Progress Report of

The Lower South Platte Irrigation Research and Demonstration Project And Final Report for the Parker Water and Sanitation District Water Supply Reserve Account Grant

January, 2010

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A Cooperative Project

of

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Executive Summary

This report presents the results of work completed under Parker Water and Sanitation District's Water Supply Reserve Account (WSRA) grant (Contract Routing No. 08 PDA 00071). While this report presents the results from work conducted under the WSRA grant, the Lower South Platte Irrigation Research and Demonstration Project is ongoing under the CWCB's Alternative Agricultural Transfer Methods Grant Program (Contract No. C-150426). Therefore, this report can be considered a final report for the WSRA grant funds and a progress report for the overall project.

Water scarcity is increasing in Colorado due in part to climate variability, drought, and groundwater depletion, but especially from increasing urban populations. Water right transfers from rural to urban use are anticipated as municipal populations grow because agriculture holds a majority of water rights in basins that are over appropriated. Significant fallowing of formerly-irrigated land is certain to follow these transfers.

Amidst a backdrop of increasing water scarcity, new approaches and technology for conserving agricultural water is desirable. Shifts from irrigated to fallowed ground or dryland cropping will significantly impact the economic viability of agricultural producers and have far reaching indirect effects on businesses and communities that support irrigated agriculture. Agricultural and municipal stakeholders are very concerned about the impacts of increased water transfers.

A cooperative project between Parker Water and Sanitation District (PWSD) and Colorado State University was initiated in 2007 to evaluate cropping systems options that address both production and water conservation goals. This project benefitted from funding from the Colorado Water Conservation Board, PWSD, the CSU Agriculture Experiment Station and CSU Extension. The principle objective of this project is to develop a model to sustain irrigated agriculture while meeting the increasing urban water needs in Colorado. This project evaluates alternatives to agricultural land dry-up in a cropping system study and is conducted in three phases: 1. Concept Discovery and Feasibility Study, 2. Viable Cropping Practices with Reduced Consumptive Water Use, and 3. Regional Adoption and Economic Impacts.

The objective of the first study phase was to identify and evaluate a feasible set of cropping systems that have potential to meet municipal and industrial water demands while sustaining agricultural production. The approach used was to evaluate existing research and published information, to seek input and suggestions from a focus group, and to conduct personal interviews with irrigators in the South Platte River Basin. Cropping systems with potential to reduce consumptive use by at least 20% compared to continuous corn with full irrigation were sought. The discovery phase identified rotational cropping, limited irrigation, and partial season irrigation cropping systems as potential water conserving practices. Rotational cropping refers to sequences of full irrigation crops with fallow or dryland crops in subsequent years. Potential dryland crops for rotational cropping include winter wheat, annual forage crops, corn, sunflower, and proso millet. Limited irrigation cropping is the application of less water than required to meet the full water demand of the crop, with an emphasis on applying the limited water during critical crop growth stages to optimize the beneficial effects of the water. All crops in a limited irrigation system receive irrigation but at lower levels than fully irrigated crops. Potential limited irrigation crops identified are corn, winter wheat, annual forages, sugarbeet, sunflower, soybean, and canola. Partial season irrigation is a combination of full irrigation during part of the growing season with no irrigation during other parts of the same growing season. Partial season irrigation has relevance to perennial crops with documented success especially for alfalfa. A set of proposed cropping systems was identified for further evaluation in Phase 2.

Phase 2 of the study is a controlled small plot and an on-farm field-scale evaluation of water conserving cropping systems. The objectives of the controlled research are to document irrigation water application, consumptive water use, crop productivity, and profitability of representative water conserving cropping systems. A controlled research site was established in Iliff, Colorado with a linear-move sprinkler irrigation system customized for research and with an on-site weather station. The site facilitates research on approximately 250 small plots where a water balance approach is used to determine evapotranspiration (ET) and drainage, crop yield, and water use efficiency. The objective of the on-farm demonstrations is to evaluate the practicality and feasibility of the cropping systems when practiced on full sized fields with farmers managing the system. Detailed results of the 2008 cropping season are reported in the main portion of the document. In summary: rotational cropping systems that alternate irrigated crops with fallow or dryland crops were effective at reducing ET, with average ET reductions of 30-40% compared to continuous corn. Rotating irrigated crops with dryland crops was a much more water efficient approach than rotating with a non-cropped fallow because of high evaporation and drainage during fallow. Annual forage crops such as triticale are good choices for the dryland phase of these rotations because they use residual water and nutrients from irrigated crops and have lower production risk than dryland grain crops. Corn produced after a fallow period or a dryland crop had a higher yield and water use efficiency than continuous corn, illustrating the benefits of crop rotation to maximize water use efficiency.

Limited irrigation cropping systems reduced ET by an average of 30%. Both rotational cropping and limited irrigation of sugarbeet and an annual forage crop saved 40% of the reference crop ET. Sugarbeet is drought tolerant and shows good adaptability to limited irrigation. Soybean had moderate yield but is a lower water use crop than corn even under full irrigation. Its growth and performance suggested it may be a good alternative crop for water conserving cropping systems in the South Platte River basin. While rotational cropping and limited irrigation systems both reduced ET relative to full irrigation, continuous corn, the rotational cropping systems have an economic advantage over limited irrigation systems because they maximize yields of profitable cash crops in the irrigated phase of the rotation and use lower input crops in the dryland phase.

An on-farm evaluation of limited irrigation corn established that practices can be successfully implemented into production scale, farmer-managed systems and can maintain viable levels of production. An on-farm evaluation of partial season irrigation of alfalfa showed that irrigation management alone cannot be used to control ET from a deep rooted crop in high water table environments. Partial season irrigation did effectively reduce ET for the more shallow rooted grass meadow hay. While water savings would be greatest by complete dry-up of irrigated land, the crop production in dryland is so low that it severely limits economic sustainability. Limited irrigation and rotational cropping systems should be considered as viable approaches to meeting changing water needs while maintaining irrigated agricultural systems.

An objective of the third project phase was to develop a regional economic impact model to quantify the direct and indirect economic effects of adopting alternative irrigation systems. The South Platte River basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. Each irrigated acre is estimated to generate economic activity equivalent to $690 in the basin. Economic effects of drying up irrigated land will be substantial, especially in sparsely populated rural areas with few other alternatives. The project also sought to understand the potential of South Platte farms to adopt limited irrigation, rotational cropping, partial season irrigation and the barriers to adoption. A farmer survey was a key instrument to determine the potential water leasing rather than 'buy and dry' fallowing, as well as the adoption of limited irrigation strategies. Importantly, the limited irrigation cropland remains in production and mitigates reduced economic effects of dry-up. The producer survey gauged the amount of water that might be made available in water leasing arrangements and the necessary compensation needed for farmers to participate in a lease arrangement. More than 60% of survey respondents are willing to lease water, with an aggregate of between 50,000 and 60,000 acre-feet of potential water supplies just among those who responded. Preferred compensation ranges from $300 - $500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity.

This project has a large outreach education component. Results from the demonstration sites are the basis of field days, workshops, seminars, and web-based information. In 2007 through 2009, educational outreach programs reached nearly 3,000 people consisting of farms, agricultural professionals, agency staff, water and watershed organizations, community leaders, and the general public. A spreadsheet decision tool has been developed to help farmers determine the tradeoffs of various limited irrigation and water saving strategies. The spreadsheet allows farm managers to input their own business information and contrast alternative water saving cropping strategies. There is a large and growing interest and demand for information about the potential of limited irrigation cropping systems in Colorado and a need to continue this project into the future.

The Lower South Platte Irrigation Research and Demonstration Project: Progress Report

January 2010

Statement of Problem

The combination of climate variability, drought, groundwater depletion, and increasing urban competition for water has created water shortages for irrigated agriculture in Colorado and is driving the need to increase water use efficiency. A statewide water supply survey predicts that 428,000 irrigated farm acres will be converted to dryland cropping or pasture within the next 15 years, mostly due to transfer of water from agricultural uses to meet the water needs associated with population growth (Colorado Water Conservation Board, 2004). A shift from irrigated to dryland cropping would significantly impact the economic viability of agricultural producers and have far reaching indirect effects on businesses and communities that support irrigated agriculture. One component of this project is to evaluate the potential economic impact of drying up irrigated farmland.

Water conservation options other than complete land fallowing are desirable because of the potential economic and environmental concerns associated with conversion to dryland. A cooperative project between Parker Water and Sanitation District and Colorado State University was initiated in 2007 to evaluate cropping systems options that address both crop production and water conservation goals. The project was developed in three phases: 1. Concept Discovery and Feasibility Study, 2. Viable Cropping Practices with Reduced Consumptive Water Use, and 3. Regional Adoption and Economic Impacts.

Project Objective

The principle objective of this project is to develop a model to sustain irrigated agriculture while meeting the increasing urban water needs in Colorado.

Work Completed To Date

Work on this project from its inception through 2008 was partially funded by PWSD and the CWCB WSRA grant to PWSD. This report summarizes the work that has been completed under the WSRA grant.

PHASE 1: CONCEPT DISCOVERY AND FEASIBILITY STUDY

Phase 1: Background and Objective

This phase's objective is to identify and evaluate a feasible set of cropping systems that have potential to meet municipal and industrial water demands while sustaining agricultural production. For a cropping system to be part of the feasible set, it was determined that it should meet the following criteria:

- Reduce consumptive use by at least 20% from an historical baseline. The baseline selected for the purpose of this study is a full irrigation, continuous grain corn system with conventional farming and irrigation approaches.
- Consumptive use savings can be scientifically documented for use in court proceedings.
- The cropping system is profitable for farmers under expected prices and yields.
- The cropping system can be adapted with existing technology, equipment, capital and labor in the South Platte River Basin.

