye on hairy vetch winter survival) rye was found to increase hairy vetch percent survival but did not affect hairy vetch spring dry weight. The rye's fibrous roots may reduce soil heaving and thereby reduce damage to the hairy vetch crown (Smith 1981). In the second analysis there was also a trend ($P < 0.10$) for the population density covariate to affect percent survival (Table 6). Estimates of the regression coefficients of these parameters on the covariate show that for each increase in population density of one plant m^{-2}, percent survival decreased on average by 0.4%. These effects may be the result of density dependent mortality and intraspecific competi-

Table 7. Origin, seed weight, percent hard seed (%HS), and hair count of selected commercially available cultivars of hairy vetch.†

Accession††	Origin	Seed Weight		%HS		Hair Count	
		g / 100 seed		%		no.	
1	Oregon, USA	2.44	a	9	c	42	a
2	Oregon, USA	2.41	a	2	b	46	a
3	Nebraska, USA	2.30	a	0	a	34	a
4	Oregon, USA	2.26	a	1	b	34	a
5	Nebraska, USA	3.37	b	14	cd	73	b
6	Nebraska, USA	3.46	b	18	d	79	b

† Means in the same column followed by the same letter are not significantly different (Tukey's HSD, P=0.05). Values are averages over two years.
†† Sources for germplasm are listed in the appendix.

tion. Finally, a location × accession interaction affected both percent survival and spring dry weight: while Accession 2 was inferior to Accession 5 at both locations, the difference was less in Stillwater than in Presque Isle (Table 6).

Experiment 3

Under conditions of the trial essentially none of the included accessions—which originated from a wide geographic distribution (Table 9)—were able to survive the winter at the Presque Isle location. At the Stillwater location, consistent with results found in Experiment 2, accessions of *V. villosa* obtained from gene banks showed that subsp. *varia* was generally less winter hardy than subsp. *villosa* (Table 8). However, wide variability exists within each subspecies, as shown by the two accessions of subsp. *varia* that were among the ten most winter hardy accessions evaluated (Table 10). These results come with the caveat that subspecific classifications used in the analysis were those given by the gene banks and there may have been misclassification of the accessions (Jannink and Merrick 1994).

The results of this trial, which included a broad spectrum of *V. villosa* accessions, do not indicate possible geographic sources of winter hardy germplasm (Table 9). Wide variability exists within regions of geographic origin for winter hardiness and the ten most winter hardy accessions span four of the five geographical regions distinguished in this study (Table 10). Significant differences existed among geographic regions for seed weight (Table 9). Because seed weights were measured on the original seeds received

Table 8. Mean across subspecies of traits measured on hairy vetch accessions. †

Subspecies	No. of Accessions	Winter Survival	Stem Length on 10/18/93	Stem Length on 6/10/94	Flowering Date	Seed Production	Seed Weight
		%	m	m	Days After 6/1/94	g / plant	g/100 seed
V. villosa ssp. *varia*	10	14.4	0.16	0.41	20	26	3.6
V. villosa ssp. *villosa*	50	29.2	0.16	0.35	24	38	3.6
Significance of Group Difference		+	NS	NS	NS	NS	NS

† Back-transformed means are shown for percent winter survival. Data is presented for the Stillwater location only, due to winter-kill of vetch at the Presque location.

NS, + indicate not significant, and significant with $P < 0.1$, respectively.

Table 9. Mean across geographic region of origin of traits measured on hairy vetch accessions. †

Geographic Region	Countries Included	No. of Accessions	Winter Survival	Stem Length on 10/18/93	Stem Length on 6/10/94	Flowering Date	Seed Production	Seed Weight
			%	m	m	Days After 6/1/94	g/plant	g/100 seed
North America	Canada, Mexico, USA	8	32.1	0.15	0.34	25	24	3.0
North Europe	Belgium, Czechoslovakia, France, Germany, Hungary, Netherlands, Poland	24	37.7	0.17	0.37	24	32	4.4
Mediterranean	Cyprus, Greece, Israel, Italy, Portugal, Spain, Turkey, Former Yugoslavia	17	20.3	0.15	0.35	21	33	3.5
Former USSR	Former USSR	13	24.1	0.16	0.35	24	63	2.7
South Asia	Afghanistan, Iran	7	16.9	0.17	0.39	24	42	3.7
Significance of Group Difference			NS	NS	NS	NS	+	*

†Back-transformed means are shown for percent winter survival. Data is presented for the Stillwater location only, due to winter-kill of vetch at the Presque location.
NS, +, * indicate not significant, and significant with $P < 0.1$, and 0.05 respectively.

