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Sustainable Cropping Systems for Transition from Full Irrigation To Limited Irrigation and Dryland

A final report to:

USDA NRCS – Conservation Innovation Grant Program

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Summary of Project Activities

Two field sites were established at CSU-ARDEC in Fort Collins to demonstrate the principles of limited and partial season irrigation cropping practices at the systems level. A range of crops and irrigation practices are demonstrated and potential water savings are documented.

An on-going alfalfa irrigation demonstration project was conducted in cooperation with Northern Colorado Water Conservancy District.

An outreach education program was conducted for irrigators, water suppliers, and municipal users about the principles of limited irrigation cropping systems as a water conserving practice. We have published a fact sheet titled "Limited Irrigation Management: Principles and Practices," which has been distributed and made available on-line. Presentations, field days, workshops, and seminars have reached 3,600 people during 2006 - 2010.

An educational website addressing limited irrigation as an agricultural water conservation practice has been established and will be used as an avenue for disseminating information developed from the project. http://limitedirrigation.agsci.colostate.edu

An annual education lecture has been established on Earth Day at the CSU campus. The lecture addresses emerging issues in soil and water and is designed to raise awareness and promote cooperation on natural resource conservation issues. Information available at: http://www.soilcrop.colostate.edu/hansen/EarthDay/EarthDay.html

- April 19, 2007. Dr. Daniel Hillel, world-renowned environmental scientist & hydrologist, "The Sustainable Management of Soil and Water Resources: Historical and Contemporary Perspectives." Attendance 350
- April 22, 2008. William Logan Bryant, popular natural resources author. Attendance 250
- April 22, 2010. Dr. Rattan Lal, internationally respected soil and water resources scientist. Attendance 320
- April 21, 2011. Sandra Postel, Global Water Policy Project. Attendance 370

We conducted a scientific literature review and developed water production functions for the crops corn, wheat, sunflowers, and alfalfa. These functions are useful for farmers, water planners and administrators, and policy makers to determine yield affect of reducing irrigation on a crop as well as differences among crops.

Scientifically defendable measurements of precipitation, applied irrigation, crop water use (ET), water dynamics under full and limited irrigation and dryland cropping systems.

Technical fact sheet "Alfalfa Growth Responses to Water and Partial Season Irrigation"

Project was the emphasis of the graduate training of a Masters of Science student, Brad Lindenmayer and PhD student, Kendall DeJonge, Soil and Crop Sciences, Colorado State University.

Narrative Summary

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. It is anticipated that water transfers from agricultural to urban and municipal uses will result in the dry-up of a significant amount of irrigated farmland in Colorado, especially in the South Platte and Arkansas River basins. Shifts from irrigated to 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. Water conservation options other than complete land fallowing are desirable because of the potential economic and environmental concerns associated with conversion to dryland. One approach to reducing consumptive use of irrigation water is adoption of limited irrigation cropping systems. This limited irrigation demonstration project is being conducted to demonstrate alternatives to complete dry-up of irrigated land. The project was based on the development of three field demonstration sites where alternative water saving irrigation systems are demonstrated and are compared to full irrigation systems and systems without irrigation inputs. Crop production, water use, and potential water savings are demonstrated. The project involved a significant outreach education component.

The objectives of the project were to:

1) Demonstrate to producers water conserving limited irrigation cropping systems
2) Evaluate limited irrigation as an economic alternative to land abandonment or dryland agriculture
3) Provide information to state agencies and urban water users about the potential of agricultural water transfers as one way to address the needs of increasing urban water needs.