Phase 1: Approach

The approach used to obtain a set of feasible, water conserving cropping systems was to 1) evaluate existing research and published information, 2) seek input and suggestions from a focus group, and 3) conduct personal interviews with irrigators in the South Platte River Basin. The evaluation of existing research and published materials focused specifically on the central Great Plains region because of its relevance to environmental conditions in Colorado. Information was gathered from extension publications, research journals, and on-going research. The focus group was done as a part of the established project advisory committee (see Appendix 1) during a meeting held May 21, 2007. The focus group included a brief presentation by the project staff followed by open discussion and input by the committee. The personal interviews with irrigators were conducted in March and April of 2007. The interviews were conducted with farmers leasing land from Parker Water and Sanitation District between the towns of Iliff and Proctor (names held confidential). At each interview, an overview of the goals of the project was provided and the following questions were used to help guide producer input:

- In what ways do you feel that agricultural water rights are changing or may change in Colorado?
- How can the CSU study best address your concerns about the future of Colorado water?
- What potential water saving cropping options would you like to be considered in the study?
- Will you please share your comments and concerns about the limited irrigation cropping systems described by CSU?
- What outcomes do you hope this study will produce?
- Would you be willing to participate in an on-farm study of limited irrigation or rotational fallowing?

The ideas obtained from research, focus group, and farmer interviews were combined and evaluated according to the listed criteria to produce a feasible set of water saving cropping alternatives.

Phase 1: Results

Evaluation of existing research and published information. There is a large body of research related to the efficient use of irrigation and results have been utilized to develop various computer models that schedule irrigations, guide cropping system planning, or even predict crop yield as a function of moisture stress. Results of these experiments and models are highly variable due to the large number of factors that ultimately affect crop yield. While many studies report applied irrigation and irrigation efficiency, fewer studies report a complete water balance with specific information on consumptive water use by the crop. Further, there is little research that has integrated the various elements of a cropping system on water use. The research and published information reported here were chosen because of the potential application to water conserving cropping systems under the broader goals of the project.

A few reported research projects have evaluated cropping systems in *limited irrigation* scenarios in the Great Plains (Hergert et al., 1996; Schneekloth et al., 1991). Limited irrigation is defined as the application of less water than required to meet the full ET demand of the crop, with an emphasis on applying the limited water during critical crop growth stages. A Nebraska study illustrated that under limited irrigation, corn produced an average of 9% higher yield when grown in a wheat-corn-sorghum rotation as compared to continuous corn (Schneekloth et al., 1991). The effect of rotation on corn yield was due to changes in soil water storage at planting time, and not to improved water use efficiency. In the same study, the limited irrigation corn yields (average irrigation of 150 mm) increased by 75% when compared to dryland corn. Yield increase depends on precipitation, and ranged from 38% in a wet year to 120% in a dry year. Results of limited irrigation for wheat showed a similar trend, with no yield improvement from irrigation in two out of four years and as much as a 4-fold increase the other years. Yield increased by an average of 18% for full irrigation corn and 0% for full irrigation wheat when compared to the limited irrigation systems, illustrating that the return per unit of irrigation water was less for applied water amounts above that used in the limited irrigation system. Some additional studies confirm that the yield increase per unit of irrigation declines with increasing irrigation amounts (Hergert et al., 1993).

Crop residues at the soil surface influence the water balance by increasing water capture and retention. Numerous studies have documented improved crop yields, water use efficiencies, and water storage efficiencies with reduced or no-till systems relative to conventional tillage. The greatest gains have been observed in dryland cropping systems. Reduced tillage is also an important element in limited irrigation systems. Residue quantities at the soil surface are a function of accumulation, disturbance, and decomposition. Higher biomass production equates to greater accumulation of crop residues. Conversion of fully irrigated cropping systems to limited irrigation will reduce productivity and potential accumulation of crop residues at the soil surface. Inversely, crop residue accumulation will be significantly greater under limited irrigation as a result of higher yield when compared to dryland systems. Reducing residue disturbing operations in the cropping system (chopping, tillage, fertilizer injection, etc) conserves the integrity of the residue at the soil surface. Finally, environmental conditions and the residue composition determine the decomposition rates of the crop residues. A Texas limited irrigation study contrasted production and water conservation variables among tillage practices in a wheat-sorghum-fallow rotation (Unger, 1994). In this study, there were no effects of tillage practice on yield of wheat or sorghum. The inclusion of a fallow period allowed for adequate moisture storage for wheat, regardless of tillage. This illustrates that the benefits of reduced tillage over conventional tillage is most evident in cropping systems that impose water stress, or by nature are intensive systems. Norwood et al. (1990) conducted a long-term study at Garden City and Tribune, KS, to evaluate the effects of reduced tillage and varying cropping systems on yield of dryland winter wheat and grain sorghum. Conventional, reduced, minimum, and no-tillage systems were compared in wheat-fallow and wheat-sorghum-fallow rotation. These treatments were compared with conventional tillage in sorghum-fallow, continuous sorghum, and continuous wheat. An increase of available soil water yield occurred because of a reduction in tillage. Reduced tillage resulted in increased wheat-fallow and wheat-sorghum-fallow yields at all locations. At the Garden City site, sorghum yields under the wheat-sorghum-fallow system demonstrated a 67% increase over continuous sorghum yields. Reduced tillage of wheat-sorghum-fallow at Tribune produced 73% higher yields than continuous sorghum and conventional tillage of wheat-sorghum-fallow produced yields equivalent to continuous sorghum yields, 60% of the time.

Irrigation timing relative to critical crop growth stages is an important management tool that can be used to maximize the efficiency of limited irrigation water use. The basic premise is to avoid water stress during key physiological growth stages that influence yield, while saving water by permitting some water stress during less critical growth stages. Critical growth stages and the effects of water stress vary with crop species. For example, grain sorghum in Kansas (Hooker, 1985) showed that it was important to have adequate water supply at the growth differentiation stage. A single irrigation at this stage resulted in grain yields that were reduced less than 10% of yields from a full irrigation comparison, while the irrigation was reduced by 40%. The efficiency of applied water was significantly higher for the limited irrigation, growth stage timed irrigation compared to conventional approaches. The efficiency of limited irrigation applied at critical growth stages varied widely from year to year depending on precipitation. As discussed previously, achieving greatest irrigation water use efficiency on a farm scale requires some flexibility on how, when, and where to apply water based on precipitation and soil moisture conditions. A study done by Schneekloth et al. (2004), compared water management strategies to reduce the amount of water applied during the vegetative and late grain fill growth periods of corn. Furrow irrigation management research was conducted at the West Central Research and Extension Center of the University of Nebraska at North Platte, NE. Gated-pipe was used to supply five irrigation water strategies for this experiment, including rainfed, limited

(150mm and 250mm), late initiation of irrigation, and full irrigation to meet ET demand. The late-initiation of irrigation system delayed any irrigation until the reproductive stages of crop growth. Results indicate average grain yields (1998-2000) for corn receiving late initiation water treatment were 2% less than yields produced by full irrigation (Full = 12.8 Mg/ha, Late = 12.6 Mg/ha). Average grain yields were 3% less for corn receiving 250 mm of water, compared with full irrigation (250mm = 12.4 Mg/ha). The average grain yields of corn receiving 150 mm of water were 90% of yields with full irrigation (150mm = 11.7 Mg/ha). With regards to rainfed corn treatments, average yields reflected a 50% decrease compared to corn receiving full irrigation (Rainfed = 6.6 Mg/ha). These results illustrate higher water use efficiency for limited irrigation applied during critical growth stages of corn compared to full irrigation.

Stewart et al. (1981) conducted a study which used a system that fully irrigated the upper one-half of a field, with limited irrigation on the next one-fourth of the field and a dryland system on the remaining one-quarter of the field that utilized tail-water runoff from the fully irrigated section of the field plot. Six irrigation treatments were applied during the course of this study, including: dryland, dryland-furrow dammed, every furrow fully irrigated (total irrigation=600 mm), every furrow partially irrigated (total irrigation=250 mm), every second furrow partially irrigated (total irrigation 185 mm), and every third furrow partially irrigated (total irrigation 125 mm). Results indicate that all water applied in irrigation furrows was retained in the field for the partially irrigated systems, while the fully irrigated system had as much as 40% of the applied water lost in tailwater. The every furrow partially irrigated system produced 90% of the grain yield as compared with full irrigation while the every second and every third furrow treatments yielded 80% and 63% of fully irrigate plots, respectively. The dryland treatments yielded only 35% of the fully irrigated system. This study shows the potential of limited irrigation to save water while maintaining reasonable crop yields well above the potential when completely drying up irrigated land. It further illustrates a high potential for optimizing the efficient use of limited amounts of irrigation water in corn.

Research was conducted by Norwood and Dumler (2002) at Garden City, KS comparing grain yield and water use of short (NK Brand 4640 Bt) and long season (NK Brand 7333 Bt) corn hybrids, in the wheat-corn-fallow system, to determine if limited irrigation is a viable alternative to dryland in an area of declining ground water. Irrigation regimes included dryland, a 150 mm water application, and a 300 mm water application. Average grain yields from 1998-2000 for dryland and 150 mm irrigation of Hybrid 1 were 6.38 (72% of 300mm) and 8.23 (97% of 300mm), respectively. For Hybrid 2, average yields for the same period were 5.75 (59% of 300mm) and 9.04 (93% of 300mm), respectively. In terms of water use efficiency (WUE), the dryland and 150 mm irrigation for both hybrids exceeded the WUEs of the two irrigation regime. However, there was no significant difference in the WUEs of both hybrids at the dryland and one irrigation levels.

