Effects of cropping-system-related soil moisture and nutrient dynamics on the sustainability of semiarid dryland agriculture

Project Summary

We propose to investigate cropping-system-related soil moisture and nutrient dynamics in the cold, semiarid environment of eastern Wyoming. Agricultural intensification in response to biofuel-related price increases and incentives for carbon sequestration require cropping systems that conserve organic matter and increase production. Minimum or no-till systems that reduce or eliminate fallow have potential for both, but altered soil moisture and nutrient dynamics compared conventional wheat-fallow systems are not well understood. Our goals for this seed grant research are to evaluate sustainability of conservation cropping systems in order to improve management approaches that intensify production and protect soil and environmental quality. Objectives include:

1. **Evaluate soil moisture, microbial community, and organic matter dynamics in conservation cropping systems used by Wyoming producers for ≥ 10 years:** Conduct on-farm studies that track soil processes and interactions during four seasonal periods for two years;
2. **Link soil process research to field and farm scale production activities through economic analysis:** Comparative assessment of systems evaluated in objective 1;
3. **Develop technological exchange among producers, advisers, and researchers from the northern Plains region:** Create an advisory committee to guide research questions and activities and ensure delivery of results;
4. **Develop extramurally funded integrated research, extension, and education program:** Results will support soil processes research within an integrated program at Wyoming’s new Sustainable Agriculture Research & Education Center.

Information on seasonal dynamics and fluxes in interrelated soil processes, and on profitability, are needed assist producers in making shifting management approaches to capitalize on benefits of conservation cropping systems.

Project Narrative

INTRODUCTION

Growth of corn-based ethanol production is expected to have ripple effects that increase crop prices and intensify production across the agricultural sector (Collins, 2006). Prices for wheat and other non-biofuel crops will increase as producers switch to corn and wheat replaces corn for livestock feeding (Elobeid et al., 2006). At the same time, incentives for carbon (C) sequestration may promote adoption of practices that store soil organic matter (SOM), especially conservation tillage (Lewandrowski et al., 2004). Cropping systems that reduce or eliminate tillage and fallow, and enable intensification, might become increasingly prevalent as producers respond to biofuel and carbon sequestration incentives. Additional knowledge about soil processes underlying such conservation cropping (CC) systems is needed.

In conventional crop-fallow systems (CF), over 75 percent of precipitation during the fallow phase can be lost to deep percolation, runoff, weeds, and evaporation (Shaver et al., 2002), but the remainder, built up during a year of fallow, provides an excess at the outset of the cropping year. Tillage turns crop residues under, stimulating microbial mineralization that favors bacteria over fungi (Frey et al., 1999). This leads to loss of nutrients, but generally provides an excess at the outset of the cropping year. Excess moisture and nutrients provide a buffer that can provide stable yields with variable precipitation. However, repeated tillage breaks down soil structure to expose previously protected SOM to mineralization (Bossuyt et al., 2002). The result is relatively high moisture and nutrient availability from the fallow effect early in the growing season and low availability later, when crops need resources for grain fill and building protein (Biederbeck et al., 1994). These effects become amplified through time as SOM stores are reduced and moisture and nutrient storage capacity is lost. Great Plains soils under long-term CF have lost from 30 to 60 percent of original SOM contents (Aguilar et al., 1988; Bowman et al., 1990).

Research from Great Plains dryland cropping systems indicates that, compared to CF, CC enhances soil porosity and water holding capacity (Shaver et al., 2002), organic matter and nutrient cycling (Biederbeck et al., 1994; Grant et al., 2002; Sherrod et al., 2005), and microbial community dynamics (Frey et al., 1999; Carpenter-Boggs et al., 2003). Conservation cropping systems that significantly reduce or eliminate tillage can conserve enough moisture to support continuous cropping without fallow, particularly when rotations include legumes and deep-rooted crops that diversify both SOM contributions and resource uptake (Grant et al., 2002; Halvorson et al., 2002). Annual grain yields from continuous cropping CC systems are often lower but average yields are higher or unchanged (Halvorson et al., 1999).

