Enhancing Grain Production of Great Plains Cropping Systems with a Legume-Pasture Phase – Final Report

Summary

Pasture-based cropping systems were demonstrated to approximately 200 commercial producers in the northern Great Plains. No adverse effects occurred on subsequent grain crops when shallow-rooted legume species were used for pasture. Interest in birdsfoot trefoil as a non-bloating alternative to alfalfa was generated. Results of this project along with related studies and a discussion forum can be accessed on the web at http://www.ag.ndsu.nodak.edu/dickinso, beginning on April 1, 2004. A working group of farmers and ranchers, extension educators, and agricultural scientists was formed to extend results of the project so that methods for developing pasture-based cropping systems on commercial operations are developed.

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Introduction

Negative economic returns are projected for many annual grain and seed crops grown in the Great Plains. Among selected crops grown in southwestern North Dakota, for example, returns to labor and management were projected by Swenson and Haugen (2000) to be -$36/acre (-89/ha) for spring wheat (Triticum aestivum L. emend. Thell) following summerfallow and -$14/acre (-$35/ha) when grown annually, -$15/acre (-$37/ha) for canola (Brassica napus L.), -43/acre (-$106/ha) for grain corn (Zea mays L.), -$7/acre (-$17/ha) for pea (Pisum sativum L. subsp. sativum), and -$6/acre (-$15/ha) for oil-type sunflower (Helianthus annuus L.). Economic reality suggests that new production and marketing methods are needed for annual grain and seed crops to be grown profitably in the Great Plains.

Pasture-based cropping systems have been used successfully for decades in Australia. These systems rely on subterranean clover (Trifolium subterraneum L.) and annual medic (Medicago) species to provide forage during a short-term (less than 3 yr) pasture phase (Walsh, 1999). Pastures first are established by seeding the legumes, then are maintained or reestablished naturally from seed produced during the pasture phase (Krall and Schuman, 1996). The pastures provide forage throughout the winter growing season, as well as during the dry summer months. Pastures are rotated with wheat and sometimes other grain or seed crops.

Subterranean clover and annual medic produce excellent quality forage when managed properly (SAN, 1998). The forage is highly palatable, nutritious, and desired by livestock. The legumes also enhance soil fertility and tilth. Soil nitrogen (N) and water-stable soil aggregates increase during the pasture phase (Reeves, 1987), thereby benefiting subsequent crops in rotation with the legume species.

The benefits of rotating legume pasture with wheat became apparent as pasture-based cropping systems were adopted across the wheat belt region of southern Australia in the 1950s. Producers became convinced that cropping systems incorporating a legume pasture phase were superior to crop-summerfallow systems. Wheat yields increased 50% following adoption of pasture-based cropping systems, with much of the increase attributed to the impact of the legume pasture phase on soil N and tilth (Donald, 1981). By 1965, crop-summerfallow systems had been replaced by pasture-based cropping systems (Halse, 1989).

Pasture-based cropping systems are not unique to Australia. Advanced cropping systems incorporating a legume pasture phase are used by some wheat producers in Argentina (Ortmann et al., 1989). These systems have reduced or eliminated the need for fertilizer when growing wheat. By contrast, fertilizer comprised 27% of the total variable costs associated with wheat production in southwestern North Dakota in 1999 (NDSB, 2000).

Krall and Shuman (1996) concluded that pasture-based cropping systems can be profitable and sustainable in the Great Plains. However, evidence suggests that these systems are used by only a few producers in this region. Even less evidence exists that legume pastures are included in wheat production systems, even though legume pastures can enhance the yield of subsequent crops in a rotation. Krall and Shuman (1996) suggested that tradition and lack of managerial experience are two major factors limiting adoption of pasture-based cropping systems. Limitations in an infrastructure that supports pasture-based cropping systems also inhibit adoption.