Klocke et al. (1996) found that growing season use of stored water strongly influences the soil's capacity to store off-season precipitation and minimizes leaching in crop rotations of corn, corn-soybean, and winter wheat. Limited irrigation (150 mm) created approximately the same soil water storage as rainfed crops during the non-growing season. The limited irrigation regime reduced the potential of off-season leaching and produced 82-89% of fully irrigated yields (18% reduction for continuous cropping and 11% for wheat-corn-soybeans). Conversely, fully-irrigated crops had the highest leaching potential because of increase available soil water at the end of the growing season. The authors also state, "an irrigator raising continuous corn with an adequate water supply could reduce his net return to land, labor, and management by $130 per ha ($52 per acre) by changing from full irrigation to limited irrigation management." In the South Platte River basin, the results of this study suggest the potential concern of altered return flows resulting from limited irrigation strategies.

Several existing research projects in Colorado were evaluated as part of the concept discovery process. One research project being conducted by Northern Colorado Water Conservancy District and Colorado State University evaluates the potential of partial season irrigation of alfalfa. Partial season irritation is defined as irrigation to meet full demand of the crop for a portion of the growing season in combination with periods of no irrigation. This approach has particular relevance to perennial forage crops like alfalfa. Alfalfa is of further interest because it is a crop with high potential for water savings in Colorado because 1) it has a relatively high consumptive use, and 2) the land area in irrigated alfalfa is significant. The field study evaluated four irrigation strategies: Full Irrigation (FI), Stop Irrigation After 2nd Cutting

(S2), spring and Fall Irrigation (SF), and Stop Irrigation After 1st Cutting (S1). Changes in yield, consumptive water use (ET), water-use efficiency (WUE), stand density, and forage quality were measured. Results of the study showed that yield decreased with ET in a fashion similar to previous research. Over a two year period, average yields were reduced by 3.1, 3.5 and 6.5 Mg ha^{-1} compared to the FI treatment for the S2, SF, and S1 treatments, respectively. Average ET was reduced by 28.2, 27.2, 48.2 cm compared to the FI treatment for the S2, SF, and S1 treatments, respectively. WUE increased as irrigation decreased with an average WUE of 0.251, 0.327, 0.311, and 0.351 Mg ha^{-1} cm^{-1} for the FI, S2, SF, and S1 treatments, respectively. Also, alfalfa crown density, measured to assess stand health, was higher in the S2 and S1 treatments compared to the FI and SF treatments. Forage quality increased as ET decreased, which may help economically offset the reduced yield. Partial season irrigation of alfalfa is a promising approach to conserve agricultural water to meet changing water demand while still keeping an irrigated agricultural system in production. One challenge with alfalfa is the deep rooting potential of this crop. Alfalfa can develop root systems more than 2 meters deep and has the potential to access water from high water tables when present. Partial season irrigation may be promising for perennial grass hay species that have shallow root development or for alfalfa where the water table is deep enough to limit access to water by roots.

A field study evaluating limited irrigation corn, sunflower, and soybean was conducted near Burlington, CO from 2006-2008. Both soybean and sunflower proved to be adaptable to limited irrigation systems. A similar study in Akron, CO showed that sunflowers are most responsive to limited irrigation applied at the bud initiation and early flower growth stages (Schneekloth, personal communication). Another study evaluated limited irrigation soybean, with a total irrigation of 6 inches. Limited irrigation soybean yielded 88% of the full irrigation treatment in North Platte, NE. The study did not quantify ET.

An on-going research study at the CSU Agricultural Research, Development, and Education Center near Fort Collins is evaluating limited irrigation practices for crop rotations that include alfalfa, corn, wheat, and sunflower. The project has shown reduced yields but improved water use efficiency through growth stage timed limited irrigation for corn. Sunflower and wheat were also shown to have good potential in water saving cropping practices. An associated demonstration of furrow-irrigated, limited irrigation corn conducted on a private farm near LaSalle, Colorado has shown that limited irrigation corn can be done in a production setting.

The Department of Soil and Crop Sciences at Colorado State University has been leading in dryland cropping systems research in Eastern Colorado for more than two decades. It is well established that winter wheat forms the base of a dryland crop rotation, with the frequency of summer fallow varying from every other year to continuous cropping without fallow. Typical crops used in dryland rotations with wheat include corn, proso millet, hay millet, forage sorghum, triticale, and sunflower. Established dryland production methods are expected to apply to rotational cropping with dryland crops in rotation with irrigated crops.

Focus Group Meeting and Interviews with Irrigators. A focus group meeting was held May 21, 2007 in Atwood, Colorado and consisted of members of the project advisory committee (Appendix 1). Interviews of irrigators were conducted during May and June, 2007. The following key issues were highlighted from participants:

- Water saving cropping practices evaluated should consider return flows. Systems that have negative water supply effects to downstream users should not be promoted by the study.
- Practices that address soil salinity may be an efficient means of improving crop water use efficiency. Some local crop consultants are recommending the use of gypsum as an amendment for salt-affected soils.
- Studies should include traditional crops as much or more than alternative crops. Sugarbeet should be included.
- In ditch systems, timing of irrigation is controlled by availability of water in the ditch and cannot be completely controlled, limiting the ability to apply a growth stage based irrigation system.
- Quantification of water use is complicated in areas with high water table and for crops with deep rooting systems. This is an especially relevant concern for alfalfa in the South Platte River basin.

- Crop insurance is a significant hurdle for limited irrigation cropping practices.
- Need for detailed monitoring of crop water stress, water use, precipitation, and irrigation return flows.

Phase 1: Summary

Based on the results of the literature review, local studies, and input from the interviews and the focus group, a list of candidate crops were identified with potential for limited irrigation, dryland, or partial season irrigation (Table 1). Several rotations were proposed using these crops as in rotational cropping, limited irrigation, or partial season irrigation systems were proposed (Table 2). These cropping systems are selected with the expectation that they will reduce consumptive use by at least 20% compared to continuous corn with full irrigation. The options include rotations with fallow and dryland crops. The feasibility study also attempted to estimate the potential profitability for farmers, but there currently is not enough information on input cost and yields of alternative irrigation practices to verify these. Most of the crops can be produced by adaption of existing technology, equipment, capital and labor in the South Platte River Basin. There may not currently be a local market for some of the alternative crops such as soybean and canola.

Table 1. Crops identified with good potential for inclusion in limited irrigation, dryland, or partial season irrigation.

Crops for Limited Irrigation	Dryland Crops	Crops for Partial Season Irrigation
Corn Sunflower Sugarbeet Wheat Soybean Canola Annual Forage Crops (sorghum, foxtail millet, triticale)	Wheat Annual Forage Crops (sorghum, foxtail millet, triticale) Corn Proso Millet Sunflower	Alfalfa Alfalfa/Grass Mixtures Cool Season Perennial Forage Grasses Warm Season Perennial Forage Grasses

Table 2. Crop rotations selected for rotational cropping, limited irrigation, and partial season irrigation field study.

Rotation Fallow Systems
Corn – Fallow
Corn – Fallow – Dryland Winter Wheat
Sugar beet – Dryland Hay Millet
Corn – Soybean – Dryland Winter Wheat – Winter Canola
Corn – Sunflower – Winter Wheat – Dryland Triticale
Limited Irrigation Systems
Sugar beet – Hay Millet
Corn – Soybean – Winter Wheat – Winter Canola
Corn – Sunflower – Winter Wheat – Triticale
Partial Season Irrigation Systems
Various species of perennial grass hay
Alfalfa
Alfalfa grass mixtures

Phase 2: Developing Viable Cropping Practices With Reduced Consumptive Water Use

Phase 2: Background and Objectives

While Phase 1 established a feasible set of alternatives, basic field research is needed to scientifically document water savings and profitability. Phase 2 of the study uses field research in a controlled setting and in on-farm settings to evaluate water-conserving cropping systems. The objectives of the controlled research are to document irrigation water application, consumptive water use, crop productivity, and profitability. The controlled research is designed to allow scientifically defendable, replicated research plots with individualized control of irrigation amounts. The objective of the on-farm demonstrations is to evaluate the practicality and feasibility of the cropping systems when practiced on full-sized fields with farmers managing the system.

Phase 2: Approach

Controlled Research. The controlled research is located on a 35-acre field approximately 1 mile to the East of Iliff, CO (Figure 1). The predominant soil at this site is Loveland Clay Loam with lesser amounts of Nunn Clay Loam. The soils are formed in flood plains and stream terraces from the nearby South Platte River and consist of calcareous loamy alluvium over mottled sand and gravel. The depth of topsoil above the sand and gravel layers is very heterogeneous, creating variable above-ground plant growth. A typical profile consists of 24 inches of clay loam, over 10 inches of sandy clay loam, over gravelly coarse sand. The depth of clay loam textured materials varies widely and ranges from only 24 inches thick to as much as 50 inches thick. The soils are somewhat poorly drained. A field drainage ditch runs approximately 10 feet below the soil surface parallel to the north boundary of the field and improves the natural drainage of the site. The native vegetation type is salt meadow with mixed perennial grasses. The site has been managed under furrow irrigation of annual small grain and forage crops. This site is typical of much of the irrigated farmland in close proximity to the South Platte River.

