Ley Farming: A Systems Approach To Integrating Crop and Livestock Enterprises

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Research Summary
Integrating crop and livestock enterprises may enhance the economic and environmental sustainability of agricultural production in the Great Plains. The development of ley farming, where wheat (*Triticum aestivum*) and legume pasture are rotated, created biological and economic synergies between crops and livestock enterprises in Australia. Preliminary research indicated that ley farming may be suited to the region encompassed by the Four-State Research Consortium (4-SRC). The objectives of this 2-yr project were to: (1) identify legume species best suited for grazing when placed in short rotations with grain and seed crops; (2) refine methods to ensure consistent success in establishing and grazing high-quality legume stands during the pasture phase; (3) document the impact of ley farming on wheat grain yield and quality as well as livestock performance; (4) determine the economic costs/benefits generated from ley farming compared with alternative crop and livestock systems used commonly in the region; and (5) develop a ley farming working group that includes a web-based interactive forum for crop and livestock producers, researchers, and others interested in ley farming in the region encompassed by the 4-SRC. Small-plot field experiments were conducted over a 2-yr period in Montana, North Dakota, South Dakota (1-yr only), and Wyoming. Large-plot field experiments with grazing by beef cattle (*Boa taurus*) in North Dakota complemented the small-plot experiments. Severe drought impacted field experiments in both years, complicating data analyses and interpretation. Fall-seeded hairy vetch (*Vicia villosa*) produced equal or greater amounts of forage compared with three other fall- and three spring-seeded legume species in eight of nine environments ($P < 0.05$). However, this annual legume species is a poor reseeder. Birdsfoot trefoil (*Lotus corniculatus*) and rigid medic (*Medicago rigidula)* reportedly will reseed naturally, but neither species demonstrated this ability consistently in all environments. Moreover, both legume species failed to produce adequate amounts of forage to support grazing in all environments. Drilling legume seed directly into small-grain stubble failed to enhance forage stand establishment compared with broadcasting and lightly incorporating legume seed into a tilled seedbed consistently, and differences in forage yield between the two establishment methods were detected in only 1 of 16 possible comparisons. Cattle preferred grazing rigid medic to alfalfa (*Medicago sativa* L.), birdsfoot trefoil, and annual sweetclover (*Melilotus annua* L.) when the medic species was available, but neither rigid medic nor sweetclover stands persisted beyond the establishment year. Conversely, alfalfa and birdsfoot trefoil stands did persist and provided a second year of grazing. The two persisting legume species were rotated with spring wheat (*Triticum aestivum* emend. Thell. cv. Parshall) in a 3-yr pasture-pasture-wheat sequence and compared with a 2-yr wheat-pea (*Pisum sativum* L.) grain rotation. Grain yield was greater when wheat followed pea compared with the legume pasture species in one of three years. No differences in yield were detected in the two other years of this 3-yr study. Preliminary analyses suggest economic advantages by integrating wheat and grazed pasture by ley farming compared with a crop rotation where only grain is harvested (e.g., wheat-pea). A ley farming site has been created on the web along with a discussion forum (http://www.ag.ndsu.nodak.edu/dickinso/agronomy/leyfarming.htm).

Introduction
The area encompassed by the 4-SRC resides within the northern Great Plains, a vast region that includes about 8 million hectares of cultivated hay and pasture land (Entz et al., 2002). A large portion of the region also is devoted to dryland production of grain and seed crops. For example, wheat production totaled 6.6 million ha within Montana, North Dakota, and South Dakota during 2003 (E. Stabenow, personal communication, 2004). Although these data indicate that both crop and livestock enterprises are widespread across the region, Krall and Schumann (1996) estimated that less than 10% of agricultural land is dedicated to integrated crop-livestock systems. The lack of integrated crop and livestock enterprises prevents benefits in environmental

quality, economic diversity, and pest management from occurring that can result when enterprises are integrated (Krall and Schumann, 1996). For example, Entz et al. (1995) reported wheat yield enhancements and weed pressure reductions when forages were incorporated into rotations with wheat and other grain crops. Additional benefits and synergies between crop and livestock enterprises can occur when grazed pasture is rotated with wheat and other grain crops (Entz et al., 2002). A review by Martin (1996) suggested that grass weed invasion was reduced by rotating grazed legume pastures with wheat compared with cropping systems which did not include grazed pasture.