Australian medic and other legume species suitable for grazing have been considered as a replacement to summerfallow in the Great Plains. Sims (1993) concluded that black medic (M. lupulina L.) could replace summerfallow in a wheat-summerfallow cropping system in Montana. Black medic was seeded in plots in 1979 and then reestablished naturally in 1980. Summerfallow plots also were maintained. Spring wheat was seeded in plots in 1981. Wheat yield was 46 bu/acre (3123 kg/ha) following black medic and 27 bu/acre (1819 kg/ha) following summerfallow. Black medic fixed more than 50 lb N/acre (56 kg/ha), which probably explains why yields were greater following black medic than summerfallow. Subsequent work showed a similar but non-significant trend in yield following black medic compared with summerfallow.

Gardner (1992) concluded that yellow-flowered sweetclover (Melilotus officinalis Lam.), hairy vetch (Vicia villosa Roth), foxtail dalea (Dalea alopecuroides L.), and 'Indianhead' lentil (Lens esculenta L.) had the greatest potential of substituting for summerfallow in cereal-summerfallow cropping systems in the central and northern Great Plains. However, soil water levels were depleted from 1 to 4 inches in the 0-to 4-ft depth following the cover crops compared with summerfallow, depending on the legume species seeded. Wheat yield was not elevated and sometimes was reduced following legume cover crops. These data indicate the importance of water use considerations when developing cereal-legume cropping systems in the Great Plains.

Several annual medic cultivars were studied over 3 yr in eastern Wyoming (Walsh, 1999). Annual medic species showed promise as potential forage crops. Some cultivars produced more than 6250 lb/acre (7000 kg/ha) of high-quality forage. However, most medic species showed limited potential for regenerating naturally from the soil seed bank. Many medic species also were unable to compete with weeds for light, nutrients, and water. One study was abandoned prior to completion because of invasion by weeds. Results of this work suggest that many medic cultivars adapted to pasture-based cropping systems in Australia may not be suited to the Great Plains.

Australian medic and subterranean clover cultivars have been developed for Mediterranean climates with mild winter temperatures. Halse (1989) indicated that Australian cultivars are not adapted to regions with cold winter temperatures. Australian cultivars generally failed to produce much seed in eastern Wyoming, probably because growth and development periods were reduced in this climate (Walsh, 1999). Only a small percentage of the viable seed that was produced survived the cold winter months. Medic stands failed to regenerate naturally, and were either reseeded or abandoned. Walsh (1999) concluded by suggesting that adaptation studies were needed that identify legumes having the greatest potential when grazed in pasture-based cropping systems in the Great Plains.

Alfalfa has been used for pasture in pasture-based cropping systems (Dalal et al., 1991), and cultivars have been developed for grazing. Black medic and other legume species have been grazed in a non-replicated demonstration in the Great Plains (Gardner, 1991), but most farmers and ranchers are unaware of the grazing potential of these legume species. No replicated and randomized, large-scale paddocks exist demonstrating that cropping systems with a legume-pasture phase can be used successfully in the central and northern Great Plains, according to prominent, cropping-systems scientists located in Canada (M.H. Entz, personal communication, 2000) and the USA (D.W. Meyer and J.M. Krall, personal communication, 2000).

Objectives/Performance Targets

Demonstrate pasture based cropping systems that can be used as alternatives to grain and seed based annual cropping systems.

Demonstrate the economic consequences associated with changing from a grain and seed based cropping system to pasture based cropping systems.

Develop a pasture-based cropping systems working group comprised of farmers and ranchers, researchers, and others in the north central region.

Materials and Methods

Objective 1.

Two Dickinson Research Extension Center (DREC) Advisory Boards are consulted regularly to identify education and research needs of agriculturists in southwestern North Dakota. The Agronomy Advisory Board is comprised of a diverse group representing agribusiness, extension service, and production interests in southwestern North Dakota. The Organic Advisory Board is comprised of organic agriculturists from across the state. Both Advisory Boards and a crop producer survey (Carr, unpublished data, 1998) indicated that agriculturists wanted information on how to integrate crop and livestock enterprises, and how this integration affected profitability.