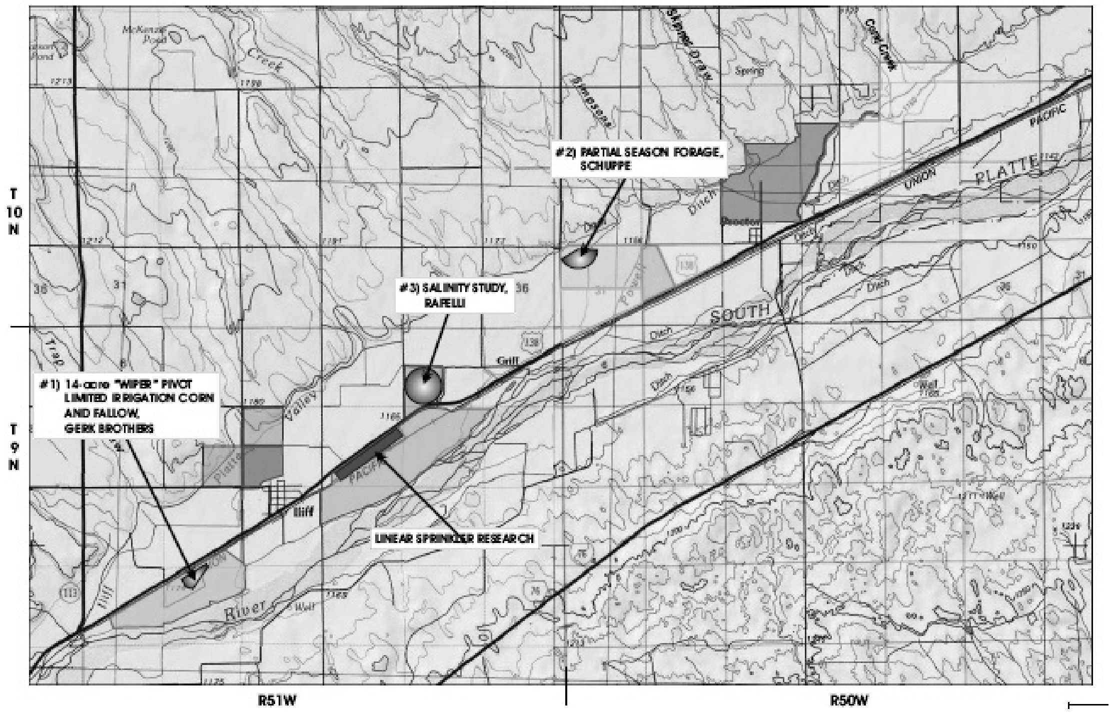

Figure 1. Locations of controlled, linear-move sprinkler and on-farm research sites. Image provided by Lytle Water Solutions.

Figure 2. Soils map of the controlled research site. The predominant soil is a Loveland Clay Loam (58) with lesser amounts of the Nunn Clay Loam (83)

A custom-manufactured, linear-move sprinkler system was erected on the site in June, 2007 (manufacturer T-L Irrigation, Hastings, NE; local supplier Pivots Plus, Iliff, CO). The sprinkler has a length of approximately 700 feet divided among four tower spans. Water is supplied to the sprinkler from a parallel irrigation ditch through an integrated pump and filter system. The ditch is filled with groundwater pumped from an on-site well using a submersible pump set in the well. The length of the sprinkler is divided into 11 individually-controlled, 60-foot wide sections that make up the width of individual research plots. Water to each section is controlled by a hydraulic valve actuated with a manual switch in a control panel on the system tractor. Water is delivered through 12 individual drop nozzles in each 60-foot section with 5-foot nozzle spacing. The travel distance of the sprinkler is approximately 2,200 feet. The field length is divided into three main ranges, each separated by an access lane planted to grass. Each main range is further subdivided into 4 plot segments of approximately 125 feet. The linear move sprinkler allows the study to include side-by-side treatments of water application levels under similar soil, climatic and geographic conditions. Further, the sprinkler allows intensive comparison of many different irrigation and crop regimes, precise control and documentation of water savings, and efficient use of land and labor resources in the research area.

A research design was created that allowed evaluation of the full set of feasible cropping systems identified in Phase 1 of the study (see detailed plot map, Appendix 2). The design created approximately 250 individual plots and was organized to group large blocks of individual crops to facilitate farm operations. Blocks of crops rotate annually throughout the study site during the life of the study. Every crop phase within each rotation is present every year. For example, the corn, wheat, and fallow phases of that rotation are all present during each year of the study. In addition, there are 4 replications of each cropping system, which facilitates the statistical comparisons among cropping systems. Thus, the number of plots devoted to each cropping system is equal to the product of the number of phases in the rotation and 4 replications. For example, the corn-wheat-fallow rotation has 3 phases x 4 replications for a total of 12 plots. The plots were arranged in a randomized, strip plot design.

An on-site weather station was installed to monitor and record weather information and for use in calculating ET by accepted energy balance methods. The weather station is part of the

CoAgMet network (www.coagmet.com; Iliff station). Weather station sensors measure air temperature, humidity, wind speed and direction, solar radiation, precipitation, and soil temperature. Data is logged hourly and reported daily. An alfalfa-based reference ET is calculated and reported using the Penman-Kimberly model. Soil moisture is determined using a neutron probe moisture meter (Campbell Pacific Nuclear, 503DR Hydroprobe). Access tubes made of galvanized steel conduit were installed in the center of each plot to a depth of 6 feet. A calibration was performed to relate soil volumetric water content to the ratio of the raw neutron probe reading and a daily standard count (Figure 3). Soil moisture was assessed weekly from planting till harvest of summer crops and during active growth periods of winter annual crops.

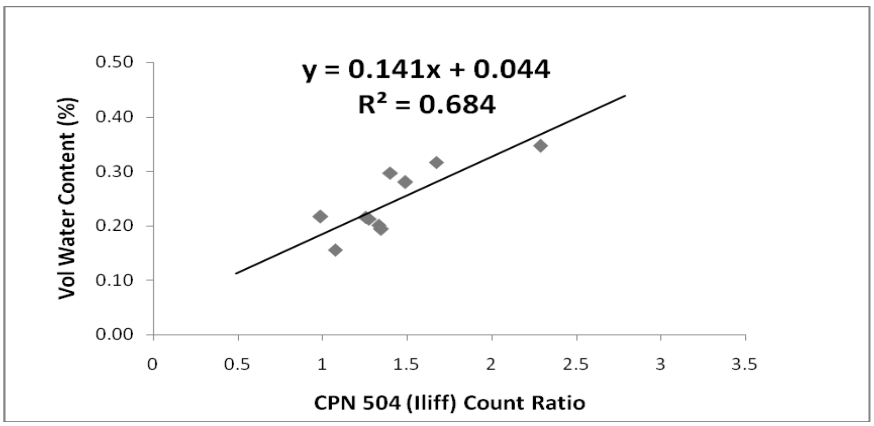

Figure 3. Calibration relationship of the ratio between the reading and a standard reading from the neutron probe soil moisture meter (CPN 503) and the volumeteric soil water content.

ET was determined using a water balance method. This method balances all of the water inputs and losses according to the following formula:

$$ET = \Delta\Theta + I + P - R - D$$

Where:

$\Delta\Theta$ is the change in soil moisture

I is the amount of irrigation applied.

P is the amount of precipitation.

R is runoff

D is the deep percolation

The $\Delta\Theta$ value was calculated from weekly soil moisture measurements with a neutron probe in 1 foot increments down to 6 feet for annual crops and 10 feet for alfalfa. Precipitation was obtained from a weather station, which also measured temperature, solar radiation, humidity, and wind. The experiment did not measure runoff or deep percolation. The combination of these values was estimated using weekly soil moisture measurements and daily rainfall and irrigation amounts. Specifically, the soil water holding capacity was determined individually at the location of each neutron probe access tube in the study. Weekly measured water content was then used to determine the soil water deficit at the time of the measurement. A daily water budget was then used to update the soil water deficit. Daily ET was calculated using the reference ET value and a crop specific crop coefficient. Water loss by drainage or runoff was calculated on all days when the daily water input from rain and irrigation exceeded the soil water deficit. In this report, water losses are referred to as drainage because little runoff was observed. Total grain and biomass yields were determined and water use efficiency was calculated as the ratio of grain or biomass yield to ET.

Crops were managed according to conventional practices and in cooperation between CSU and local farmers. The 2007 cropping season was the first year of the study, but was not an ideal year for data collection because the sprinkler was not useable until late in the growing season. The first winter annual crops (wheat, triticale, and canola) were planted in the fall of 2007 and were evaluated in 2008. The perennial hay crops were planted in the fall of 2007 but had very poor establishment. They were reseeded in the summer of 2008 and established well. The first irrigation comparisons for perennial hay crops will be for production during 2009. A plot harvester with precision weighing system was used to determine crop yields for all annual grain crops. Grain samples from every plot were collected for determination of grain moisture content and test weight. Forage crop yield was determined by collecting the forage from 20 feet of individual windrows and weighing in a suspension balance. A subsample is then collected for determination of moisture content and forage quality.

On-Farm Research. On farm demonstration of cropping systems were conducted to test water saving concepts under the conditions of production-scale systems. In each case, farmers conducted all crop management practices and CSU staff monitored the demonstrations, made soil and water measurements, and assessed yields.

1. Limited Irrigation and Conservation Tillage Corn Grain Production

Farm cooperator(s):	Alan and Randy Gerk
Study years:	2007, 2008
Site description:	14 ac sweep of pivot following alfalfa
	Adjacent fully irrigated corn reference
Practices demonstrated:	Limited irrigation corn with growth stage timed irrigation
	Strip tillage
Concepts evaluated:	Reduced planting populations
	Reduced N fertilizer inputs
	ET and water use efficiency

2. Partial Season Irrigation of Established Alfalfa and Grass Meadow Hay

Farm cooperator(s):	Mike Schuppe (alfalfa) and Gordon Schuppe (Hay Meadow)
Study years:	2007
Site description:	6 ac interior span of center pivot alfalfa
	6 ac interior span of center pivot grass meadow hay
	Adjacent fully irrigated spans of both crops
Practices demonstrated:	Partial season irrigation
Concepts evaluated:	Focusing irrigation to cool seasons
	Maintaining stand under dry conditions
	ET and water use efficiency

3. Evaluation of Soil Salinity and Salinity Remediation Methods

Farm cooperator(s):	Nick Raffaeli
Study years:	2007, 2008, 2009
Site description:	Center pivot irrigated corn East of Iliff
Practices demonstrated:	Land application of gypsum for remediation of salt affected soils
Concepts evaluated:	Effects of salinity and gypsum on ET and crop yield

Phase 2: Results

Controlled Research. The objectives of the controlled research are to document irrigation water application, consumptive water use, crop productivity, and profitability. The controlled research is designed to allow scientifically-defendable, replicated research plots with individualized control of irrigation amounts. Results of the 2008 cropping season are reported here (results for 2009 year forthcoming).