Production economics have improved in the region encompassed by the 4-SRC for crop and livestock enterprises recently, but returns for several crops remain low. For example, returns to labor and management in southwestern North Dakota are projected to be only $5/ha for hard red spring wheat (Swenson and Haugen, 2006).

Integrating crop and livestock systems have been developed as a response to the environmental degradation and poor economic returns that result from single enterprise systems (i.e., crops or livestock), although not in the region encompassed by the 4-SRC. In Australian ley farming, wheat is rotated with legume pastures that both profitably and ecologically integrate cereal crop and livestock enterprises to form the foundation for flexible and sustainable dryland agricultural systems (Cocks et al., 1980). The annual medics (*Medicago spp*.) used for pasture regenerate from the soil seed bank, and in the pasture phase of the cropping sequence provide forage for sheep and cattle. In the cereal phase of the cycle, regenerating medics may briefly furnish forage before seedbed preparation for planting wheat or barley (*Hordeum vulgare*). Annual medics were the principal legume component on more than 20 million ha in the wheat-sheep zone of southern Australia in the latter half of the 20th century, where they provided myriad benefits to Australian agriculture including more profitable cereal production (Boyce et al., 1991), high-quality livestock forage (Mann, 1991), integrated pest management with a better break to pest and disease life cycles and weed suppression by medic swards (Loomis and Conner, 1992), reduced fertilizer inputs and improved air and water quality (Grierson et al., 1991), soil conservation and improved soil quality (Cocks et al, 1980), and the potential global benefit of C-sequestration as related to the higher primary productivity of ley farming.

Past research identified legume species for use as dryland pasture in North Dakota and Wyoming. Birdsfoot trefoil was identified as a promising spring-seeded candidate for regenerative pasture in southwestern North Dakota (Carr et al., 2005a, b). Rigid medic was identified as a good candidate for winter annual regenerative pasture in southeastern Wyoming (Walsh et al., 2001). The adaptation of both species throughout the region encompassed by the 4-SRC is unknown because of the relatively limited geographic scope of previous research. Other legume species have recently been identified that also may be suited to ley farming and should be included in side-by-side comparisons with rigid medic if fall sown and birdsfoot trefoil if spring sown. Also, methods are needed in the region encompassed by the 4-SRC so legume pasture can be established consistently since the initial legume stand determines pasture productivity as well as subsequent success at pasture regeneration following a cereal crop phase.

Limited grazing of rigid medic by sheep in Wyoming and of birdsfoot trefoil by cattle in North Dakota suggests that both species can be grazed successfully in the region (P.M. Carr and J. Krall, unpublished data). More extensive grazing studies are needed to determine if rigid medic and birdsfoot trefoil are suitable as ley pasture species in the region. Economic analyses are needed to determine if economic returns are enhanced and risks are reduced by ley farming compared with single enterprise (i.e., crop or livestock) systems.

Materials and Methods

Legume species adaptation study (Objective 1).
Austrian winter pea, common hairy vetch, woolypod vetch (*V. villosa* ssp. *dasycarpa* cv. Namoi), rigid medic (cv. WY-SA-10343), birdsfoot trefoil [cv. Leo and Norcen], alfalfa [cv. Travois] and white annual sweetclover [cv. Hubam]) were included in field experiments at the NDSU Dickinson and Hettinger Research Extension Centers in southwestern ND, at the Southern Agricultural Research Center near Huntley in southeastern MT, and at the University of Wyoming's research facility near Lingle in northeastern WY to compare vegetative productivity and reproductive capacity. A field experiment also was located in northwestern South Dakota. A total of 10 site-years (i.e., environments) were included (Dickinson: 2; Hettinger: 1; Huntley: 2; Lingle: 4; and South Dakota: 1), although pervasive drought

and weed control problems resulted in some experiments failing to generate usable data (e.g., Hettinger, ND, in 2006). Legume species treatments were allocated in a randomized complete block design and replicated four times in each environment.