Results from five years of field demonstration sites are reported including results for alternative crops and irrigation approaches. Crops evaluated include corn grain, corn silage, winter wheat, sunflower, and alfalfa. Corn was selected for the limited irrigation demonstration because it is the dominant crop produced in Colorado. Our demonstration shows that irrigation on corn could be reduced by 50% while yields were reduced by only 25%. Although yields on an area basis are reduced, the yield per unit of evapotranspiration by the crop (ET) increases for limited irrigation corn. We demonstrated that limited irrigation corn could save 6-9 inches of ET relative to traditional, fully irrigated production and we report information that can be utilized to determine the farm level economics of this practice. We report the potential of rotating corn with other limited irrigation crops. Production of limited irrigation sunflower was demonstrated as a viable alternative, with an ET savings of 4-6 inches. Limited irrigation of winter wheat is a potential alternative, but will require more irrigation than the levels in this demonstration. Average ET from winter wheat in the demonstration was 12 inches, representing a savings of 11 inches relative to full irrigation corn. However, yields for this system were below sustainable levels. Limited irrigation alfalfa was demonstrated at all three field sites and was found to have great potential for limited irrigation. Because of its natural drought tolerance and perennial growth habits, limited irrigation alfalfa can generate large savings in ET while still maintaining a viable crop production system. We also demonstrated potential ET savings in a dryland cropping system where no irrigation is applied. In this system, ET savings were as high as 16 inches. Although water savings for the dryland system are high, the crop production in this system is too low for 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 cropping systems should be considered as a means of meeting urban water needs while maintaining viable irrigated agricultural systems.

This project had a large outreach education component. We have published a fact sheet titled "Limited Irrigation Management: Principles and Practices," which has been distributed and made available on-line. Results from the demonstration sites are the basis of field days, workshops, seminars, and web based information. In 2006 - 2010, educational outreach programs reached nearly 3,600 people consisting of farms, agricultural professionals, agency staff, water and watershed organizations, and the general public. 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.

Sustainable Cropping Systems for Transition from Full Irrigation To Limited Irrigation and Dryland

PROGRESS REPORT, OCTOBER 2011

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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.

Water conservation options other than complete land fallowing are desirable because of the potential economic and environmental concerns associated with conversion to dryland. One approach to reducing consumptive use of irrigation water is adoption of limited irrigation cropping systems. With limited irrigation, less water is applied than is required to meet the full evapotranspiration demand of the crop. Crops managed with limited irrigation experience water stress and have reduced yields compared to full irrigation, but management is employed to maximize the efficient use of the limited irrigation water applied. These systems are a hybrid of full irrigation and dryland cropping systems and are currently of great interest to Colorado farmers. Successful limited irrigation systems are based on the concepts of: 1) managing crop water stress, 2) timing irrigation to correspond to critical growth stages for specific crops, 3) maximizing water use efficiency by improving precipitation capture and irrigation efficiency, and 4) matching crop rotations with local patterns of precipitation and evaporative demand. Research in the Great Plains illustrates that limited irrigation cropping systems are significantly more profitable alternatives than dryland (Schneekloth, 1991 and 1995). In addition to reducing consumptive water use, well managed limited irrigation systems can reduce the risk of deep water percolation and the associated leaching of soluble nutrients such as nitrate. Agricultural water in Colorado is under extreme pressure that will limit agricultural production. A compromise between full irrigation and dryland must be found if farmers and agriculturally based communities are to maintain their viability.

Organization Background

The project team consisted of an interdisciplinary team of researchers and educators at Colorado State University. The team was made up of soil scientists, agronomists, water quality and irrigation specialists, economists, and pest management specialists. Our team is experienced in managing agricultural field research and demonstration projects. In addition, we have statewide responsibilities for outreach and extension education and have a successful track record of leading education projects. We are also an educational and training institution for both undergraduate and graduate students. We incorporate an educational component in all of our projects by involving students in meaningful ways. We are committed to solving natural resources concerns in Colorado, with a special interest in agriculturally related issues such as water conservation.

Project Objectives

The objectives of this technology transfer and demonstration project were to:

1) Demonstrate to producers water conserving limited irrigation cropping systems
2) Evaluate limited irrigation as an economic alternative to land abandonment or dryland agriculture
3) Provide information to state agencies and urban water users about the potential of agricultural water transfers as one way to address the needs of increasing urban water needs.