Still, uncertainty about economic and agronomic benefits of CC remains. Results from the literature on CC are situational, and economic studies do not account for recent increases in fuel and fertilizer prices, or for biofuel-related grain price increases. Early season resource excesses – the buffer provided by CF systems – are mostly lost with adoption of CC. Crop resource needs are more closely tied to availability so that CC systems are more reliant on in-season rainfall for supplying crops with moisture and nutrients. This means managers must be more attuned to soil moisture and nutrient levels and to increasing and protecting SOM. More complete knowledge of soil resource dynamics through the growing season is needed to optimize CC approaches, especially in challenging environments like those of Wyoming's dryland wheat producing areas.

In 2004, only 20 percent of wheat acres in Wyoming were planted with any kind of CC and less than five percent with no-till (CTIC, 2004), compared to significantly more in surrounding states. It has been suggested that Wyoming's challenging growing conditions make CC more difficult and less profitable (Dalrymple et al., 1993) than in other regions. Those growing conditions also make CC crucial for protection of fragile soils subject to high winds and intense thunder storms (Krall et al., 1991). The 20 percent of Wyoming producers that do practice no-till and other CC systems are probably perceptive managers with knowledge about balancing soil resources and crop needs to take advantage of documented benefits of CC systems. Comparing existing Wyoming CC and CF systems may provide an opportunity to better understand differences and improve management approaches with respect to soil fertility and moisture dynamics. Engaging producers and Cooperative Extension Service (CES) educators will ensure delivery of results at a time when producers may be considering intensified production.

Goals and Objectives

The immediate goal of this seed grant proposal is to evaluate agricultural sustainability of CC systems that Wyoming dryland wheat farmers have used for ten or more years. Our long-term goal is to develop or improve upon management approaches that both intensify production and protect soil and environmental quality. Four objectives guide the project:

1. **Evaluate effects of reduced tillage and diversified cropping systems used by Wyoming producers on soil properties that support sustainable production:** Conduct on-farm and laboratory studies of interactions among soil moisture, SOM, and microbial community dynamics in a range of CC systems for two cropping seasons;
2. **Link soil processes research to field and farm scale production activities using comparative economic analyses of cropping systems:** Comparative assessment of systems evaluated in objective 1 to link soil processes to farm-scale activities;
3. **Develop technological exchange among producers, agricultural advisers, and cropping system researchers from Wyoming and the region:** Create an advisory committee to guide research questions and activities;
4. **Develop integrated research, extension, and education program and apply for extramural support by the end of this seed grant:** Results will support combined soil processes research and an integrated, managed ecosystems program combining research, extension, and education at the new University of Wyoming Sustainable Agriculture Research and Education Center (SAREC).

RATIONALE AND SIGNIFICANCE

The proposed work would investigate soil processes and economic factors defining agricultural sustainability at a time when economists predict intensified production due to incentives for biofuels crops (Collins, 2006; Elobeid et al., 2006; Brown, 2007) and increased conservation due to incentives for soil-C sequestration (Lewandrowski et al., 2004). Both endeavors require increased knowledge about interactions among soil physical, chemical, and biological processes. Wyoming's relatively cold, dry, high elevation climate presents a unique opportunity to investigate these interactions and extend knowledge of progressive producers. Objectives 1 and 2 address Priority 1 of the NRI Soil Processes program:

> *"Interdisciplinary studies of the interrelationships among soil physical, chemical, and biological characteristics and processes related to soil quality and sustainability, especially regarding water and nutrients in relation to agricultural quality and productivity and environmental health. Multi-scale research that can help bridge the gap between molecular and mechanistic process studies and field-landscape- and/or watershed-scale studies is encouraged."* (P.66, 2007 NRICGP 2007 RFA)

Objectives 3 and 4 address the purpose of the NRI seed grant program by building a broad, multidisciplinary, multi-institutional research team with many levels of experience that will increase competitiveness for future research funding.

APPROACH

Objective 1: Evaluate effects of reduced tillage and diversified cropping systems used by Wyoming producers on soil properties that support sustainable production.

Research Questions: Do diversified cropping systems that reduce tillage and fallow enhance soil quality and alter seasonal moisture and nutrient dynamics in Wyoming wheat-producing areas? Do changes in moisture and nutrient dynamics impact crop yield and quality?
Summary: Conduct a two-year, season-long, on-farm comparative study of soil physical and chemical properties, soil hydrology, soil biology, soil organic matter, and grain yield and quality in dryland CC and CF systems in long-term use by Wyoming producers.

Study Area. The study will focus on Laramie, Platte, and Goshen Counties in Southeastern Wyoming where most intensive dryland grain production is located. Annual precipitation in this area averages about 300 mm, nearly 80 percent of which falls from April to September. Growing season length ranges from 120 to 150 days across the region.