Four legume species (Austrian winter pea, common hairy vetch, woolypod vetch, and rigid medic) were fall seeded at all locations except Dickinson and Hettinger in 2006 and at the South Dakota location in 2005. Seeding was delayed until the following spring at both North Dakota locations because of concerns about winterkill susceptibility for most treatments. Dry seedbed conditions in the fall delayed seeding until the following spring at the South Dakota location. The other legume forage treatments included in the study (alfalfa, annual sweetclover, and birdsfoot trefoil) were spring-seeded in all 10 environments.

Seedling density was determined at approximately 21 days after planting (DAP) for both fall- and spring-seeded treatments, and a second time the following spring after temperatures warmed and seedlings resumed growth for fall-seeded legume species. Winter survival was reported on a percentage whole number basis as: [winter survival = (seedling no. in spring/seedling no. in fall)] x 100. Forage yield was determined at flowering and reported on a dry matter (DM) basis. Data were analyzed using the appropriate ANOVA model and PROC MIXED from SAS.

Seed production, survival, and success at regenerating new plants from the soil seed bank were determined at selected locations using accepted methods (Walsh et al., 2001; Carr et al. 2006a). Data were analyzed using PROC MIXED from SAS.

Tillage and seeding method study (Objective 2). Rigid medic and birdsfoot trefoil were broadcast seeded with incorporation and drilled into standing small grain stubble and a tilled seedbed at the locations identified in the description of the *Legume species adaptation study*, although pervasive drought and weed control problems resulted in experiments in some environments failing to generate usable data as discussed already (e.g., Hettinger, ND, in 2006). Rigid medic was seeded in the fall in all environments except Dickinson and Hettinger in 2006 and South Dakota in 2005 for reasons explained in under the *Legume species adaptation study heading*, and in Montana in 2005 because of a misunderstanding in seeding method protocol. Rigid medic at those four locations and birdsfoot trefoil at all 10 locations were seeded in the spring

A randomized complete block design was used with legume species (whole plot) and tillage x seeding method factorial combinations (subplots) in a split plot arrangement with treatments replicated four times. Pasture composition, dry matter production, seed yield, survival, and success at regenerating new plants was determined as described under the *Legume species adaptation study*. The study was conducted at Dickinson, Huntley, and Lingle over a 2-yr period, and for a single year at Hettinger and in South Dakota. Data from the study were analyzed as described under the *Legume species adaptation study*.

Legume pasture preference study (Objectives 1,3). Alfalfa (cv. Travois), annual sweetclover (cv. Hubam), birdsfoot trefoil (cv. Norcen), and rigid medic (cv. WY-SA-10343) were grazed by loala heifers to determine grazing preference. The four forage species were allocated randomly in 9 by 30 m plots in each of three replicates that comprised four pastures with enough mowed grass border on all sides to allow for maintenance. Heifers were allowed access to each pasture for 48 hr before moving on to the next pasture, and were stocked at a density sufficient to remove 50% of the forage in a 48-hr period. Water, salt and poloxaline (to protect against frothy bloat) were available at all times.

The study included two environments. Treatments were established in the first environment in 2005 and data were collected both that year and in 2006. Treatments were established in the second environment in 2006 but subsequently were abandoned without producing usable data because of pervasive drought and an infestation of Russian thistle (*Salsoli tragus*).

Forage DM was determined by clipping above-ground biomass from two 0.5-m^2 areas within each plot in every pasture before and after the 48-hr grazing period to estimate consumption. Cattle grazing preference also was assessed by visual observation during four 2-hr periods (5:30 to 7:30 AM; 9:30 to 11:30 AM; 2:30 to 4:30 PM; and 6:30 to 8:30 PM) on both days comprising a 48-hr grazing period. The observations consisted of recording the number of cattle located in each plot every 5 minutes during a 2-hr observation period.