Study Background and Approach

At the core of this demonstration project are field demonstration sites where potential water savings from limited irrigation practices are compared with a traditional fully irrigated cropping system and a dryland cropping system. The demonstration project was initiated at the CSU Agricultural Research, Demonstration, and Education Center (ARDEC) north of Fort Collins in 2005 with seed grants from the Colorado Agricultural Experiment Station and the USDA-NRCS Conservation Innovation Grant Program. The U.S. Bureau of Reclamation became a major collaborator on the project beginning July, 2006, allowing continuation of the pilot project and expansion of the scope and objectives.

Demonstration Sites: Two demonstration sites were established in the spring of 1995 at the Colorado State University, Agricultural Research, Demonstration, and Education Center (ARDEC - 4616 NE Frontage

Road, Fort Collins, CO; 5 miles north of Fort Collins). The sites are designed to demonstrate how farmers can conserve water by altering their cropping systems and optimizing the timing of irrigation. The goal is to increase the crops water use efficiency (yield per inch of ET) and to optimize their economic return to irrigation water. One demonstration site is a 2.5 acre area managed under a linear-move sprinkler irrigation system and the second site is a 10 acre area managed under furrow irrigation. The sprinkler irrigation site is designed with plots 30 feet wide and 85 feet long (Figs. 1 and 2). The plots represent the four crop rotations outlined in Table 1. Each crop phase within each crop rotation is present every year. The crop rotations were arranged in a randomized complete block design, with the phase of each crop randomized within the rotation and each rotation is replicated four times. A linear irrigation system is used with low impact drop nozzles spaced five feet apart. The system is not capable of controlling irrigation exactly to the borders of the individual plots, so only the center 10 feet of each plot is used for data collection, with the remaining area used as a buffer zone for transition of irrigation level with the adjacent plots. Irrigation opportunity with the linear irrigation system is one time per week during the growing season, with possible irrigation amounts ranging from 0.5 to 2.2 inches per week. The irrigation timing was determined by crop growth stage and follows the irrigation plan outlined in Table 1. All irrigation events and amounts are recorded and are reported in Table 3. An example comparison of irrigation timing is illustrated for the corn crop with different irrigation systems in Figure 6. A weather station is used to monitor daily rainfall, temperature, solar radiation, humidity, and wind. Two neutron probe access tubes were installed in each plot of two study replications. A neutron probe moisture meter is used to measure soil moisture before and after each irrigation or on two week intervals when no irrigation occurs. Spring of 2008 all of the neutron probe access tubes were removed and one tube was installed in the center of each plot in all four replications. The soil moisture was measured once per week before irrigation. The neutron probe has been calibrated against measured gravimetric soil moisture and bulk density so that counts from the probe can be converted to volumetric soil moisture (see Figure 7). Canopy temperature is measured weekly on all growing crops using an infrared thermometer. These temperature readings will be used to calculate the crop water stress index. All of the cropping systems under the sprinkler are managed with a no-till system.

The furrow irrigation site in 2005-2007 was designed with plots 30 feet wide and 300 feet long (Figs 3 and 4). The plots represent the same four crop rotations as in the sprinkler irrigated site and as outlined in Table 1. Each crop phase within each crop rotation was present every year. The crop rotations were arranged in a randomized complete block design, with the phase of each crop randomized within the rotation and each rotation was replicated four times. These plots were furrow irrigated using well water delivered through gated pipe with each replication of the study having a separate line of gated pipe and tail water drainage ditch. In-line flow monitors (SeaMetrics AG2000 Irrigation Magmeter) accurately measured irrigation inflow to a block replicate of the study and careful notes are taken about time of irrigation for specific plots within the block replicates in order to assess irrigation application amounts. We also estimated applied irrigation by measuring the change in stored soil moisture to a depth of six feet with a neutron probe before and after each irrigation. Neutron probe readings were made in two access tubes per plot on two of the four replications. The fully irrigated system was managed with conventional tillage, while a minimum till system was employed for the two limited irrigation treatments. For these treatments, tillage was limited to furrow building and cleaning operations. The dryland cropping system was managed with in a no-till system.