Cropping Systems Selection. We propose to assemble a "research advisory committee" of researchers, producers, and agricultural advisers with the following roles:

1. To define the "conventional" system;
2. To select a spectrum of the cropping systems in long-term use (≥10yr) along a gradient from conventional to less and less tillage, to perennial cover. All fields will have previously been under long-term CF before conversion to CC;
3. To identify and facilitate collaboration with producers practicing each selected system;
4. Ongoing input on and assistance with research activities;
5. Dissemination of information from the research;
6. Develop program/proposal integrating research, extension, and education at SAREC.

Based on preliminary meetings with local experts and producers, examples of cropping systems that will likely be selected include:

1. conventional wheat-fallow;
2. organic wheat;
3. wheat-sunflower or millet-fallow;
4. stripper-header no-till (leaves whole stalk for wildlife cover);
5. continuous crop no-till, and;
6. long-term CRP or native prairie;

Field Sampling. We propose to maximize the different types of systems we can evaluate during repeated seasonal sampling within a sound statistical design:

1. Three fields (replicates) with similar soil-landscape parameters under each selected cropping system (system) will be identified using USDA Soil Surveys for southeastern Wyoming. Each system will be located on one farm so that management is constant;
2. Soils within a wheat phase of each cropping system (except permanent grass) will be sampled four times (season) each in 2008 and 2009 (year):
    a. early spring before fertilization or planting;
    b. early summer at peak growth rates;
    c. late summer/early fall harvest, and;
    d. late fall pre-freeze.
3. Soil cores (0- to 5-cm and 5- to 20-cm depth increments) will be collected from six points evenly spaced along three transects in each field. For soil physical and chemical properties (described below) samples will be composited by depth within transect. These

will be analyzed for within-field variability. For soil hydrology, biology and SOM dynamics, samples will be composited by field (one sample per depth per replicate);

4. One soil profile core from the center of each transect will be sampled by horizon;
5. Subsamples will immediately be extracted with 0.5M K_2SO_4 and packed on ice with soil samples for transport to the laboratory.

An estimated 18 study fields will be sampled eight times over the 2008 and 2009 growing seasons to monitor soil moisture, biology, and organic matter dynamics (~6 systems X 3 replications = ~18 study fields X 2 depths X 4 seasons X 2 years = ~288 total soil samples over two years. The actual number will depend on the number of different systems selected.

Soil Physical and Chemical Properties. Basic soil properties that impact crop production will be quantified by standard soil analysis methods. Analyses include particle-size distribution by the hydrometer method (Gee and Bauder, 1986), bulk density by the core method (Blake and Hartge, 1986), pH and EC by electrode (Thomas, 1996), inorganic C by gravimetric analysis (Loeppert and Suarez, 1996), and gravimetric moisture. These analyses will be done one time for the study fields (~108 surface samples and ~90 profile samples = 198 one-time samples).

Soil Hydrology. <u>Research Question:</u> *How do soil hydraulic properties differ by season and cropping/tillage system?* Higher levels of soil organic matter are expected to increase soil water retention and infiltration capacity. Furthermore, fewer disturbances under reduced tillage are likely to reduce wind and water erosion (because of more stable aggregates and macro-pores) and increase soil water storage (more infiltration, less soil evaporation). Soil wetness and soil temperature will be monitored on an hourly basis by installing automated sensors at five different depths in three selected fields. By limiting monitoring three sites with distinctly different cropping systems we can assess overall temporal trends with a feasible design. Soil water content and temperature data will be used to test whether different cropping systems show different soil moisture and temperature regimes. Effects of the cropping systems on infiltration capacity will be studied by conducting a minimum of three infiltration experiments for each of the 18 fields. Both tension infiltrometers and ring infiltrometers will be used in order to distinguish between unsaturated flow infiltration (only the soil matrix contributes) and saturated flow infiltration (both the soil matrix and the macro-pores contribute). The combined soil water content, soil temperature, and infiltration dataset will initially be used to quantify differences in soil hydrology between the different cropping systems. At a later stage, we envision using the data for process-oriented studies such as: 1) relating the observed changes in soil organic matter and soil microbiology to the observed soil moisture and temperature dynamics, and; 2) calibrating a numerical vadose zone model such as HYDRUS-1D (Simunek et al., 1998) or UNSAT-H (Fayer, 2000) to quantify vertical non-isothermal liquid water flow and vapor transport for the fields.