Forage DM was analyzed using the Chesson-Manly index (Smit et al., 2006) by assigning a preference score to the four legume species in each pasture based on the amount of forage consumed over a 48-hr period. The scores then were analyzed using the appropriate nonparametric tests. Grazing preference observations were analyzed by calculating the proportion of time spent in each plot in every 48 hrs relative to total time spent grazing.

Ley farming grazing study (Objectives 3 and 4). A ley farming system (wheat-birdsfoot trefoil) was established in 1-ha paddocks along with a wheat-pea grain production system and a wheat-alfalfa system at the NDSU Dickinson Research Extension Center in southwestern North Dakota in 2002 and 2003 (before this project was begun; the experimental design, treatment protocol, and statistical analyses methods are provided in the NDSU AES research project report entitled *Integrating Crops and Livestock by Ley Farming in the northern Great Plains* [CRIS project id ND06257]). Wheat grain yield and quality was determined for the wheat phase of the three rotations, and livestock performance was measured using yearling beef heifers rotationally grazing legume pastures. Accurate records of labor and management, equipment, and fuel requirements were maintained for each paddock. An economic comparison of the contrasting wheat production systems was not completed at the time of this report, but will include all sources of revenue, including crop and livestock receipts and government program payments (that a farmer would receive), and all costs, including variable and investment (i.e., fixed) costs. The system[s] generating greatest returns to labor and management and the system[s] requiring the least amount of risk will be identified. The returns and risk associated with ley farming and other wheat production systems will be compared with returns and risk associated with a perennial grazing system. The PI is working closely with a cooperating agricultural economist to ensure that economic analyses are conducted correctly.

Ley farming working group (Objective 5).
A working group of researchers, extension service personnel, and commercial producers was formed during development of this project proposal. Site visits were made during summer tours, and more crop and livestock producers became aware of the benefits offered by integrating crop and livestock enterprises by ley farming. A portion of an information processing specialist's time was allocated to maintaining information from this project on the NDSU Dickinson Research Extension Center's web page, with a direct link on the home page or indirectly from both the Agronomy and Beef icons at the web site. Users can click on an icon and be taken to an informational page outlining the project but will have the option of accessing specific information via clickable links. A discussion forum for users to post information and questions related to this project also provided.

Results and Discussion

Legume species adaptation study (Objective 1).
Legume plant stand in the 10 environments is reported in Table 1, with three exceptions. Establishment of fall-seeded legume treatments was not attempted because of dry seedbed conditions in South Dakota, and all eight treatments were seeded in the spring. In Wyoming, establishment of spring seeded legume treatments was attempted under rainfed conditions in 2005 but was unsuccessful because of a persistent dry seedbed. Fall-seeded treatments under rainfed and fall- and spring-seeded treatments under irrigation were established successfully in Wyoming, but plant stand data were not provided.

More plants occurred for spring- compared with fall-seeded treatments in North Dakota (Table 1), but in part this reflects the higher seeding rates for the spring-seeded legume treatments. A similar trend in plant numbers between fall- and spring-seeded treatments was not detected in other environments.

Plant numbers were equal or greater for birdfoot trefoil compared with other legume species in North Dakota and Wyoming (Table 1). Conversely, plant numbers for hairy vetch, rigid medic, and alfalfa were equal to or greater than birdsfoot trefoil numbers in Montana, and were greatest for alfalfa in South Dakota. Though generally lower than expected, plant numbers for most treatments and environments seemed adequate for forage production at levels that would support grazing, based on previous research (e.g., Carr et al. 2006).

Hairy vetch produced equal or greater amounts of forage compared with other legume species in all environments, except under dryland conditions in Wyoming during 2006 (Table 2). Other fall-seeded legume species produced little if any forage in North Dakota, primarily because of extensive winterkill (5 to 10% survival) compared with the hairy vetch treatment (80% survival; Table 1). Rigid medic also winterkilled extensively (15% survival) under dryland conditions in Wyoming in 2006. Those data suggest that rigid medic may be susceptible to winterkill in the northern Great Plains when dry conditions occur, perhaps because of a lack of insulating snow cover. Winter temperatures also can be highly variable in the region, sometimes becoming warm enough in mid-winter to induce growth only to be followed by extreme cold.