Table 10. Traits of hairy vetch accessions with the highest winter survival rate. †

Accession	Subspecies	Origin	Source ††	Winter Survival	Stem Length on 10/18/93	Stem Length on 6/10/94	Flowering Date	Seed Production	Seed Weight
				%	m	m	Days After 6/1/94	g/plant	g/100 seed
NSL 6822 †††	*villosa*	USA	NSSL	74	0.18	0.36	24	59	3.5
varia 5 iz.	*varia*	Poland	PNDGR	70	0.17	0.43	28	16	4.5
PI 284102	*villosa*	Portugal	WRPIS	67	0.16	0.43	21	38	3.0
Hairy Vetch	*villosa*	USA	Reikofski	65	0.18	0.36	24	13	3.6
form A3 7 iz.	*villosa*	Poland	PNDGR	64	0.16	0.44	25	38	4.1
form B1 8 iz.	*villosa*	Poland	PNDGR	64	0.21	0.52	25	22	5.6
PI 234053	*villosa*	Spain	WRPIS	61	0.15	0.47	19	18	2.8
PI 201882	*villosa*	Iran	WRPIS	51	0.15	0.46	24	56	3.6
PI 222177	*varia*	France	WRPIS	43	0.13	0.42	19	26	2.8
PI 206492	*villosa*	Turkey	WRPIS	42	0.17	0.34	22	19	3.6

† For complete information on all accessions evaluated, see Jannink and Merrick (1994). Data is presented for the Stillwater location only, due to winter-kill of vetch at the Presque Isle location.
†† See Appendix for full addresses of sources.
††† NSL 6822 = Madison vetch.

from gene banks these differences may have environmental rather than genetic causes. In particular, all accessions from the PNDGR had high seed weight, biasing the mean seed weight for North Europe accessions upward.

Evaluations performed in Experiment 3 showed that hairy vetch commercially available in the United States (e.g., the cultivar from Reikofski Grain Co. or NSL 6822, which is Madison hairy vetch) is equally winter hardy to the best accessions in the trial derived from gene banks, which are typically unimproved cultivars or, in some cases, wild material (Table 10). Nevertheless, large variability for vigor was observed within accessions (J.-L. Jannink, pers. obs.) and it may be possible to select for genotypes superior in winter hardiness and spring regrowth within germplasm currently available.

CONCLUSIONS

Results from Experiment 2 indicate that hairy vetch commercially available in the USA is of two types, hairy and less hairy (or smooth). While we did not perform detailed observations of flower morphology to ascertain subspecific classification, we surmise that hairy vetch of the hairy type belongs to *V. villosa* subsp. *villosa* while hairy vetch of the smooth type belongs to *V. villosa* subsp. *varia.* The experiment confirmed previous observations that the hairy type of hairy vetch is typically more winter hardy than the smooth type.

Results from all three experiments indicate that hairy vetch does not reliably overwinter in central or northern Maine. Winterkill was nearly complete in Presque Isle for virtually all of the broad range of genotypes in Experiment 3, which included both hairy and smooth types—although two of those genotypes (Accessions 2 and 5 of Experiment 2) were grown concurrently in an adjacent field (Experiment 2 plots) where they survived the winter to either a limited or substantial extent (Tables 5 and 6). Differences in microsite (e.g., snow cover or soil moisture or texture) or plant array (e.g., density or single vs. multiple row plots) may also partially explain observed differences in winter survival that cannot be attributed to differences in genotype. Hairy vetch used in Experiment 1 was of the smooth type, which might explain poor survival under certain winter conditions (Tables 3 and 4). Even with a hairy genotype, however, the low hairy vetch dry weights observed in Experiment 2 (Tables 5 and 6) indicate that, for the mid- to late May harvest dates considered, nitrogen contribution of hairy vetch to a hairy vetch and rye cover crop would be low, particularly in northern Maine. The profitability of adding hairy vetch to a rye cover is therefore questionable. Further study is needed to determine if continued hairy vetch growth in the spring would improve its economic viability as a winter green manure in cases where spring planting of a subsequent crop occurs later, e.g., if hairy vetch were to be followed by sweet corn, dry or snap beans, or fall brassicas (Schonbeck et al. 1993).