Legume species have been evaluated for forage production at the DREC for years, but not in the context of an integrated crop-livestock system. In response to Advisory Board and farmer/rancher directives, legume species began to be screened for their adaptation in pasture-based cropping systems in the 1990s. The screening of these species represented a major shift in research priorities from grain- and seed-based cropping systems to pasture-based cropping systems, and reflected the directives of DREC Advisory Boards. Twenty-six replicated and randomized paddocks were built to support pasture-based cropping systems research, and a research specialist was reassigned responsibilities to reflect the focus on pasture-based cropping systems research and education efforts. An additional paddock was built in 2001.

The project submitted for NCR-SARE funding was developed so the benefits of pasture-based cropping systems compared with a grain- and seed-based cropping system could be demonstrated to farmers and ranchers in the northern Great Plains. To do so, three crop rotations were established in the paddocks, beginning in 2002: (i) wheat-pea (2-yr; both crops harvested for grain), (ii) wheat-alfalfa-alfalfa (3-yr; wheat harvested for grain and alfalfa grazed), and (iii) wheat-black medic or other regenerating legume species (2-yr; wheat harvested for grain and regenerating legume species grazed). Two sets of the wheat-regenerating legume species were maintained to provide for seasonal grazing. All phases of each rotation were maintained each year. Paddocks were randomized in blocks and treatments replicated three times.

Individual paddocks were 2.5 acres (1 ha). Two alfalfa and two regenerating legume paddocks were maintained in each block for grazing by cattle during a planned 90-d grazing period (15 May to 15 August). Legume paddocks were grazed sequentially within each species. An average stocking rate of 1.2 animal unit months (AUM)/acre (3 AUM/ha) was used within species. This stocking rate was maintained across regenerating legume paddocks. The stocking rate across alfalfa paddocks was variable according to the year of production (establishment year, 0.8 AUM/acre [2 AUM/ha] and second year, 1.6 AUM/acre [4 AUM/ha]).

Regenerating legume paddocks were paired within each block. Each paddock was separated into three strips with electric fence with plans to rotationally graze using a 7-d graze and a 35- to 39-d rest cycle. Alfalfa paddocks also were paired within blocks (establishment- and second-year alfalfa). Paddocks of alfalfa during the first-year and second-year growth were separated into 2 and 3 strips, respectively. Management plans consisted of a 6- to 8-d grazing and a 28- to 30-d rest cycle. Grazing of alfalfa began in second-year alfalfa paddocks (established in 2001), then proceeded to first-year alfalfa paddocks. Second-year alfalfa paddocks were grazed three times during the grazing season, while first-year alfalfa paddocks were grazed twice. Salt/bloat guard supplements was available in paddocks.

Grazing animals consisted of yearling heifers. The heifers were weighed at the beginning of grazing and every 4 wk thereafter, until the end of the grazing cycle when a final weight was recorded. Intermediate and seasonal weight gain and average daily gain were determined.

Wheat and pea were seeded mechanically each year. Alfalfa and regenerating legumes were seeded when paddocks first were established, and thereafter were expected to reseed or regrow naturally although this will occur beyond the time-frame of this project.

Aboveground dry matter (DM) production of forage was determined in alfalfa and regenerating legume strips by harvesting biomass from a 2.7-sq. ft. (0.25-sq. m.) area within 4 larger 10.8-sq. ft. (1.0-sq. m.) exclosures within each strip whenever grazing animals were introduced into legume strips. Biomass was dried until a constant weighed and recorded. Biomass also was collected from an unclipped, 2.7-sq. ft. area within each exclosure when heifers were removed from a strip, and DM production determined. Forage quality was determined by standard wet-chemistry methods. The rest of the exclosure was clipped and plant biomass removed at this same time. A similar procedure was used to determine aboveground DM production in four 2.7-sq. ft. areas in grazed portions of paddocks whenever yearling heifers were introduced into strips and again when heifers were removed.