Soil Biology. <u>Research Question:</u> *How do soil microbial community characteristics differ by season and cropping/tillage system?* Tillage and crop residue management practices are major determinants of soil temperature and moisture regimes as well as the spatial and temporal availability of energy and nutrients to microbes (Doran and Linn, 1994). Reduced tillage cropping systems generally provide soil environmental conditions that more closely resemble the undisturbed soil environment than traditional tillage practices and therefore facilitate microbial activity (Doran and Linn, 1994; Stahl et al., 1999). Soil microbial community structure will be quantified by analysis of soil phospholipids fatty acid (PLFA) contents on a seasonal basis over two years (up to 288 samples).

Soil Organic Matter Dynamics. <u>Research Question:</u> *How do SOM characteristics and fluxes differ by season and cropping/tillage system?* Studies of minimum- and no-till practices in the Central and Northern Great Plains show that minimizing disturbance facilitates recovery of SOM lost during long-term intensive tillage (Six et al., 1998; Grant et al., 2002; Sherrod et al., 2005) and suggests that SOM dynamics change with better in-season water use. We propose to characterize labile-pool and active, slow, and passive SOM fractions:

Labile-pool SOM: To quantify available and readily mineralizable C and N, field-extracted samples will be analyzed for nitrate (NO_3^-) and ammonium (NH_4^+) using the Technicon TRAACS flow injection system (Technicon, Tarrytown, NY). Dissolved organic C will be measured using a UV-persulfate TOC Analyzer (Phoenix 8000, Tekman-Dorhmann, Cincinnati, OH). Dissolved organic N will be measured as NO_3^- generated upon N persulfate oxidation of $0.5M$ K_2SO_4 extracts (Cabrera and Beare, 1993). Microbial biomass will be analyzed on fresh, refrigerated soil samples within 72 hours of collection by fumigation-extraction (Horwath and Paul, 1994). Mineralizable C and N will be analyzed by aerobic incubation (Zibilske, 1994). These dynamic, temperature-, moisture-, and substrate-dependent SOM constituents will be measured seasonally over 2008 and 2009 (up to 288 total samples over two years).

Physical fractionation of SOM: To quantify SOM fractions known to respond to changes in soil C processes affected by management, physical fractionation of the soil will be done by separating the light, intra-aggregate (protected), and mineral-associated SOM fractions following the density fractionation method of Sohi et al. (2001), combined, on a subset of samples, with aggregate separation techniques of Six et al. (1998). The light, protected, and mineral-associated fractions separated by this method are chemically distinct and correspond to the active, slow, and passive SOM pools, respectively (Sohi et al., 2005). Total C and N in fractions and whole soils will be measured by Carlo Erba combustion on an EA1100 Soil C/N analyzer (Carlo Erba Instruments, Milan, Italy). Inorganic C (described under physical and chemical properties) will be subtracted from total C to determine total organic C. These relatively stable SOM pools will be analyzed in one set of samples from the study fields (~36 total samples).

Grain and Biomass Production. *Research Question: Do wheat yields differ by cropping/tillage system?* Grant et al. (2002) found that increased fertilizer rates were necessary to maintain grain yields in Saskatchewan as reduced disturbance created more diverse and growing soil microbial communities that rapidly immobilized available nutrients during initial conversion to no-till. Later, however, increasing mineralization rates in the growing SOM pool increased available nutrients. Halvorson et al. (2004) found that increased seasonal moisture increased yield potential in CC and required seasonal N fertilization. Grain will be harvested using SAREC's small-plot combine in a 1.5- x 6-m plot in each replicate field. Grain will be analyzed for yield, test weight, and grain protein.

Objective 2: Use economic analyses of cropping systems to link soil sample/plot scale research to field and farm scale production activities.

Research Question: Currently, only a small percentage eastern Wyoming wheat producers use CC systems. In contrast, adoption rates in neighboring states, whose farm systems share many similarities with those in eastern Wyoming, are notably higher. It is unclear why more producers in this region have not adopted CC systems. *One testable hypothesis is that eastern Wyoming farm systems exhibit unique characteristics that limit profitability of reduced tillage practices, as compared to conventional practices, and thereby preclude widespread adoption.* Objective 2 will link soil processes data from Objective 1 to farm scale outcomes by calculating and comparing the profitability of alternative tillage practices. Should reduced tillage practices applied to an eastern Wyoming setting prove profitable, soil characteristics can be eliminated as a cause of low adoption rates. Alternative hypotheses, such as a high option value for adoption, risk aversion, or the lack of targeted extension programs can then be tested.