In the Spring of 2008 the furrow irrigation site design was changed. The plot sizes were 45 by 600 feet and 45 by 300 feet (Figs 3 and 4). A crop rotation of conventional tillage corn and soybeans was inserted. The north plot was divided into 3 replications of fully irrigated corn and 3 replications of limited irrigated corn, which was irrigated through siphon tubes from well water delivered through a ditch. The south plot was divided into 3 replications of fully irrigated soybeans and 3 replications of limited irrigated soybeans, which was irrigated through gated pipe. Neutron access tubes were installed to measure soil moisture with 12 access tubes in the corn and 4 access tubes in the soybeans.

A third demonstration site was added to this project as a result of cooperation with NCWCD. The demonstration is located on a 4.7 acre field with a silty clay loam soil near Berthoud, Colorado (Figure 5), and was conducted during the 2006 - 2009 seasons. Irrigation is provided through a 2-span linear sprinkler utilizing a guidance furrow for the end cart with water from the Handy Ditch. Sprinkler drops were 5 feet on center with LDN heads 3 feet above the ground. The field is divided into 12 plots, 4-wide by 3-long grid, to provide three replicates of each of four irrigation treatments. The sprinkler has an on-board programmable controller/logger interfaced with the base station controller for the sprinkler valves on the linear cart to automatically control irrigation to each plot in the alfalfa field. Utilizing a GPS receiver, the controller was able to determine the position of the linear cart within 3.5 to 5 feet and control which plots were turned on or off at any given time. Four soil moisture monitoring stations were installed in the alfalfa field, one in each irrigation treatment. Each station employed a programmable data logger with a 100 milli-Watt spread-spectrum radio for communication to the headquarters office. A total of four soil moisture sensors were connected to each data logger, measuring the dielectric constant of the soil to determine volumetric soil moisture. Moisture sensors were installed vertically at depths of 6, 18, 30, and 42 inches below the surface.

Each station included a tipping bucket rain gauge, 18 amp-hour rechargeable battery, and 5-watt solar panel. Spring of 2009 neutron probe access tubes were installed in the center of each plot and soil moistures were measured at each harvest. On the same day as the alfalfa was swathed, alfalfa yield was determined by hand sampling and weighing a 20 foot length of windrow (16 foot wide swath) from the center of each plot. Sub-samples were weighed and placed in paper bags for oven drying and determining moisture content and were also used for alfalfa quality analysis.

Results of Field Demonstrations

This report will detail results from field seasons 2005, 2006, 2007, 2008, 2009 and 2010 for the sprinkler irrigated field demonstration site. Results for the furrow irrigation site are similar and will be included in the final project report. Results for the alfalfa irrigation demonstration site are not included here, but can be found in the attached technical report "Alfalfa Growth Responses to Water and Partial Season Irrigation."

Sprinkler Irrigation Demonstration Site Results

Precipitation

Precipitation was below the long term normal during all five years of the demonstration (Figure 8). In 2005, precipitation totaled 11.6 inches and was characterized by a wet spring followed by a very dry summer and fall. July, August, and September were very dry, with just over one inch of total rainfall for the three months (Table 2). The 2006 year was very dry, with a total precipitation of only 4.4 inches. Precipitation in 2007 totaled 10.4 inches. The spring and early summer were very dry, while the mid summer months were wet (Table 2). In 2008, 11.54 inches of precipitation neared the 30 year average due to the 4.41 inches of precipitation in August, but with significant hail. The 2009 year had a wet spring with a total precipitation of 11.22 inches. 2010 started with a wet spring, but then tailed off below the 30 year average. These irrigation amounts illustrate the arid conditions that exist for the agricultural ecosystems of the Colorado Front Range. Without irrigation, production agriculture would not make a significant contribution to the local economy. Application of large amounts of irrigation water allows for high yielding agricultural production and reduces the risk associated with variable climatic conditions. Limited irrigation cropping practices seek to conserve irrigation water while maintaining viable crop production systems.

These five years in this demonstration project have been good years for a limited irrigation project because precipitation has been below normal, allowing more control over water inputs.