Annual sweetclover produced equal or greater forage yields compared with the other spring-seeded treatments, whereas birdsfoot trefoil produced relatively low yields in both irrigated environments in Wyoming (Table 2). These data suggest that birdsfoot trefoil may be lower yielding than alfalfa and other spring-seeded legume forages, in contrast to previous research indicating that birdsfoot trefoil and alfalfa produce comparable yields in the northern Great Plains (Carr et al., 2005a). Alfalfa and birdsfoot trefoil were relatively low yielding compared with other legume treatments in at least some environments, but this was expected since both species are perennials whereas the other six are annual species.

The ability of legume treatments to persist the year after seeding was evaluated in North Dakota environments. Established alfalfa and birdsfoot trefoil plants of both species persisted, as expected. Birdsfoot trefoil also demonstrated an ability to reseed naturally, with an average of 165 seedlings/m^2 regenerating from the soil seed bank the year after seeding, whereas alfalfa did not. All six annual legume species failed to reseed naturally from the soil seed bank and so were unable to persist beyond the year of planting. These results are in agreement with previous research (Carr et al., 2005a).

Tillage/Seeding Method Establishment Study (Objective 2).

Seeding rigid medic directly into a tilled seedbed resulted in a plant stand comparable or superior to broadcasting and lightly incorporating seed into a tilled seedbed in 7 of 10 environments included in this study (Table 3). Similarly, comparable or even greater numbers of birdsfoot trefoil plants resulted when seed was drilled into a no-till seedbed. Seeding directly into standing stubble did not guarantee successful establishment of legume forage species during drought, as was the case in Wyoming in 2006. Few if any legume plants resulted even when seeding directly into stubble under rainfed conditions in that environment, regardless of legume species. Still, results of this study suggest that plant establishment is superior when small-seeded legume forages are drilled into a no-till seedbed compared with broadcast seeding in a tilled seedbed, presumably because of soil water conservation that results when tillage is eliminated.

Forage yield differences were not detected between the two seeding methods, with one exception (Table 4). Birdsfoot trefoil yields were enhanced when drilled into standing stubble rather than broadcasted and incorporated into a tilled seedbed under irrigation at Wyoming in 2006. However, yields for both seeding methods were low in that environment. Similarly, yields for birdsfoot trefoil were low (500 kg/ha) in two of the other five environments where measurable amounts of forage were harvested. These results fail to indicate a distinct advantage for drilling seed directly into small grain study compared with broadcasting and incorporating seed in a tilled seedbed for yield (Table 4), even though plant stand is comparable or superior under no-till (Table 3).

There was no evidence that rigid medic regenerated naturally from the soil seed bank the year after being seeded using either method (data not presented). Birdsfoot trefoil did reseed naturally using either seeding method, but at a much lower rate (21 seedlings/m^2) than expected based on results of the *Legume species adaptation study (Objective 1)* or previous research (Carr et al., 2005a, b) for reasons that remain unclear.

Legume pasture preference study (Objectives 1,3).

Heifers failed to show any preferred for grazing rigid medic compared with alfalfa, but did prefer rigid medic to both birdsfoot trefoil and annual sweetclover pasture in 2005 (data not presented). There was no preference among the heifers between grazing alfalfa, birdsfoot trefoil, and annual sweetclover. The preference for medic forage was reflected in the proportion of time the heifers spent grazing the four legume forages (Table 5). Roughly one-third of the time heifers were grazing was spent in rigid medic pasture, with approximately equal amounts of the time remaining in alfalfa, birdsfoot trefoil, and annual sweetclover pastures.