Annual precipitation during 2008 totaled 14.5 inches (Figure 4). June was drier than normal, but the month of July was fairly wet, with 4.2 inches of rain. The largest single day rainfall was 2.1 inches on July 26. Other large single day rainfall totals include 1.3 inches on August 16 and 0.74 inches on May 24. All other rain events were smaller than 0.5 inches per day. The annual total is a typical rainfall for this region, which averages between 13 and 19 inches of rain per year.

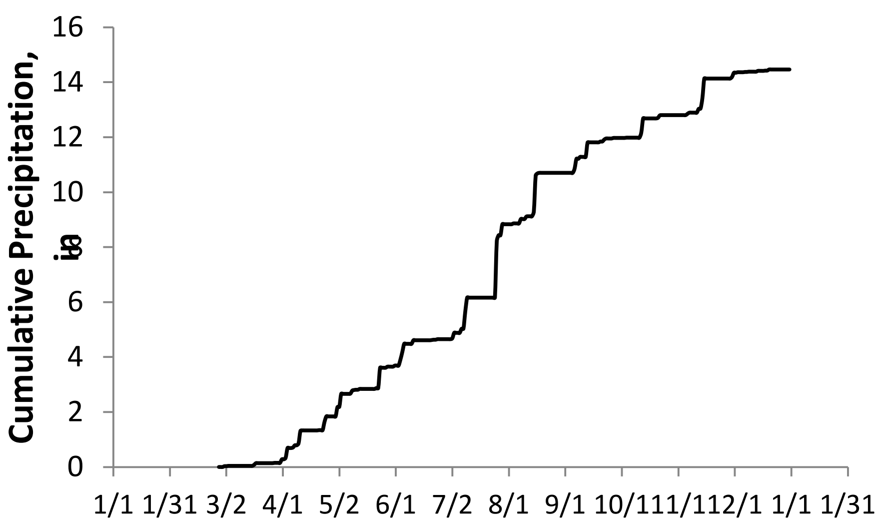

Figure 4. Cumulative precipitation for the 2008 study year at the controlled research site near Iliff, CO.

The water balance approach was used to determine average ET for the cropping system of each crop and individual crop ET values were averaged to determine the average annual ET for the entire crop rotation (Table 3). For the purposes of this study, the full irrigation, continuous corn treatment was selected as the reference system and the ET for all other systems were compared to that reference. The full irrigation, continuous corn treatment had 19 inches of applied irrigation and a total ET of 24.4 inches, with 5.7 inches of drainage. The majority of drainage corresponded to two large rainfall events (July 26=1.7 in., Aug 16=0.95 in.), with drainage amounts less than 0.5 inches occurring for 5 of the 27 individual irrigation events. The corn yield was 146 bu/ac and water use efficiency was 6.0 bu/ac/in.

The corn-fallow system was evaluated as a rotational cropping approach to water conservation. The 2008 corn produced in this study followed a fallow period in 2007, where the fallow was managed to maintain a clean, weed free soil surface. The corn in this system was managed and irrigated the same as the full irrigation, continuous corn and the ET was equivalent. The corn yield in the corn-fallow system was higher than for continuous corn. A yield drag for continuous corn has been widely observed and is often associated with increased pressure of pests and diseases in continuous monoculture based systems. The higher yield in the rotational cropping system resulted in improved water use efficiency of 7.1 bu/ac/in (Table 3). The fallow system has an ET of 7.9 inches and drainage of 2.4 inches. Thus, fallow reduced ET relative to a continuous corn system, but clean fallowing was not an efficient means of storing water in the soil profile for the subsequent crop. Average annual ET for the corn-fallow system was 16.1 inches, representing a savings of 8.3 inches relative to the continuous corn reference, or more than 30% savings in ET. The drawback to the corn-fallow system is that half of the land is left without any production.

The corn-fallow-dryland winter wheat rotation is a rotational cropping system that uses even less water than the corn-fallow system because no irrigation is applied two out of three years. Corn in this rotation yielded higher than the full irrigation continuous corn, even though it was managed and irrigated the same (Table 3). This further shows the benefits of crop rotation to maximize water use efficiency. The water balance for the fallow in this system behaved the same as for the corn-fallow system. The dryland winter wheat had an ET of 10.2 inches and a grain yield of 54 bu/ac. ET by dryland wheat was only 2.3 inches greater than the clean fallow, but the wheat generated 54 bu/ac of grain. This is a clear illustration of the disadvantage of water transfers that are based on fallowing of land. It is a poor means of conserving water.

Average annual ET for the corn-fallow-winter wheat rotation is 14.8 inches for a savings of 9.6 inches (40% savings) relative to full irrigation, continuous corn.

A sugarbeet-hay millet rotation was evaluated in both rotational cropping and limited irrigation approaches. The full irrigation sugarbeet had 14.9 inches of applied irrigation, ET was 22.4 inches, and yield was 34 T/ac. Full irrigation sugarbeet had an ET similar to the ET of full irrigation corn, but there was essentially no drainage from the sugarbeet crop. Dryland hay millet had an ET of 7.1 inches and yielded 1.6 T/ac. This rotational cropping system saved 9.6 inches of ET relative to full irrigation, continuous corn (40% savings). In the limited irrigation system, both sugarbeet and hay millet crops were irrigated at levels below the full demand of the crop. Irrigation for limited irrigation sugarbeet was 7.1 inches, ET was 17.4 inches, and yield was 33 T/ac. The limited irrigation sugarbeet had higher water use efficiency (1.8 T/ac/in) than the full irrigated sugarbeet (1.5 T/ac/in). Limited irrigation hay millet had an irrigation of 4.4 inches, an ET of 12.4 inches, and a yield of 1.6 T/ac. It is unclear why the limited irrigation and dryland hay millet had similar yields despite very different ET values. The limited irrigation sugarbeet-hay millet rotation has an average annual ET of 14.9 inches and an ET savings of 9.5 inches (40% savings). With the sugarbeet systems, there was not a clear water savings advantage to either the rotational cropping or limited irrigation approach but there was a modest yield advantage for full irrigation sugarbeet in the rotational cropping system. Sugarbeet, however, proved to be very adaptable to limited irrigation.

A corn-soybean-winter wheat-canola rotation was evaluated in both rotational cropping and limited irrigation approaches. In the rotational cropping system full irrigation was applied to corn (19 in), soybean (10 in), and canola (8 in), while the winter wheat was produced as a dryland crop. The full irrigation corn in this rotation behaved similar to the corn in other rotations, with total ET of 23.9 inches and yield of 173 bu/ac. This again confirms the water use advantage of corn in rotation as opposed to continuous corn. Full irrigation soybean ET was 16.7 inches and yield was 38 bu/ac. Soybean is a lower water using crop than corn even under full irrigation. The yield from this study is moderate but good enough to demonstrate that soybean has potential to be a profitable crop. Its growth and performance suggested it may be a good alternative crop for both rotational and limited irrigation systems in the South Platte River basin. Soybean is susceptible to iron deficiency when grown in alkaline soils, which causes leaf chlorosis (yellowing) and can suppress yields. Some chlorosis was observed in the soybeans, but it was interesting to observe that it was less severe under limited irrigation. In this crop rotation, canola production was a failure. The crop looked nice in the field and produced ample pods, but a majority of the pods had no seed. Thus ET for this crop was relatively high at 18 inches, but the yield was only 13 bu/ac. Additional work will be done to identify why canola yields were so poor. Sensitivity to salinity is suspected. The dryland winter wheat had an ET of 10.6 inches and yield of 48 bu/ac. The full rotational cropping system had an average annual ET of 17.4 inches, a 7.0 inch ET savings compared to full irrigation continuous corn (30% savings). The same rotation managed under limited irrigation (all crops irrigated) had an average annual ET of 16.4 inches for a savings of 8 inches relative to full irrigation continuous corn (33% savings). Corn and soybean performed well under limited irrigation, maintaining or exceeding the water use efficiency for full irrigation. Water use efficiency of limited irrigation wheat was slightly better than for dryland wheat. Although the amount of saved ET was similar between the rotational cropping and the limited irrigation approaches, under a typical grain market scenario, the loss in corn yield with limited irrigation would not be offset by the gain in wheat yield. Therefore, the rotational cropping approach, with dryland wheat produced the year without irrigation, would be preferred over a limited irrigation approach in this situation.

A corn-sunflower-winter wheat-winter triticale rotation was evaluated in both rotational cropping and limited irrigation approaches. In this rotational cropping system, full irrigation was applied to corn (19 in) and sunflower (13 in), while both winter wheat and triticale were produced as dryland crops. The full irrigation corn behaved similar to the corn in the other rotational cropping systems, with total ET of 22.9 inches and yield of 167 bu/ac. ET from full irrigation sunflower was 19.3 inches and yield was 1890 lbs/ac. The yield from this study was negatively affected by predation from birds that migrated from nearby wooded areas along the river. Bird predation may be a significant deterrent to sunflower production near riparian areas. The dryland winter wheat yield following sunflower was lower than dryland wheat in other rotations (38 bu/ac). Others have observed that crops produced following sunflower have depressed yields because sunflower effectively extracts nutrients and water from the soil. The dryland triticale was produced as an annual forage crop. The hay yield of 2.9 T/ac is a very good dryland yield. Triticale and other annual forages may be well suited to rotational cropping systems. They are able to produce by scavenging residual water and fertility from the preceding irrigated crop, and have less risk of failure than grain crops. The rotational cropping system had an average annual ET of 14.3 inches and an ET savings of 10.1 inches (41% savings). By comparison, the limited irrigation approach for the same rotation had an average annual ET of 16.7 inches and an ET savings of 7.6 inches (31% savings). The limited irrigation sunflower had the same ET as the full irrigation sunflower. This is because the limited irrigation sunflower was able to mine more water from the soil profile, but was less efficient in converting that water to grain. Crops with aggressive rooting and water uptake traits may not be as good for reducing ET through limited irrigation management.