Research on soil properties and processes suggest that CC systems increase effective soil moisture and reduce fuel, machine maintenance, and labor costs in the long-run compared to CF (Uri, 2000). Despite these findings, the profitability of CC in dryland wheat cropping systems of has not been definitively established in the literature. Williams (1988) found that risk-averse managers in wheat-fallow, wheat-sorghum-fallow, and sorghum-fallow cropping systems of western Kansas should prefer conservation tillage systems over conventional tillage systems. DeVuyst and Halvorson (2004) found that no-till and minimum-till systems combined with annual cropping and proper nitrogen (N) fertilization were more profitable than conventional crop-fallow in North Dakota spring wheat systems. Kaan et al. (2002), working with progressive producers in the Northeast Colorado Maximum Economic Yield Club, found that crop-crop-fallow rotations were more profitable than a wheat-fallow system. Epplin et al.(1994), in contrast, found that, for continuous winter wheat in Oklahoma, conventional tillage generates higher net returns than reduced tillage. Janosky et al. (2002) found that minimum tillage in wheat-fallow systems of eastern Washington is economically equivalent to conventional tillage. Halvorson et al. (2002) indicate that yields in a wheat-fallow system in eastern Colorado are not affected by no-till and reduced-till practices; however, they provide no economic analysis. We cannot conclude, based on existing literature, that reduced tillage practices are unprofitable in Wyoming. Data from Wyoming producers who practice CC versus CF practices are needed.

Comparative Economic Analysis. Standard enterprise budgeting techniques will be used to estimate total revenue, and total fixed and variable costs of production for each tillage practice considered. Janosky et al. (2002) provide an example application of this approach. Production costs will be determined using information provided by participating Wyoming producers and other experts. Based on previous studies, machinery maintenance, fuel, and labor costs under reduced tillage practices are expected to be lower in the long-run than under conventional tillage; herbicide and pesticide costs are expected to be higher, and the expected direction of machinery and fertilizer costs have not been well established in the literature (Epplin et al., 1983; Uri, 2000). Management costs might also be higher, due to the smaller gap between nutrient demand and supply under reduced tillage practices, and the resulting need to more closely monitor nutrient levels. Crop prices from recent history will be multiplied by wheat yield to calculate total revenue. Net returns to alternative tillage practices will then be compared to determine the relative profitability of reduced tillage practices as compared to CF.

Objective 3: Develop technological exchange among producers, research station managers, agricultural advisers, and cropping system researchers from Wyoming and the region.

The research advisory committee will provide valuable forums for interaction among extension educators and producers, as well as among new and established researchers from Wyoming, Nebraska, and Colorado that will lead to ongoing, extension and applied research.

Objective 4: Develop integrated research, extension, and education program and apply for extramural support by the end of this seed grant.

Data and collaborative relationships will contribute to planning long-term farming systems research at SAREC, as well as continued on-farm research, that incorporates components of the integrated farms in Wyoming. The next step would include building upon new concepts by creating or adapting management tools attuned to moisture and nutrient dynamics in various CC systems.

Statistical analysis

For soil properties that will be measured seasonally for two years, the design is a completely randomized split split plot in time with the effect of year being a random and the effect of season and system being fixed. In this analysis the main effect of year will be tested against the replicate x year term (error A), the main effect of season will be tested against the replicate x season term (error B), the main effect of season will be tested against the replicate x season term (error C), and all interactions will be tested against the error mean square (error D). Means for fixed terms that are deemed significant ($P < 0.10$) in the analysis will be separated using Fisher's protected LSD. Statistical calculations will be facilitated by use of the MIXED procedure of the Statistical Analysis System (SAS Institute, Version 9.1.3, Cary, NC).

For dependent variables not affected by the timeframe of this proposed work (e.g., texture, total organic C, SOM fractions, etc.) data will be analyzed using the GLM procedure, Statistical Analysis System, in a one-way analysis of variance set in a completely randomized design. If the F test for system indicates differences, means will be separated using Fisher's protected LSD.