Although there was a clear preference for grazing rigid medic compared with the other three legume species for grazing by heifers, medic pasture did not persist beyond the seeding year. Rigid medic is an annual, so established plants were not expected to survive beyond the seeding year, but new plants failed to develop from the soil seed bank. In part, this was because seed production by rigid medic was low in this and other field experiments in North Dakota during this study (data not presented). However, the proportion of viable seeds resulting in new plants by natural reseeding also was low. While results of this study demonstrated that heifers preferred grazing rigid medic to other legume pasture species (Table 5), the failure of this species to persist by natural reseeding limits it suitability as a pasture species in a ley farming context in northern portions of the region encompassed by the 4-SRC. In areas further south within the region where rigid medic has demonstrated an ability to reseed naturally (e.g., Wyoming; Walsh et al., 2002), our results support greater scrutiny of rigid medic as a suitable species for ley farming.

Annual sweetclover pasture failed to persist beyond the seeding year. In contrast, alfalfa and birdsfoot trefoil pasture persisted the year after being seeded as expected, since both species are perennials. Perennation of established plants was the sole way in which alfalfa pasture persisted beyond the seeding year, whereas the birdsfoot trefoil pasture persisted through a combination of established plants surviving and establishment of new plants from the soil seed bank. Heifers prefers grazing alfalfa compared with birdsfoot trefoil pasture (data not presented), but both legume species appeared to be consumed readily by the animals.

Previous research by Carr et al., (2006 a, b) demonstrated that birdsfoot trefoil can regenerate naturally from the soil seed bank in small-plot studies in North Dakota. Results of the current study demonstrated that this ability extended to situations where pasture actually was grazed, demonstrating the potential this species may have when ley farming in North Dakota. However, there are new concerns about the ability of birdsfoot trefoil to produce adequate amounts of forage to support grazing under rainfed conditions in the region encompassed by the 4-SRC, even within North Dakota in some years. Additional research is needed to determine how well adapted birdsfoot trefoil is in the Northern Great Plains, particularly when drought conditions develop and persist over one or more growing seasons.

Ley Farming Grazing Study (Objectives 3 and 4).
The 3-yr (two years of birdsfoot trefoil followed by spring wheat) ley farming system produced comparable wheat yields to those produced by the grain-only (wheat and pea in rotation) farming system and the 3-yr (two years of alfalfa followed by spring wheat) grain-forage farming system in both 2005 and 2006 (Table 6). The ley farming system was intermediate between the grain-only and grain-forage farming systems for wheat yield in 2004. These data suggest that wheat production in a ley farming system is comparable to wheat production in a grain-only, wheat-pea farming system in the northern Great Plains. The importance of this observation cannot be overstated, since Carr et al. (2006) demonstrated the grain-only, wheat-pea system is highly competitive with other wheat production systems in the region. The ley farming system had the advantage of providing adequate amounts of high-quality forage during both 2004 and 2006 to support grazing, when pervasive drought occurred. Pea yield averaged only < 900 kg/ha in both those years. While the loss of a former Co-PI on the project have delayed economic comparisons of the three farming systems, preliminary analyses indicate that economic loss during the pea phase of the grain-only system was significant. Results of the economic comparison will provided when completed in 2007.

Ley farming working group (Objective 5).
A working group of researchers, extension service personnel, and commercial producers was formed during development of this project proposal, as mentioned previously. A site visit attended by approximately 60 commercial producers was made to the Ley Farming Grazing Study in 2005 where this project was described. A ley farming portion site was created on the NDSU Dickinson Research Extension Center's web page, which can be accessed directly by going to the home page (http://www.ag.ndsu.nodak.edu/dickinso) or indirectly from both the Agronomy and Beef icons at the web site. An informational page at the ley farming site outlines this project with options for accessing specific information via clickable links. A discussion forum for users to post information and questions related to this project also was provided. Loss of the information processing specialist assigned to this project has prevented this site from being maintained, and it presently is unclear whether this position will be refilled due to lack of funds. This is unfortunate since the site was identified specifically in a recent paper published in Agronomy Journal (Russelle et al, 2007).