Understanding the effects of changing irrigation and cropping patterns on return flows is an important issue in the South Platte River basin. Some inferences can be made about the effects of rotational cropping and limited irrigation systems on return flows from the drainage estimates from the controlled study. All of the cropping systems had less drainage than the full-irrigation, continuous-corn reference. In general, average annual drainage will be greater for a rotational cropping system than for limited irrigation systems because of the higher likelihood of drainage during phases with crops under full irrigation.

Table 3. Growing season summary of crop and cropping system water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency. The average annual ET saved is calculated relative to the full irrigation, continuous corn system.

#1 — A. Continuous Corn (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	0.4	-5.7	24.4	146	bu/ac	6.00
Rotation Average	19.0	10.7	0.4	-5.7	24.4			
	Average Annual ET Saved				0.0			

#2 — A. Corn (Full) B. Fallow

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	-1.3	-4.1	24.3	171	bu/ac	7.1
B. Fallow	0.0	10.7	-0.5	-2.4	7.9			
Rotation Average	9.5	10.7	-0.9	-3.3	16.1			
	Average Annual ET Saved				8.3			

#3 — A. Corn (Full) B. Fallow C. Wheat (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	20.4	10.7	0.7	-4.8	27.0	169	bu/ac	6.3
B. Fallow	0.0	8.3	0.9	-2.1	7.1			
C. Wheat	0.0	5.8	6.6	-2.2	10.2	54	bu/ac	5.2
Rotation Average	6.8	8.3	2.7	-3.0	14.8			
	Average Annual ET Saved				9.6			

#4 — A Sugar Beet (Full) B. Hay Millet (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	13.9	8.3	0.3	-0.2	22.4	35	T/ac	1.53
B. Millet	0.0	8.3	-0.4	-0.8	7.1	1.6	T/ac	0.11
Rotation Average	6.9	8.3	-0.1	-0.5	14.7			
	Average Annual ET Saved				9.6			

#5 — A. Sugar Beets (Limited) B. Hay Millet (Limited)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	7.1	8.3	2.2	-0.3	17.4	33	T/ac	1.82
B. Millet	4.4	8.3	0.0	-0.3	12.4	1.6	T/ac	0.13
Rotation Average	5.8	8.3	1.1	-0.3	14.9			
	Average Annual ET Saved				9.5			

Table 3 (Continued). Growing season summary of crop and cropping system water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency. The average annual ET saved is calculated relative to the full irrigation, continuous corn system.

#6 A. Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Canola (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	-0.8	-5.0	23.9	173	bu/ac	7.26
B. Soybean	10.2	9.0	-0.1	-2.5	16.7	38	bu/ac	2.28
C. Wheat	0.0	7.1	4.6	-1.1	10.6	48	bu/ac	4.50
D. Canola	8.2	7.1	3.5	-0.6	18.2	13	bu/ac	0.73
Rotation Average	9.3	8.5	1.8	-2.3	17.4			
		Average Annual ET Saved			7.0			

#7 A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Canola (Limtd)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	10.0	10.7	1.2	-1.1	20.9	152	bu/ac	7.27
B. Soybean	6.7	9.0	0.3	-0.2	15.8	38	bu/ac	2.39
C. Wheat	6.5	7.1	2.9	-2.6	13.9	57	bu/ac	4.07
D. Canola	4.4	7.1	3.7	-0.2	15.0	8	bu/ac	0.51
Rotation Average	6.9	8.5	2.0	-1.0	16.4			
		Average Annual ET Saved			8.0			

#8 A Corn (Full) B. Sunflower (Full) C. Wheat (Dry) D. Triticale (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	-1.4	-5.4	22.9	167	bu/ac	7.29
B. Sunflower	13.0	9.0	1.5	-4.1	19.3	1887	bu/ac	97.6
C. Wheat	0.0	7.1	3.2	-2.1	8.2	38	bu/ac	4.66
D. Triticale	0.0	7.1	2.1	-2.4	6.7	2.9	T/ac	0.44
Rotation Average	8.0	8.5	1.3	-3.5	14.3			
		Average Annual ET Saved			10.1			

#9 A. Corn (Limtd) B. Sflower (Limtd) C. Wheat (Limtd) D. Triticale (Limtd)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	10.0	10.7	0.2	-1.4	19.5	155	bu/ac	7.96
B. Sunflower	8.5	9.0	2.4	-0.2	19.6	1137	lbs/ac	58.0
C. Wheat	6.5	7.1	3.4	-1.9	15.1	42	bu/ac	2.77
D. Triticale	6.7	7.1	1.2	-2.2	12.7	3.2	T/ac	0.25
Rotation Average	7.9	8.5	1.8	-1.4	16.7			
		Average Annual ET Saved			7.6			

On-Farm Research. The objective of the on-farm demonstrations is to evaluate the practicality and feasibility of the cropping systems when practiced on full-sized fields with farmers managing the system. Results of three on-farm projects are reported.

Limited Irrigation and Conservation Tillage Corn Grain Production. A 14-acre field irrigated with a center-pivot sprinkler was utilized for an on-farm comparison of full and limited irrigation corn managed with conservation tillage practices. Limited irrigation was achieved by manually turning off sprinkler drop nozzles for entire spans of the sprinkler during non-critical growth periods. The limited irrigation crop yields were compared to the conventional full irrigation yields on both sides of the controlled span. Using a water balance approach, crop ET was determined to be 26 inches for full irrigation and 19 inches for limited irrigation. Although the corn crop showed signs of water stress during vegetative growth, it recovered well when irrigation resumed. The limited irrigation crop was shorter in stature than the full irrigation treatment. A high intensity wind storm just prior to harvest caused some plants and ears to fall to the ground, but the damage was noticeably worse in the taller, full irrigation corn. As a result, corn yield was 147 bu/ac for full irrigation and 167 bu/ac for limited irrigation. Without the wind damage, it is expected that the full irrigation corn would have had a higher yield than the limited irrigation corn. Nonetheless, the demonstration showed that irrigation water management at a field production level can effectively reduce ET while maintaining potentially profitable yields.

Partial Season Irrigation of Established Alfalfa and Grass Meadow Hay. In 2007, an on-farm study of partial season irrigation was conducted for an established stand of alfalfa and grass meadow hay. This was accomplished by manually turning off irrigation drop nozzles for one tower span on a center-pivot sprinkler following the first alfalfa harvest while the remainder of the field was irrigated normally by the producers. The same sprinkler irrigates both the alfalfa and the meadow hay field. The crops inside the span (partial season irrigation) were compared to the crops on either side of the span (full irrigation). Full irrigation for both alfalfa and grass hay totaled 25 inches, while limited irrigation totaled 13 inches. A water balance approach was used to estimate ET, with soil moisture determined weekly with a neutron probe. Full irrigation alfalfa yielded 4.5 T/ac and the limited irrigation alfalfa yielded 4.2 bu/ac (Figure 5). As estimated by the water balance method, ET was 24 inches and 14 inches for full and limited irrigation alfalfa, respectively. The small reduction in yield from the limited irrigation treatment suggests that the limited irrigation alfalfa was using more water than accounted for in the water balance. It is suspected that the rooting system of the established alfalfa was deep enough to access water from the water table, but this water balance study had no means of quantifying sub-irrigation. It is typical in this region for alfalfa to require approximately 5 inches of ET per ton of dry matter harvested, confirming that 14 inches of ET is an underestimation for the limited irrigation yield of 4.2 T/ac. Irrigation management alone may not be an effective approach for reducing ET for deep rooted crops in areas with a high water table. For grass meadow hay, full irrigation had a yield of 1.9 T/ac and ET of 27 inches and the limited irrigation has a yield of 0.9 T/ac and an ET of 16 inches. Perennial grasses have much more shallow root systems and as a result were more responsive to limited irrigation.

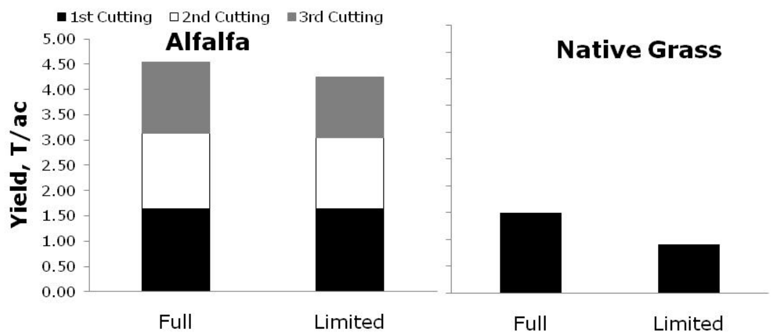

Figure 5. Yield of alfalfa and native grass hay crops under full and limited irrigation in an on-farm evaluation during 2007.

Evaluation of Soil Salinity and Salinity Remediation Methods. Some soils in the South Platte River basin are affected by saline and sodic conditions. Salinity and sodicity can negatively affect water use efficiency. An on-farm study evaluated the use of gypsum as a soil amendment on a field with moderate levels of salinity and sodicity. Gypsum was applied at different rates in full length field strips as follows: 1200 lbs/ac - surface applied; 1200 lbs/ac – incorporated into the soil with tillage; 2400 lbs/ac – incorporated; no gypsum control. The crop yields were irrigated identically and yields were monitored, but a complete water budget was not determined. There were no observed differences in crop yield among any of the treatments in 2007.