Herbicide selection and use was determined during the wheat phase by weed species composition and density for each cropping system. Wheat grain and pea seed yields were determined by harvesting two 167-sq. m. areas within each paddock. Weight of 1000 kernels and grain test weight was determined. Grain protein concentration was determined by near-infrared refrectometry.

Soil nitrogen (total, ammonium, and nitrate) and phosphorus was determined for 0- to 6-in (0- to 15-cm) soil depths in each wheat paddock following grain harvest or the final grazing period late fall using accepted soil testing methods. Nitrogen at the 6- to 24-in (15- to 60-cm) and 24- to 48-in (60- to 122-cm) depths also was determined at these same times. Soil organic matter content was determined in wheat paddocks prior to beginning the demonstration to provide a reference for future activity at these sites.

Objective 2.

Accurate records of labor and management, equipment, and fuel requirements were maintained for each paddock. Records also were maintained of prices that would have been received for crops and livestock produced in this field demonstration. Economic returns were determined for each of the systems included using these data. Returns were computed considering all revenues except for government program payments, and all costs, including variable and investment (i.e., fixed) costs. Expected returns were compared between the contrasting cropping systems.

Objective 3

On-site visits of this project were made during summer tours at the DREC in both 2002 and 2003. Results of this project were presented at annual winter meetings, in progress reports and press releases, and at a directory on the DREC web page.

Information from this project was included in annual reports for both 2003 and 2004 that can be accessed electronically at http://www.ag.ndsu.nodak.edu/dickinso. Results of this project along with related field experiments will be accessible by a direct link on the DREC home page beginning on April 1, 2004, or indirectly from both the Agronomy and Beef icons at the web site. Users will be able to click on an icon and be taken to an informational page outlining integrated crop-livestock systems and also 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 and related research will be provided.

Results and Discussion/Milestones

Objective 1.

Alfalfa, black medic (representing a regenerating legume forage species), pea, and wheat were seeded in paddocks in 2002 so that comparisons between the grain based crop sequence (wheat/pea) and pasture based crop sequences (wheat/alfalfa and wheat/medic) could be made in 2003. Severe drought after seeding resulted in poor establishment of alfalfa and particularly black medic, and developing legume plants were unable to suppress weeds. Forage production was 2609 lb/acre (2922 kg/ha) in alfalfa paddocks and 2930 lb/acre (3281 kg/ha) in black medic paddocks, but legume vegetation comprised less than 20% of forage. Heifers grazed alfalfa paddocks for only 14 d and medic paddocks for 21 d. Grain yield averaged 24 bu/acre (1613 kg/ha) for wheat and 13 bu/acre (840 kg/ha) for peas across paddocks where both crops were grown.

Greater than 4 alfalfa plants/sq. ft. were established by spring 2003 from the seeding that occurred in 2002. In contrast, few black medic plants that became established in 2002 overwintered and few new seedlings regenerated from the soil seed bank. A decision was made to seed birdsfoot trefoil rather than black medic in 2003 to improve the likelihood of establishing regenerative legume pasture after consultation with knowledgeable experts of regenerating legume forage species and receiving approval from NCR-SARE administrative personnel. Birdsfoot trefoil and alfalfa paddocks also were seeded with an oat nurse crop in 2003 to increase the chances that sufficient forage would be provided during the seeding year to support a 90-d grazing period.

Birdsfoot trefoil-oat pasture provided 69 d of grazing during the 2003 growing season. Second-year alfalfa plus alfalfa-oat pasture provided an additional 23 d of grazing ($P=0.01$). However, differences were not detected between birdsfoot trefoil and alfalfa paddocks seeded along with an oat nurse crop for the number of grazing days ($P=0.38$), average daily gain ($P=0.50$), total gain over the grazing period, area grazed ($P=0.51$), or body condition score ($P=0.31$). Average daily gain in legume-oat paddocks was 2.9 lb/AU (1.3 kg/AU) over the grazing period. By comparison, average daily gain was only 0.9/AU (0.4 kg/AU) for animals grazing second year alfalfa paddocks.