Crops and Crop Yields

Yields for all crops and all years are summarized in Table 4. Corn was selected for the limited irrigation study because it is the dominant crop produced in Colorado. For example, corn makes up 50% of all irrigated acres in the South Platte basin of Colorado (38%=corn grain, 12%=corn silage). Corn yield is very responsive to water supply and is also sensitive to the timing of water relative to the crop growth stage. Yields of corn grown under three different irrigation regimes at the sprinkler irrigation demonstration site are shown in Figure 9. The fully irrigated corn yield was greatest in every demonstration year except 2008 due to hail and insect damage with yields of 237, 177, 186, 173, 215, and 196 bu/ac for 2005-2010. The six year average full irrigation corn yield was 197 bu/ac. While slightly lower than high yield goals often sought for by area corn producers, these corn yields are fairly typical for irrigated fields along the Colorado Front Range. Yields from the limited irrigation corn systems are less than those for the fully irrigated corn, as a result of reduced irrigation inputs. Average yield for limited irrigation corn in the forage based system was 159 bu/ac and was 151 bu/ac for corn in the grain crop rotation. Grain yield reductions are expected with lower water inputs. The goal of growth stage timing of limited irrigation is to increase the water use efficiency, meaning that the amount of grain produced per unit of water used increases, even while the grain yield per unit of land area decreases. In this demonstration, limited irrigation corn received approximately half of the applied irrigation, while yields were reduced by only 25% compared to the full irrigation system. Corn along the Front Range is frequently harvest as a silage crop rather than a grain crop. In the demonstration project, corn was produced for grain, but each year we harvest corn biomass within sub-plots in order to assess the corn silage production impacts associated with limited irrigation. Corn silage yields are reported in Figure 10. Silage yield on fully irrigated corn ranged between 8.0 and 9.0 T/ac. Silage yield reductions associated with the limited irrigation treatments were greater than grain yield reductions.

Sunflower was selected as a crop for the limited irrigation demonstration because it is a crop that is well adapted to this region. Cultivated sunflowers were developed from native sunflowers in North America and it is only of the few agricultural crops native to this region. Sunflower is drought tolerant, having developed with an aggressive root system and the ability to extract moisture from drier soils compared with many other crops. Currently, sunflower production does represent a large acreage in Colorado, although there has been modest gain in production acres in recent years. It is anticipated that sunflower may become a more significant crop as competition for limited water resources becomes greater. Sunflower yields at the sprinkler irrigated demonstration site averaged 1560 lbs/ac, 2500 lbs/ac, and 1700 lbs/ac for 2005, 2006, and 2007, respectively (Figure 11). Due to hail and bird damage no seed yields were taken, but silage yields were taken in 2008 (Figure 10). In 2009 Sunflowers were replaced with Forage Sorghum to allow for more timely wheat planting dates. All sunflowers were produced with limited irrigation and there were no irrigation level comparisons for this crop. Irrigation inputs for sunflower represent a 60% reduction in applied irrigation relative to the fully irrigated corn crop. The average yield of 1900 lbs/ac is below optimum, fully irrigated sunflower crop yields, but can be an economically viable yield when sunflower prices are high. Producers adopting sunflowers to conserve irrigation water may want to increase irrigation some relative to the levels evaluated in this demonstration, while still irrigating significantly less than for corn.

Winter wheat was chosen as a rotation crop for the demonstration project because it is a common crop in this region and has a lower water requirement than corn. Wheat is most common as a dryland crop in Colorado, representing up to 80% of dryland farmland in the state. However, irrigated wheat is an important crop in the region. In the demonstration, wheat is included in both the grain based limited irrigation crop rotation and in 2005-2007 as a dryland crop in rotation with summer fallow and in 2008-2010 as a dryland crop in rotation with dryland corn. The dryland winter wheat is demonstrated as a reference system illustrating the scenario that an irrigator chooses to completely dry-up irrigated land as a result of a water transfer agreement. Currently, ag-to-urban water transfers require the producer to cease irrigation on the land associated with the transferred water. This limited irrigation demonstration project is being conducted to demonstrate alternatives to complete dry-up of irrigated land. The wheat-summer fallow and wheat-corn systems represents grain crop production potential for land without any irrigation. Other possible land uses for formerly irrigated land include conversion to range land for livestock grazing or re-vegetation with a cover crop to reduce wind and water erosion. These other land uses were not included in the current demonstration project. Irrigated winter wheat can be a good rotation crop for a limited irrigation system because of its relatively low water requirements. Wheat yields averaged 44bu/ac for both irrigation treatments in the 2005-2006 growing season (Figure 12). Yields were lower in 2007 for both treatments with 22 bu/ac for the dryland treatment and 33 bu/ac for limited irrigation. 2008 yield for the dryland treatment was 27 bu/ac and no grain yield was taken for the limited irrigation treatment due to low germination at planting. In lieu of grain yields, limited irrigation grass forage yields were taken which resulted in 1 ton/ac