Phase 2: Summary

Crops evaluated for their potential use in a rotational cropping or limited irrigation systems include corn, winter wheat, sugarbeet, sunflower, soybean, triticale, canola and hay millet. Partial season irrigation is being evaluated for alfalfa and various perennial grass hay species. Corn and alfalfa are the dominant crops produced under irrigation in Colorado, representing about 80% of the irrigated acres.

A controlled field study used a water balance approach to evaluate ET and drainage, yield, and water use efficiency and savings in ET were determined relative to full irrigation, continuous corn. Rotational cropping systems were effective at reducing ET, with average ET reductions of 30-40% compared to continuous corn. Rotating irrigated crops with dryland crops was a more water efficient approach than rotating with non-cropped fallow land because of high water loss during fallow to evaporation and drainage. Corn produced after a fallow period or dryland crop had a higher yield and water use efficiency than continuous corn, illustrating the benefits of crop rotation to maximize water use efficiency.

Both rotational cropping and limited irrigation of sugarbeet in rotation with an annual forage crop saved 40% of the reference crop ET. Sugarbeet is drought tolerant and shows good adaptability to limited irrigation. Soybean had moderate yield but is a lower water use crop than corn even under full irrigation. Under limited irrigation, soybean had higher water use efficiency and was less susceptible to iron deficiency chlorosis. Its growth and performance suggested it may be a good alternative crop for water conserving cropping systems in the South Platte River basin. Canola did not yield well in the study, having a high degree of empty seed pods. Salinity is suspected as a potential cause.

Full and limited irrigation sunflower had a similar ET with lower yields in limited irrigation. The aggressive rooting and water scavenging ability of sunflower allowed it to access more water from the soil under limited irrigation. Crops with deep root systems will be less effective for reducing ET through irrigation management. Yields of crops the year following sunflower were depressed. In proximity to riparian areas such as the site in this study, bird predation can be another significant obstacle for profitable sunflower production. Triticale was evaluated as a dryland and limited irrigation crop in rotation. It had good production levels with very low input.

Both rotational cropping and limited irrigation systems effectively reduced ET relative to full irrigation, continuous corn. Rotational cropping systems have an economic advantage over limited irrigation systems because they can maximize yields of profitable cash crops and then use lower input crops in the dryland phase of the rotation. Triticale and other annual forages may be well suited to rotational cropping systems. They can produce by scavenging residual water and fertility from the preceding irrigated crop, and have less risk of failure than grain crops.

While water savings would be greatest by complete dry-up of irrigated land, the crop production in dryland is too low to maintain sustainable agricultural production. As Colorado citizens make decisions about the future of water use and how water transfers will be used to address growing urban populations, limited irrigation and rotational cropping systems should be considered as a means of meeting urban water needs while maintaining viable irrigated agricultural systems.

Phase 3. Regional Adoption and Economic Impacts

Phase 3. Background and Objectives

Adoption of innovative, water-saving cropping systems has the potential to extend throughout the South Platte Basin in order to satisfy the water needs of growing municipalities. The objectives of this study phase were to evaluate the potential of South Platte farms to adopt limited irrigation, rotational cropping, or other water saving cropping systems and to evaluate the barriers to adoption. A farmer survey was a key instrument to obtaining this information. Additionally, a strong potential for spillover effects into the regional economy exists because adopting alternative irrigation systems will have effects on farm cash flow and productivity. Altered cash flows create ripple effects that include, but are not limited to, agribusinesses that sell inputs directly to adopting farms, businesses that receive revenues from adopting farms' and agribusiness employees that spend their wages locally and a changing sales/property tax base. Another objective of this project phase is to develop a regional economic impact model to quantify these effects.

Phase 3: Results and Conclusions

Quantifying Economic Activity: The economic activity generated by irrigated agriculture in the South Platte Basin has been quantified and these results are reported in a variety of venues. In sum, the basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. An irrigated acre generates significant economic activity in the basin, so potential losses are substantial in sparsely populated rural areas with few other alternatives. Impacts include the direct loss of crop sales, the lost revenues to agribusinesses that supply irrigated farms, and the wages spent by affected employees.

Table 4. Economic activity generated by irrigated agriculture[a]

Basin	Population Increase by 2020 (%)	Additional Annual Water Demand (AF)	Forecasted Fallowing of Irrigated Acres	Economic Activity $/ac
Arkansas	55%	98,000	23,000 to 72,000	$428
Rio Grande	35%	43,000	60,000 to 100,000	$1,235
South Platte	65%	409,700	133,000 to 266,000	$690

[a]Population, water demand and lost irrigated acres drawn from the Colorado Water Conservation Board, Statewide Water Supply Initiative (2004). Thorvaldson and Pritchett (2006) provide economic activity estimates.

The economic activity represents a snapshot of the activity generated by irrigated agriculture in these basins. It is not a forecast for lost economic activity as it does not capture adaptation, multiple year impacts or the potential threshold impacts if economic activity is sufficiently limited to drive firms out of business.

Producer Survey: One alternative to 'buy and dry' strategies is gaining interest. The alternative allows farmers to lease a portion of their water portfolio to cities. Leased water is generated as farmers fallow their land on a rotational basis or reduce the consumptive use of their cropping operations by limiting irrigation or fallow rotation. Importantly, the limited irrigation cropland remains in production so that rural economies suffer reduced impacts vis a vis buy and dry activity. But will farmers adopt limited irrigation strategies or rotational cropping if water lease markets materialize? The producer survey objective was to gauge potential adoption of limited irrigation strategies, the amount of water that might be made available in water leasing arrangements, the necessary compensation needed for farmers to participate and their perceptions of lease arrangements. The results of the survey suggest that more than 60% of the respondents are willing to lease garnering between 50,000 and 60,000 acre feet of potential water supplies and preferred compensation ranges from $300 - $500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity. The next step in this research is to uncover the barriers to adopting limited irrigation practices noting where they might be overcome with cost shares and technical assistance.

Spreadsheet Decision Tool: Many farmers in Colorado face limited irrigation water supplies. Limitations are imposed by a variety of circumstances including declining groundwater levels, significantly higher energy costs, evolving water case law and decreasing return flows in river systems. Regardless of the circumstance, farmers face the same question: what is the "best" allocation of limited water resources?

This research objective sought to develop a spreadsheet decision tool to help farmers determine the tradeoffs of various limited irrigation and water saving strategies. The spreadsheet allows farm managers to input their own business information and contrast potential limited irrigation strategies.

Crops examined in the spreadsheet tool include corn, alfalfa, wheat, dry beans and sunflowers. A copy of the spreadsheet and a technical document describing its use can be found at: http://limitedirrigation.agsci.colostate.edu/ under the resources tab. The underlying crop water production functions have been developed as part of the research performed in the field at the Iliff site, and as part of a literature review. The spreadsheet decision tool provides a basis for the risk analysis that follows. This tool also informs the work of other Alternative to Agriculture Transfer projects.

Risk Decision Analysis: The risk profile of a fully-irrigated farm is likely to change when water supplies are limited. The research objective in this provides preliminary insights into how the risk profile may change. The “benchmark” for the analysis is a fully-irrigated, center pivot, continuous corn operation and a continuous alfalfa operation. The limited irrigation opportunities include limited irrigation corn (12 inches applied water), limited irrigation alfalfa (12 inches applied water), corn-dryland wheat rotation, corn (15 inches applied) - wheat (6 inches applied)-sunflower (6 inches applied) rotation. In general, limited irrigation scenarios tended to increase the variability of net cash returns, but substantially increased the likelihood of failing to meet a critical cash flow. In this case, the critical level of cash flow is treated as $130,000 that includes a land payment, machinery payment and family living expenses. Depreciation is not treated as an expense when calculating the critical cash flow. This research is to be augmented with the crop rotations that have been developed in the first two phases of this study.

Conclusions

This project seeks a model to sustain irrigated agriculture while meeting the increasing urban water needs in Colorado. The focus is on cropping systems that reduce consumptive water use without complete dry-up of irrigated land. A concept and discovery phase of the project sought cropping systems with potential to reduce consumptive use by at least 20% from an historical baseline in a way that could be scientifically documented for use in court proceedings. In addition, potential cropping systems were to be profitable for farmers under expected prices and yields and adapted to existing technology, equipment, capital and labor in the South Platte River Basin. Rotational cropping, limited irrigation, and partial season irrigation cropping systems were identified as potential water conserving practices.

Rotational cropping refers to sequences of full irrigation crops with fallow or dryland crops in subsequent years. Potential dryland crops for rotational cropping include winter wheat, annual forage crops, corn, sunflower, and proso millet. Limited irrigation cropping is the application of less water than required to meet the full water demand of the crop, with an emphasis on applying the limited water during critical crop growth stages to optimize the beneficial effects of the water. All crops in a limited irrigation system receive irrigation but at lower levels than fully irrigated crops. Potential limited irrigation crops identified are corn, winter wheat, annual forages, sugarbeet, sunflower, soybean, and canola. Partial season irrigation is a combination of full irrigation during part of the growing season with no irrigation during other parts of the same growing season. Partial season irrigation has relevance to perennial crops with documented success especially for alfalfa.