Wheat produced around 30 bu/acre (2029 kg/ha) when preceded with alfalfa for 2 yr in the project. Greater grain yields occurred when wheat followed peas (45 bu/acre; 3007 kg/ha) or black medic (44 bu/acre; 2957 kg/ha). The depressed yields following alfalfa were expected because this legume has a well developed taproot that can extract plant-available water from greater depths than can wheat. Pea is a shallow rooted crop, and results of this project suggest that black medic also is shallow rooted. Grain yields following birdsfoot trefoil could not be determined within the time-frame of this project since birdsfoot trefoil first was seeded in 2003. However, wheat yields following birdsfoot trefoil pasture will be quantified in 2004 and beyond.

Post-harvest soil nitrate-N content to a depth of 48 inches (122 cm) averaged only 32 lb/acre (36 kg/ha) following two years of alfalfa pasture. By contrast, soil nitrate-N content was 57 lb/acre (64 kg/ha) following a single year of black medic and 79 lb/acre (88 kg/ha) following peas when harvested for grain.

Objective 2

Returns to labor and management were estimated to be -$46/acre (-$114/ha) for wheat following a 2-yr alfalfa stand, $0.30/acre ($0.74/ha) for wheat following a single year of black medic, and $3.60/acre ($8.90/ha) for wheat following peas during 2003. These projected returns excluded government price supports. An estimated return of -$15/acre (-$37/ha) were projected from growing peas for grain following spring wheat. The estimated net returns generated from yearling heifers grazing the legume paddocks ranged from -$80/acre (-$197/ha) for alfalfa and birdsfoot trefoil during the establishment year to $20/acre ($49/ha) for second-year alfalfa.

Readers are cautioned that the economic data are preliminary and do not reflect the returns that probably would be generated from either pasture-based or wheat-pea cropping systems.

Cropping systems were established in a field that previously was managed as unimproved hay land because no other fields were large enough and available for the field demonstration included in the project. Soil fertility levels were very low and annual weed populations were high when the pasture-based and wheat-pea cropping systems were established. As a result, fertilizer and herbicide costs were excessive throughout this 2-yr project compared with projected costs for these inputs when growing wheat, peas, and forage legumes in southwestern North Dakota (Swenson and Haugen, 2000). More time is needed than was provided by this 2-yr project for the N-fixing and pest suppression benefits resulting from rotating legume pasture to develop.

Objective 3

Contact was made by the Project Director with scientists at Montana State University and the University of Wyoming to make them aware of the project. Contact also was made with Canadian and USDA-ARS scientists along with extension educators. One benefit of this interaction was an intensive evaluation of various soil quality parameters within each paddock by USDA-ARS scientists in 2002, at no cost to the project. A second evaluation is planned in 2007. The two data sets will be compared so the benefits of pasture based cropping systems on soil quantity (including carbon sequestration) can be quantified. A second benefit of this interaction was agreement by scientists, extension educators, and farmers to collaborate on a multi-state effort to develop pasture-based cropping systems. A proposal was written and is being considered for funding that would expand upon efforts initiated by this project.

Farmers and ranchers contacted the Project Director and expressed interest in working jointly to adopt or improve pasture based cropping systems on their farms and ranches. A working group has formed that currently is comprised of extension educators in Wyoming and North Dakota, university scientists in Montana, North Dakota, and Wyoming, USDA-ARS scientists in North Dakota, and farmers in Montana, North Dakota, and South Dakota. The goal of the working group is to stimulate the adoption of self-regenerating, forage legumes for use as pasture in cropping systems presently dominated by grain and seed crops in Montana, North Dakota, South Dakota, and Wyoming.

Information from this project can be accessed at an interactive web site dedicated solely to pasture-based cropping systems, beginning on April 1, 2004. This site will be maintained on the DREC's web page at http://www.ag.ndsu. nodak.edu/dickinso/. There will be a clickable menu item on the left hand side of the research extension center's homepage entitled "Ley Farming". Once clicked, a new page will open which will include a narrative describing ley farming, a final report of the pasture-based cropping systems project funded by NCR-SARE, similar research projects and related field experiments, contact information, and a link to a discussion forum. The discussion forum will be dedicated to ley farming and visitors will be able to view messages on existing topics, post replies to existing topics or post new messages and questions. Visitors will have the option to email other visitors directly as well. The discussion forum will be maintained and regulated by an employee of the DREC.