Research Timeline

A search will begin for a qualified graduate student upon notification of funding. The research advisory committee will be formed and convene to begin defining relevant tillage/cropping systems and selecting study sites. If possible, funding would begin January 1, 2008, to facilitate two full growing seasons for field data collection.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 1	Planning, prep, site selection with advisory group (**Obj. 3**)			Soil & plant sampling and laboratory analyses (**Obj. 1**)								
				Information gathering for economic analysis (**Obj. 2**)								
Year 2	Continued field work, laboratory analyses, and data analysis (**Objs. 1 & 2**).									Data compilation, nat'l meeting presentation	NRI letters of Intent (**Obj. 4**); Final report	

Expected Outcomes

Outcomes from this research will be collaborative relationships and a rich dataset that will contribute to ongoing work. Results will be published in research journals and extension bulletins and will be presented at grower association meetings and scientific meetings.

Limitations and Potential Pitfalls

Statistical power is limited because replication is sacrificed to be able to sample more CC systems. Careful site selection will minimize variability and collection of soils data as covariates will improve statistical analyses. Management variability will be minimized by sampling each system within one farm only. By running the investigation for two growing seasons we will minimize limitations of short-term research in an unpredictable climate.

Potential Hazards

All personnel will be required to attend laboratory and field work safety training provided by the University of Wyoming Department of Environmental Health and Safety. They will be trained in field and laboratory procedures by experienced research technicians.

Key Personnel Roles & Responsibilities

The research team includes new and established faculty from the University of Wyoming stationed both on the Laramie campus and at a University research station in the proposed field area. It also includes two Cooperative Extension Service area agriculture educators. We think this configuration will facilitate the best possible link between researchers, agriculture advisers, and producers to ensure our work addresses relevant questions, resulting management concepts are practical, and information is delivered. This team will also facilitate the next step of developing an integrated research, extension, and education program based on results from this proposed seed grant.

Jay B. Norton, PD/PI, has previous project and personnel management experience with a three-year, $450,000 National Science Foundation project and projects ranging from $10,000 to $230,000 funded by the Kearney Foundation of Soil Science, the US Forest Service, the Renewable Resources Extension Act, and others. He has been director of a cooperative extension office and is currently director of the University of Wyoming Soil Resource Laboratory. He currently supervises two MS-level graduate students and a laboratory manager. His roles and responsibilities for this proposed seed grant project include:

- General project and budget management;
- Coordination and administration of field sample and data collection;
- Management of soil organic matter studies (Objective 1);
- Supervision and committee chair for graduate student;
- Supervision of research technician/laboratory manager;
- Data management and publication coordination;
- Annual and final report coordination;
- Development of integrated program based on results of this seed grant work.

Peter D. Stahl, Co-PI, directs the University of Wyoming Soil Ecology Laboratory. He will conduct soil microbiological field and laboratory studies (Objective 1) and will manage data analysis and publication of results for that part of the project. He may serve on the committee of the graduate student, depending on the focus of the thesis project that results from this proposed work.

Thijs J. Kelleners, Co-PI, directs the University of Wyoming Soil Physics Laboratory. He will conduct studies of soil hydraulic properties and moisture dynamics (Objective 1) and will manage data analysis and publication of results for that part of the project. He may serve on the committee of the graduate student, depending on the focus of the thesis project that results from this proposed work.

James M. Krall, Co-PI, is stationed at the University of Wyoming Sustainable Agriculture Research and Education Center in Lingle, Wyoming, where conducts cropping system studies both on farms and on the research station. He will manage crop harvest and grain analysis activities (Objective 1). With his long-term research and extension experience in eastern Wyoming, Dr. Krall will have a key role in identifying producer/collaborators and coordinating the research advisory committee (Objectives 1 and 3) as well as developing collaboration with soil and cropping system researchers from surrounding states. He may serve on the committee of the graduate student, depending on the focus of the thesis project that results from this proposed work.

Dannele E. Peck, Co-PI, will oversee economic analysis of the cropping systems studied during this project (Objective 2). She may serve on the committee of the graduate student, depending on the focus of the thesis project that results from this proposed work.

Dallas E. Mount and Sandra M. Frost, Co-PIs, will have key roles in facilitating technological exchange among producers and the research team. They will coordinate collaboration with producers and coordinate field data collection activities. As Wyoming Cooperative Extension Service Area Agriculture Educators, they will facilitate delivery of information/results in their respective areas.

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