Improvement of hairy vetch as a winter annual green manure will entail increasing its winter hardiness as well as reducing its percent hard seed. From Experiment 2 it appears that in Maine some natural selection for winter hardiness may occur as percent survival was considerably less than 100%. However, selection for winter hardiness is notoriously difficult (Fowler and Gusta 1979; McKenzie and McLean 1984). Evaluation of hairy vetch from a broader range of *V. villosa* subsp. *villosa* may prove to be a more expedient way to obtain winter hardy hairy vetch. Evidence from Experiment 3 suggests that variability both among and within accessions available from gene banks is considerable. Nevertheless, hairy vetch commercially available in the United States compared favorably to the best gene bank accessions included in the study (Table 10).

With respect to hairy vetch management, it appears that early planting (Schonbeck et al. 1993) and well drained soils are necessary for adequate production (Tables 1 and 2). The inclusion of a rye companion crop led to greater weed suppression and stability of cover crop yield relative to sole-cropped hairy vetch. This was not the case for oat as the vigorous oat growth in the fall smothered the hairy vetch leading to reduced cover crop N content (Table 2). Hairy vetch spring growth was less suppressed by the rye companion crop in Experiment 2 than in Experiment 1 (Tables 3 and 5). This may have resulted from the reduced seeding rate of rye in Experiment 2 relative to Experiment 1. More information is needed on appropriate seeding rates for rye that would maximize its benefits yet minimize its negative effect on hairy vetch.

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APPENDIX

Addresses of all sources of germplasm used in Experiment 1

1990 source:

Ernst Crown Vetch
R.D. 5
Meadville, PA 16335

1991 source:

Peaceful Valley Farm Supply
P.O. Box 2209
Grass Valley, CA 95945

Addresses of all sources of germplasm used in Experiment 2

Commercial sources by accession number:

1. Agway Inc.
   Seed Division
   P.O. Box 4741
   Syracuse, NY 13221
2. Andrews Seed Co.
   580 S. Oregon St.
   Ontario, OR 97914
3. Mangelsdorf Seed Co.
   1415 N. 13th St.
   St. Louis, MO 63106
4. Peaceful Valley Farm Supply
   P.O. Box 2209
   Grass Valley, CA 95945
5. Reikofski Grain Co.
   Foster, NE 68737
6. Sexauer Co.
   P.O. Box 58
   Brookings, SD 57006

Addresses of all sources of germplasm used in Experiment 3

Gene bank sources:

National Plant Germplasm System (NPGS):
Western Regional Plant Introduction Station (WRPIS)
USDA-ARS
Washington State University
Johnson Hall, Rm. 59
Pullman, WA 99164

National Seed Storage Laboratory (NSSL)
USDA-ARS
Colorado State University
Fort Collins, CO 80523

Polish National Department of Genetic Resources (PNDGR):
Dr. Waleria Mlyniec
Polish Academy of Science
Institute of Plant Genetics
ul Nowy Swait 72
00-330 Warsaw, Poland.

Commercial Sources:

Andrews Seed Co.
580 S. Oregon St.
Ontario, OR 97914

L.L. Olds Seed Co.
2901 Packers Ave.
Madison, WI 53707

Reikofski Grain Co.
Foster, NE 68737

Baumann Deutsche Saatveredelung
Lippstadt-Bremen GmbH
Weissenburger Str. 5
59557 Lippstadt, Germany