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Impact of Results/Outcomes

Approximately 200 farmers and ranchers made on-site visits to the field demonstration of pasture-based cropping systems that was included in this project. Roughly half of these agriculturists were introduced to birdsfoot trefoil, a forage legume species that has not been grown to any extent in much of the northern Great Plains and previously was reported as not being adapted to growing conditions in the region (Kapusta and French, 1964). The Project Director received requests for additional information on birdsfoot trefoil from several farmers and ranchers who visited the field demonstration, as well as crop scientists in Montana, North Dakota, and Wyoming. Seven birdsfoot trefoil cultivars were included in an adaptation trial focusing on alfalfa under the direction of USDA-ARS scientists in southwestern North Dakota that began in 2004. The birdsfoot trefoil cultivars were included largely because of the performance of this legume species in the field demonstration and related experiments at the DREC.

Grazing legume pasture is not a common practice in the northern Great Plains; many farmers and ranchers saw that legume pasture can be grazed because of this project. The farmers and ranchers were shown that a non-bloating forage legume species, birdsfoot trefoil, exists as an alternative to alfalfa, which can cause bloat.

It currently is impossible to know how many farmers, ranchers, and others interested in integrating crop and livestock enterprises learned about the project by accessing the DREC's web page. However, a conservative estimate is that several thousand became aware of the project based on the number of visits to the web page. For example, almost 540,000 visits to the web page were made during 2002, the most current year for which statistics have been summarized (L. Vance, 2004, personal communication). Even if only 1% of those visiting the web page accessed the annual report, over 5000 readers would have learned of the project.

Economic Analysis

Please refer to Objective 2 in the Results and Discussion/Milestone section.

Publications/Outreach

Baltensperger, D., and P.M. Carr. 2003. Role of annual forages in continuous systems. In Annual Meetings Abstracts [CD-ROM computer disk]. ASA, CSSA, and SSSA, Madison, WI.

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On-site visits were made by more than 100 farmers and ranchers as well as extension educators on July 10, 2002, and July 11, 2003. An on-site visit also was made during the Northern Plains Sustainable Agriculture Society annual summer symposium conducted jointly with the Organic Crop Improvement Association #1's summer meeting on July 18, 2003. A power-point presentation of the project was made to farmers, ranchers, and crop consultants in a training session at the Crop Pest Management School in Bozeman, MT, on January 6, 2004, and to farmers and ranchers during a session on integrating crop and livestock systems at the cropping systems update in Regent, ND, on December 18, 2003. A power-point presentation of the project also was made to extension educators during a session on forage management at the Western Crop and Pest Management School in Dickinson, ND, on February 27, 2003.

A power-point presentation was made during a session devoted to the project at the Northern Plains Sustainable Agriculture Society winter conference in Aberdeen, SD, on February 1, 2003. Power point presentations of the project also were made during a special symposium session to graduate students and faculty at Montana State University on January 7, 2004, and to USDA-ARS scientists, university researchers, and extension educators at the Dynamic Cropping Systems Symposium in Bismarck, ND, on August 5, 2004. The project was described during a presentation at the annual meeting of the American Society of Agronomy in early November, 2003, in Denver, CO.

Farmer Adoption

Approximately 200 farmers attended tours of the field demonstration included in the project. There is no way of knowing how many of the attendees returned to their operations and modified practices based on the site-visits. However, two farmers presently are working closely with the Project Director at developing and implementing pasture-based cropping systems on their farms. Two additional farmers/ranchers expressed plans to seed birdsfoot trefoil for pasture on their operations.