Conclusion
Results of this project demonstrated the potential that ley farming has in the region encompassed by the 4-

SRC. The ability of birdsfoot trefoil to persist when grazed in part because of natural reseeding provides new evidence that this legume species is suitable for pasture in a ley farming system in the northern Great Plains. Additionally, this project was the first to demonstrate heifers preferred grazing rigid medic to alfalfa and other legume species when offered the choice, and failed to identify any negative consequence of grainv the medic species. This information regarding rigid medic is important since that species is suggested as another pasture candidate for ley farming in the region.

Several obstacles were identified by this project that most be overcome for ley farming to gain credibility among commercial producers. First, zones of adaptation for both birdsfoot trefoil and rigid medic must be delineated within the region. Future research should determine if birdsfoot trefoil only has potential as a regenerating forage species in North Dakota, as this project suggested, or if other suitable areas exist that are within the region but were not included in this project. Likewise, rigid medic showed limited potential in several environments in this project, but may perform well at locations beyond those included in this investigation.

This project demonstrated that both birdfoot trefoil and rigid medic can be grazed by heifers. However, only birdsfoot trefoil pasture was grazed and then rotated with wheat in a system that mimicked ley farming as practiced in Australia. Rigid medic was grazed but not in the context of a ley farming system where the medic species was rotated with wheat. Additional work is needed which demonstrates that rigid medic, like birdsfoot trefoil, can be grazed and then rotated with wheat. More importantly, both legume species must demonstrate an ability to regenerate naturally following the wheat phase in large replicated plots where grazing occurs during the pasture phase.

Beyond the scope of this study was documentation that ley farming enhances the soil N pool and also reduces weed populations during the pasture phase. These attributes of this production system were critical to the success and popularity of ley farming in Australia, and similar benefits must be demonstrated before ley farming may develop interest among commercial wheat growers and livestock producers in the region encompassed by the 4-SRC.

The inability to regenerate naturally from the soil seed bank in this study suggests that hairy vetch is unsuited for ley farming. However, that legume species produced relatively large amounts of DM and may be well suited as a fall-seeded annual forage crop in the region encompassed by the 4-SRC. Additional research might be considered on the suitability of hairy vetch as a hay crop and for annual pasture, either alone or in combination with other forage species. The impact of hairy vetch on the soil N pool and yield of subsequent grain and seed crops should be determined in this research.

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Table 1. Mean fall- and spring-seeded legume seedlings numbers (plants/m^2) for the project locations.

Variety	North Dakota	Montana	South Dakota	Wyoming	
				Dryland	Irrigated
	2005/06†	2005/06	2005	2006	2006
Fall Seeded					
Hairy vetch	36*e*‡ (79)§	120*bc* (62)	--	62*a* (53)	122*a* (82)
Austrian winter pea	41*de* (12)	61*e* (91)	--	47*a* (72)	53*c* (92)
Woolypod vetch	20*f* (3)	82*d* (81)	--	43*a* (44)	101*a* (48)
Rigid medic	53*d* (3)	153*a* (66)	--	50*a* (16)	64*bc* (64)
Spring Seeded					
Annual sweetclover	93*c*	80*d*	78*c*	58*a*	119*a*
Norcen birdsfoot trefoil	276*a*	106*c*	134*b*	48*a*	91*ab*
Alfalfa	157*b*	143*ab*	216*a*	68*a*	105*a*
Leo birdsfoot trefoil	259*ab*	134*ab*	134*b*	33*a*	115*a*

†Where counts did not differ significantly between years data were pooled. No seedling counts in Wyoming in 2005.

‡Counts taken approx. 21 days after planting. Treatments in the same column with the same letter are not significantly different at p = 0.05.

§Numbers in parenthesis denote approximate % winter survival of fall seeded crops.

Table 2. Mean fall- and spring-seeded legume yields (kg/ha) for the four project locations.