(Figure 12). Yields were higher in 2009 for both treatments due to the wet spring with 48 bu/ac for the dryland wheat and 63 bu/ac for the limited irrigation wheat. 2010 yields were a little lower than expected due to some frost damage with 44 bu/ac dryland and 52 bu/ac limited irrigation. The average winter wheat yield in the limited irrigation grain crop rotation of 48.0 bu/ac is average and is considered economically viable. The initial plan of the demonstration project was to restrict irrigation for this system to approximately 5 inches per year, representing 3 irrigation events for the typical farmer. Our results suggest that more irrigation would be required to make winter wheat a successful limited irrigation crop. This may especially be true in the scenario of this demonstration where winter wheat follows sunflower. The sunflower crop leaves a very dry soil profile, leaving very little water available for the subsequent wheat crop. Another challenge we experienced in the demonstration of a winter wheat-corn-sunflower rotation was a late planting date for the wheat following sunflower harvest. The sunflower growing season and harvest data forced a late planting of the wheat, which results in reduced wheat yields. Dryland wheat yields averaged 37bu/ac and require two years because of the rotation with summer fallow and dryland corn. This very limited production is not economically sustainable and represents how a complete dry-up of irrigated agricultural land along the Colorado Front Range would affect the agricultural economy at both farm and regional scales.

Alfalfa is an economically important crop grown in Colorado and is a high water use crop with the potential to use up to three acre feet of water per year. Alfalfa has good potential for limited irrigation because it has natural drought tolerance, is a perennial crop, and has large potential water savings. In our demonstration sites at ARDEC, alfalfa was seeded in the fall of 2005. The 2006 growing season was an establishment year for alfalfa and no irrigation comparisons were made. Average dry matter yield in 2006 was 3.5 T/ac. The first year of irrigation comparisons was made in 2007. The limited irrigation alfalfa treatment consisted of partial season irrigation. Partial season irrigation means that the crop was fully irrigated during part of the year, while irrigation was terminated during other parts of the year. The partial season irrigation system demonstrated consisted of irrigation through the first alfalfa harvest (May 24), followed by no irrigation in the middle of the summer, and finally, irrigation was resumed after the third alfalfa harvest (Aug 6). Yields were 3.8 and 3.5 T/ac for the fully irrigated and limited irrigation systems, respectively. 2008 yields for the fully irrigated was 3.8 T/ac and limited irrigated was 2.1 T/ac. A colder spring delayed green up resulting in a lower yield. The 2009 year had higher yields due to a wet spring with the fully irrigated of 5.6 T/ac and limited irrigated of 3.5 T/ac. In the spring of 2010 the alfalfa and corn were rotated. So, the yields 2.6 T/ac were lower in the establishment year. Alfalfa is a perennial crop that has evolved with drought tolerance traits that make it good crop choice for limited irrigation. When under drought stress, alfalfa goes into dormancy but remains viable, storing energy in the crown and maintaining buds that are capable of rapid growth when water becomes available. Alfalfa develops a very deep and aggressive root system that is very effective at exploring the crop root zone for water. Another advantage of alfalfa production under limited irrigation is the potential for improving the quality of the forage through irrigation management. Higher quality hay has a price incentive in the marketplace. Our study found that limited irrigation alfalfa does have higher quality in terms of both protein content and digestibility. The higher value of the limited irrigation hay partially offsets the reduced yields.