Refinement of the wheat-legume systems used in this project is needed before adoption can occur on more than a few commercial farms in the northern Great Plains. Still, some recommendations can be made based on experience gained from this project. Commercial operators should limit early attempts to adopt pasture-based cropping systems to relatively small fields until experience is gained working with these systems. Weedy fields should be avoided when establishing legume pasture; preceding legume pasture with cereal crops where few weeds occur is a good management practice to use. If possible, grazing should be avoided or done so sparingly during the seeding year when legume pasture first is established. Light grazing may occur if a dense plant stand develops, as long as livestock are removed so reproductive growth by regenerating legume species is not deterred. Seeding the legume species with an oat nurse crop sown at a very low rate (oat seeding rate = 10 to 20 lb/acre [11 to 22 kg/ha] of pure live seed) is recommended if grazing is unavoidable during the seeding year.

Animals must be managed carefully during the pasture phase so that seed production by regenerating species like birdsfoot trefoil is sufficient to replenish the soil seed bank. Crop water use should be monitored to avoid depleting soil water to levels where recharge is unlikely and depression of subsequent grain and seed crop yields probably will occur. Results of our project demonstrate that wheat yield depression resulted when a deep rooted legume species (alfalfa) was allowed to grow past mid-summer, while wheat yields were maintained when a shallow rooted species (black medic) was grown.

Established forage legumes are difficult to terminate when drought conditions develop in the northern Great Plains. For this reason, cattle should be removed by mid-summer during the pasture phase that precedes a grain or seed crop phase. Regrowth of legume species is desirable to improve efficacy if herbicides are used to terminate plant growth in legume pasture. Conversely, pasture probably should be grazed heavily to impose additional stress on plants if legume plants are terminated mechanically.

Areas Needing Additional Study

A thorough review of the literature published on pasture-based cropping in Australia has been completed and much of the work has relevance in the northern Great Plains of the USA. However, several problems have not been solved and some new ones have developed which justifies additional work. Production research should focus on developing methods that promote consistent establishment of forage species in northern Great Plains, both when legumes first are seeded and also when pasture is expected to regenerate naturally from the soil seed bank. These practices must rely on low disturbance methods which reflect the conservation tillage systems that are replacing clean tillage systems across the Great Plains.

Management strategies must be developed that optimize animal performance without sacrificing seed production beyond levels required to perpetuate self-regenerating legume pasture. Methods are needed which optimize livestock performance on legume pasture but also manipulate grazing so benefits (e.g., weed control by grazing weeds) are provided to a subsequent grain and seed crop phase. For example, strategies should be developed which optimize N-fixing and pest suppression benefits during the grazing but avoid depleting soil water reserves so much that subsequent crop performance is depressed.

Various legume species have been evaluated as possible candidates for ley farming by the Project Director and other university scientists in studies related to the project. Birdsfoot trefoil has been identified as a spring-seeded species with the greatest near-term potential for regenerating pasture among the legume species considered. However, other legumes not included in previous research also may have potential as regenerating pasture species. These species should be included in side-by-side comparisons with birdsfoot trefoil so that legumes best suited for regenerating pasture when rotated with wheat and other grain or seed crops can be identified.

Cost/benefit analyses of pasture-based cropping systems must be done and compared with similar analyses of grain- and seed-based cropping systems and perhaps systems relying exclusively on perennial pasture species. These analyses must incorporate both the short- and long-term costs and benefits of the competing systems. This work will require the establishment and maintenance of long-term field studies that includes pasture-based and grain- and seed-based cropping systems along with perennial pasture systems.

Emerging concerns about domestic food security have not been considered in previous research on integrated crop-livestock systems. These concerns should be integrated into research on pasture-based cropping systems since the dispersal of livestock across the landscape could impact domestic food security. Domestic energy use, particularly from non-renewable sources, also is becoming a concern. The use of animals to 'harvest' forages and cycle nutrients has implications on off-farm energy inputs, particularly fossil fuels. Comparative studies are needed to determine the impact of pasture-based cropping systems, cropping systems that exclude forages, and forage systems that exclude grain and seed crops on domestic food security and non-renewable energy use.