Variety	North Dakota	Montana	South Dakota	Wyoming			
				Dryland		Irrigated	
	2005/06†	2005/06	2005	2005	2006	2005	2006
Fall Seeded							
Hairy vetch	1735*a*‡	3879*a*	1499*a*	3820*a*	400*b*	8020*a*	4380*a*
Austrian winter pea	143*c*	3428*a*	2568*a*	3830*a*	1340*a*	--§	5215*a*
Woolypod vetch	0*d*	33387*a*	2864*a*	2640*b*	250*b*	6360*b*	1640*bc*
Rigid medic	0*d*	3978*a*	2366*a*	2570*b*	250*b*	7570*ab*	660*c*
Spring Seeded							
Annual sweetclover	1064*ab*	2205*ab*	1451*a*	--	--	6260*b*	4640*a*
Norcen trefoil	905*b*	723*c*	1206*a*	--	--	1490*de*	840*c*
Alfalfa	891*b*	1743*bc*	3032*a*	--	--	4340*c*	2230*b*
Leo trefoil	838*b*	446*c*	1146*a*	--	--	1630*d*	950*bc*

†Where yields did not differ significantly between years data was pooled. South Dakota was harvested in 2005 only.
‡Treatments in the same column with the same letter are not significantly different at $p = 0.05$.
§Crop destroyed by strong winds.

Table 3. Mean rigid medic and birdsfoot trefoil (Trefoil) seedlings (plants/m^2) depending on tillage and seeding method for the four project locations.

Variety	North Dakota		South Dakota	Montana	Montana	Wyoming	
						Dryland	Irrigated
	2005	2006	2005	2005	2006	2006	
Rigid medic							
Till	10*b*† (53)‡	80*a*	31*b*	61*a*	111*a* (32)	4*b*	22*b*
No Till	43*a* (0)	43*b*	54*a*	52*a*	139*a* (36)	9*a*	67*a*
Trefoil							
Till	281*a*	48*b*	237*a*	74*a*	61*b*	0	4*b*
No Till	305*a*	164*a*	188*a*	71*a*	190*a*	0	12*a*

†Counts taken 21 days after planting. Values with the same letter within each column and each variety are not significantly different at $p = 0.05$.

‡Numbers in parenthesis indicate approximate % winter survival. Rigid medic spring seeded in ND in 2006 and in SD and MT in 2005.

Table 4. Mean rigid medic and birdsfoot trefoil (Trefoil) yields (kg/ha) depending on tillage and seeding method for the four project locations.†

Variety	North Dakota		South Dakota	Montana		Wyoming
	2005	2006	2005	2005	2006	2006‡
Rigid Medic						
Till/Broadcast	0*a*§	2414*a*	1883*a*	557*a*	902*a*	3251*a*
No Till/Drilled	0*a*	2096*a*	2556*a*	1943*a*	1268*a*	3790*a*
Trefoil						
Till/Broadcast	164*a*	1277*a*	599*a*	1622*a*	190*a*	113*b*
No Till/Drilled	371*a*	1444*a*	1155*a*	1302*a*	289*a*	250*a*

†Rigid medic fall seeded and trefoil spring seeded, except in ND 2006 and MT and SD 2005, where all treatments were spring seeded.

‡Irrigated trial.

§Values with the same letter within each column and each variety are not significantly different at $p = 0.05$.

Table 5. Mean percent of time spent grazing on each variety based on visual observations during the three grazing studies in North Dakota.

Variety	Mean % of grazing
Rigid medic	33.9*a*†
Alfalfa	25.2*b*
Birdsfoot trefoil	20.9*b*
Annual sweetclover	20.0*b*

†Treatments with the same letter in the same column are not significantly different at $p = 0.05$.

Table 6. Difference in wheat yields depending on previous year crop in the North Dakota ley farming experiment.

	Wheat Yield		
Previous Crop	2004	2005	2006
	(kg/ha)		
Pea	2412*a*†	2868*a*	2455*a*
Alfalfa	1391*c*	2613*a*	2154*a*
Birdsfoot Trefoil	1842*b*	2479*a*	1599*a*

†Within columns, means followed by the same letter are not significantly different at $p = 0.05$.