Crop Water Use, Water Use Efficiency, and Potential Water Savings

Crop water use was determined in the demonstration by the water balance method. The water balance method determines crop evapotranspiration (ET) by accounting for all potential inputs of water to the crop. Precipitation and irrigation water inputs are determined as well as the extraction of water stored in the soil profile by plant roots. In this demonstration, potential water losses due to runoff and to deep leaching of water below the crop root zone are assumed to be zero for the sprinkler irrigation site. Observations and soil profile water measurements support these assumptions. Crop water use for all crops and crop rotations for the 2006-2010 years are summarized in Table 5. Precipitation amounts reported in this table are the amounts of precipitation between the date of planting and harvest of the crop and are not annual totals. Crop ET and the contribution to ET by precipitation, applied irrigation, and water use from the soil profile are shown for corn, winter wheat, sunflower, and alfalfa by contribution for 2006 – 2010, grass forage for 2008, and forage sorghum for 2009-10 at the CSU-ARDEC demonstration site in Figure 14. Applied irrigation for the fully irrigated corn and alfalfa system averaged over five years was 15.5 inches. Crop ET for the fully irrigated system averaged 23.5 inches of water. The fully irrigated ET is used as the standard of comparison for estimated water savings of the limited irrigation systems. The limited irrigation forage based system averaged 8.7 inches of applied irrigation and an average ET of 16.5 inches. This system demonstrated a modest irrigation savings of 7 inches of water. Applied irrigation for the limited irrigation, grain based system averaged 8.1 inches and ET was 15.5 inches, with an ET savings of 8 inches relative to the fully irrigated corn-alfalfa reference. The ET for the dryland rotation was 11 inches, with and ET saving of 12.5 inches. Although water savings for the dryland system are high, the average crop production in this system is too low for 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 cropping systems should be considered as a means of meeting urban water needs while maintaining viable irrigated agricultural systems.

Crop water use efficiency is a means of expressing the crop harvestable yield in terms of the quantity of ET to produce that yield. While most are familiar with representing crop yield on a per unit of land area bases (ie: bu/ac or T/ac), water use efficiency represents yield on a per unit of water used basis (bu/ac/in or T/ac/in). Crop water use efficiencies are reported in Table 6 and are illustrated for each crop in Figure 15. As noted for corn produced with different irrigation methods, the limited irrigation systems have higher water use efficiency values than the fully irrigated corn system. Limited irrigation systems have the potential to increase crop production per unit of ET relative to traditional irrigation systems.

Summary

Crops evaluated for their potential use in a limited irrigation system include corn grain, corn silage, winter wheat, sunflower, forage sorghum, and alfalfa. Corn and alfalfa are the dominant crops produced under irrigation in Colorado, representing about 80% of the irrigated acres. This demonstration shows that limited irrigation practices can reduce total applied irrigation on corn by as much as 50% while reducing yields by only 25%. Although yields on an area basis are reduced, the yield per unit of ET increases for limited irrigation corn, representing an increase in water use efficiency. ET savings from limited irrigation were 7-8 inches per year relative to traditional, fully irrigated production. There is also potential water savings associated with rotating corn with other limited irrigation crops. Production of limited irrigation sunflower was demonstrated as a viable alternative, with an ET savings of 4-7 inches relative to fully irrigated corn. Although not currently produced on a large scale in Colorado, sunflower is well adapted to this region and tolerates drought stress associated with limited irrigation systems. Limited irrigation of winter wheat is a potential alternative, but will require more irrigation than the levels used in this demonstration. Average ET from winter wheat in the demonstration was 12.5 inches, representing a savings of 11 inches relative to full irrigation corn. However, average yields for this system were below sustainable levels. Limited irrigation alfalfa was demonstrated at all three field sites and was found to have great potential for limited irrigation. Because of its natural drought tolerance and perennial growth habits, limited irrigation alfalfa can generate large savings in ET while still maintaining a viable crop production system.

Potential ET savings in a dryland cropping system where no irrigation is applied was as high as 12.5 inches. Although water savings for the dryland system are high, the crop production in this system 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 cropping systems should be considered as a means of meeting urban water needs while maintaining viable irrigated agricultural systems.