The study includes a field research phase with both controlled and on-farm field components to evaluate irrigation water application, consumptive water use, crop productivity, and profitability of representative water conserving cropping systems. The controlled research used a water balance approach to study rotational cropping, limited irrigation, and partial season irrigation for various crops and crop sequences. Rotational cropping approaches evaluated corn, soybean, sunflower, sugarbeet, and canola as fully irrigated crops in rotation with either fallow or a winter wheat, triticale, or millet. There was a 30% ET savings when irrigated corn was rotated with a non-cropped fallow year. While fallow reduced ET, water losses during fallow to evaporation and drainage were high and little water was stored in the soil profile for the subsequent crop. Rotating irrigated crops with dryland crops was a much more water efficient approach than rotating with a non-cropped fallow because of high evaporation and drainage during fallow. Triticale and other annual forages are suited to rotational cropping systems because they scavenging residual water and fertility from the preceding irrigated crop, and have less risk of failure than grain crops. Corn produced after a fallow period or a dryland crop had a higher yield and water use efficiency than continuous corn, illustrating the benefits of crop rotation to maximize water use efficiency.

The study demonstrated that corn, soybean, and sunflower were good crops for ET savings through a limited irrigation approach. Sunflower under limited irrigation had reduced yield, but did not result in ET savings compared to full irrigation. Crops like sunflower that have aggressive rooting and water uptake traits may not be as good for reducing ET through limited irrigation management. Limited irrigation resulted in ET savings of 30-40%, a level similar to the ET savings for the rotational cropping systems evaluated. There is less drainage and potential return flow for limited irrigation systems. An on-farm study of limited irrigation corn showed that irrigation water management at a field production level can effectively reduce ET while maintaining potentially profitable yields.

The South Platte River basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. Each irrigated acre is estimated to generate economic activity equivalent to $690 in the basin. Economic effects of drying up irrigated land will be substantial, especially in sparsely populated rural areas with few other alternatives. A producer survey gauged the amount of water that might be made available in water leasing arrangements and the necessary compensation needed for farmers to participate in a lease arrangement. More than 60% of survey respondents are willing to lease water, with an aggregate of between 50,000 and 60,000 acre-feet of potential water supplies just among those who responded. Preferred compensation ranges from $300 - $500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity.

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Appendix 1: Project Advisory Committee

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Appendix 2: Detailed Plot Map of Controlled Research Site

Cropping System	1		2		3	4		1		2	
	101	102	103	104	105	106	107	108	109	110	111
2007	C F	C L	C L	C F	C	C	F	Can F	Can L	T L	T
2008	S F	S L	~~Sun~~ L	~~Sun~~ F	C	F	C	C F	C L	C L	C F
2009	W	W L	W L	W	C	C	F	S F	S L	S L	S F
2010	Can F	Can L	T L	T	C	F	C	W	W L	W L	W
	201	202	203	204	205	206	207	208	209	210	211
2007	C F	C L	C F	C L	C	C	F	Can F	Can L	T	T L
2008	S F	S L	~~Sun~~ F	~~Sun~~ L	C	F	C	C F	C L	C F	C L
2009	W	W L	W	W L	C	C	F	S F	S L	S F	S L
2010	Can F	Can L	T	T L	C	F	C	W	W L	W	W L
	301	302	303	304	305	306	307	308	309	310	311
2007	C L	C F	C F	C L	C	C	F	Can L	Can F	T	T L
2008	S L	S F	~~Sun~~ F	~~Sun~~ L	C	F	C	C L	C F	C F	C L
2009	W L	W	W	W L	C	C	F	S L	S F	S F	S L
2010	Can L	Can F	T	T L	C	F	C	W L	W	W	W L
	401	402	403	404	405	406	407	408	409	410	411
2007	C L	C F	C L	C F	C	C	F	Can L	Can F	T L	T
2008	S L	S F	~~Sun~~ L	~~Sun~~ F	C	F	C	C L	C F	C L	C F
2009	W L	W	W L	W	C	C	F	S L	S F	S L	S F
2010	Can L	Can F	T L	T	C	F	C	W L	W	W L	W

Cropping System	1		2		5			1		2	
	501	502	503	504	505	506	507	508	509	510	511
2007	W	W L	W L	W	F	C	-	S F	S L	~~Sun~~ L	~~Sun~~ F
2008	Can F	Can L	T L	T	W	F	C	W	W L	W L	W
2009	C F	C L	C L	C F	C	W	F	Can F	Can L	T L	T
2010	S F	S L	S L	S F	F	C	W	C F	C L	C L	C F
	601	602	603	604	605	606	607	608	609	610	611
2007	W	W L	W	W L	F	C	W	S F	S L	~~Sun~~ F	~~Sun~~ L
2008	Can F	Can L	T	T L	W	F	C	W	W L	W	W L
2009	C F	C L	C F	C L	C	W	F	Can F	Can L	T	T L
2010	S F	S L	S F	S L	F	C	W	C F	C L	C F	C L
	701	702	703	704	705	706	707	708	709	710	711
2007	W L	W	W	W L	F	C	W	S L	S F	~~Sun~~ F	~~Sun~~ L
2008	Can L	Can F	T	T L	W	F	C	W L	W	W	W L
2009	C L	C F	C F	C L	C	W	F	Can L	Can F	T	T L
2010	S L	S F	S F	S L	F	C	W	C L	C F	C F	C L
	801	802	803	804	805	806	807	808	809	810	811
2007	W L	W	W L	W	F	C	W	S L	S F	~~Sun~~ L	~~Sun~~ F
2008	Can L	Can F	T L	T	W	F	C	W L	W	W L	W
2009	C L	C F	C L	C F	C	W	F	Can L	Can F	T L	T
2010	S L	S F	S L	S F	F	C	W	C L	C F	C L	C F

Cropping Systems:
1 = CSWCa   2 = CSWT   3 = CC   4 = CF   5 = CFW
S = Soybean   C = Corn   W = Wheat   ~~Sun = Sunflower~~   F = Fallow   T = Triticale
CC = Continuous Corn   Can = Canola

Cropping System	6				7	
	901	902	903	904	905	906
2008	Sug F	Sug L	AG	AG L	A F AG	A L AG
2009	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
2010	Sug F	Sug L	S Can	S Can L	A F AG	A L AG
2011	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
	1001	1002	1003	1004	1005	1006
2008	Sug L	Sug F	AG L	AG	A L AG	A F AG
2009	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
2010	Sug L	Sug F	S Can L	S Can	A L AG	A F AG
2011	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
	1101	1102	1103	1104	1105	1106
2008	Sug L	Sug F	AG L	AG	A L AG	A F AG
2009	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
2010	Sug L	F	S Can L	S Can	A L AG	A F AG
2011	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
	1201	1202	1203	1204	1205	1206
2008	Sug F	Sug L	AG	AG L	A F AG	A L AG
2009	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
2010	Sug F	Sug L	S Can	S Can L	A F AG	A L AG
2011	S Can	S Can L	Sug F	Sug L	A F AG	A L AG

1301 (7)	1302 (8)	1303 (9)	1304 (10)	1305 (11)
West Wheat	Pub Wheat	Medw Br. 2	Tall Fes F	Hybrid Br.
Pub Wheat	Cres Wheat	Int Wht 1	Newhy	Russ Wild
Int Wht 1	Orchard	Medw Br. 1	Russ Wild	Newhy
Medw Br. 2	Slendr Wh	Tall Fes F	Int Wht 2	Medw Br. 2
Orchard	Newhy	Hybrid Br.	Pub Wheat	Orchard
Int Wht 2	Tall Fes Q	Tall Wheat	Orchard	Tall Fes F
Cres Wheat	Russ Wild	Cres Wheat	West Wheat	Medw Br. 1
Slendr Wh	Int Wht 2	Tall Fes Q	Tall Fes Q	West Wheat
Tall Fes F	West Wheat	West Wheat	Cres Wheat	Slendr Wh
Russ Wild	Tall Fes F	Pub Wheat	Int Wht 1	Int Wht 2
Hybrid Br.	Hybrid Br.	Russ Wheat	Slendr Wh	Tall Wheat
Medw Br. 1	Tall Wheat	Orchard	Medw Br. 1	Cres Wheat
Newhy	Int Wht 1	Slendr Wh	Hybrid Br.	Tall Fes Q
Tall Wheat	Medw Br. 2	Newhy	Tall Wheat	Pub Wheat
Tall Fes Q	Medw Br. 1	Int Wht 2	Medw Br. 2	Int Wht 1

1306 (7)	1307 (8)	1308 (9)	1309 (10)	1310 (11)
Russ Wild	Newhy	Int Wht 2	Hybrid Br	
Tall Fes F	Tall Fes Q	Hybrid Br.	Tall Wheat	
Int Wht 1	Int Wht 2	Medw Br. 2	Int Wht 2	
Newhy	West Wheat	Pub Wheat	Orchard	
Medw Br. 1	Orchard	Tall Fes Q	Tall Fes F	
Tall Wheat	Tall Fes F	Orchard	West Wheat	
West Wheat	Slendr Wh	Cres Wheat	Crest Wheat	
Cres Wheat	Pub Wheat	Medw Br. 1	Tall Fes Q	
Orchard	Hybrid Br.	Int Wht 1	Medw Br. 2	
Tall Fes Q	Cres Wheat	Tall Wheat	Pub Wheat	
Slendr Wh	Russ Wild	West Wheat	Int Wht 1	
Pub Wheat	Medw Br. 1	Russ Wild	Russ Wild	
Hybrid Br.	Medw Br. 2	Slendr Wh	Newhy	
Int Wht 2	Int Wht 1	Newhy	Slendr Wh	
Medw Br. 2	Tall Wheat	Tall Fes F	Medw Br. 1	

Grass Plots (15 spp.)

	Full season long Irrigation
	Spring & Fall Irrigated
	Spring only irrigation

Cropping Systems:
6 = Sug Beets Annual/Canola or Grass
Sug = Surgar Beets AG = Annual Grass
S Can = Spring Canola
7 = Alfalfa and AlfalfaGrassMix