Table 1. Four cropping systems and the irrigation water management plans at the CSU-ARDEC sprinkler and furrow irrigated field sites.

Cropping System	Crop Rotation	Planned Irrigation, (in)	Critical Irrigation Timing
Dryland	Winter wheat	0	
	Fallow*	0	
	Average Annual	**0**	
Limited Irrigation Grain based system	Winter wheat	5.0	Feeks stage 10, early flower
	Corn	8.0	12 leaf, tassel, early blister
	Sunflower	8.0	Bud initiation, early flower
	Average Annual	**7.0**	
Limited Irrigation Forage based system	Corn	10.0	Irrigate for full ET after 12 leaf stage
	Alfalfa	10.0	Full irrigation until July 1, then no irrigation
	Average Annual	**10.0**	
Full Irrigation	Corn	17.0	Full irrigation
	Alfalfa	27.0	Full irrigation
	Average Annual	**22.0**	

*In 2008 fallow was replaced with dryland corn.

Table 2. Monthly summary of precipitation and average temperature for 2005 - 2010 at the CSU-ARDEC demonstration site.

IWOP Annual Monthly Precipitaion at ARDEC - 2005-2010

2005			2006			2007		
Month	**Avg. Temp (°F)**	**Precip (in.)**	**Month**	**Avg. Temp (°F)**	**Precip (in.)**	**Month**	**Avg. Temp (°F)**	**Precip (in.)**
January	30.1	0.18	January	35.1	0.00	January	19.8	0.08
February	34.2	0.10	February	28.5	0.08	February	29.7	0.08
March	39.1	0.75	March	36.0	0.52	March	44.1	1.19
April	45.6	1.66	April	49.7	0.16	April	45.8	1.03
May	54.8	2.17	May	58.6	0.60	May	56.2	0.89
June	63.8	3.20	June	70.8	0.24	June	66.7	0.52
July	73.0	0.28	July	73.4	0.58	July	74.3	1.61
August	67.8	0.87	August	70.0	0.29	August	72.0	2.46
September	62.4	0.12	September	56.5	0.83	September	61.9	1.15
October	49.8	2.19	October	46.2	0.74	October	50.3	1.30
November	39.7	0.08	November	36.7	0.15	November	37.9	0.12
December	27.9	0.00	December	27.5	0.24	December	22.4	0.31
Total Annual Precip.		**11.60**	**Total Annual Precip.**		**4.43**	**Total Annual Precip.**		**10.74**

2008			2009			2010		
Month	**Avg. Temp (°F)**	**Precip (in.)**	**Month**	**Avg. Temp (°F)**	**Precip (in.)**	**Month**	**Avg. Temp (°F)**	**Precip (in.)**
January	34.7	0.00	January	31.4	0.04	January	28.2	0.02
February	39.0	0.00	February	34.2	0.02	February	26.6	0.33
March	44.7	0.45	March	39.0	0.16	March	39.3	0.85
April	52.6	1.58	April	44.3	2.54	April	45.9	4.23
May	62.6	1.59	May	57.3	1.41	May	55.7	2.14
June	73.4	1.65	June	62.3	3.75	June	66.2	1.53
July	81.8	0.48	July	68.4	1.59	July	70.7	0.94
August	74.4	4.41	August	67.6	0.10	August	70.3	0.49
September	65.4	0.98	September	60.5	0.26	September	62.4	0.07
October	55.6	0.39	October	40.5	0.85	October	51.7	0.83
November	48.9	0.01	November	38.7	0.32	November	35.0	0.89
December	24.3	0.00	December	21.0	0.18	December	32.0	0.07
Total Annual Precip.		**11.54**	**Total Annual Precip.**		**11.22**	**Total Annual Precip.**		**12.39**

*All climate data taken from COAGMET station FTC03 "CSU ARDEC"

Table 3. Irrigation amounts and timings for all cropping systems and crops at the CSU-ARDEC demonstration site for 2006 - 2010.

1070 - 2006

Applied Irrigation Amounts and Timing 2006

	Cropping System 1		Cropping System 2		Cropping System 3		Cropping System 4		
Date	W	F	C	A	C	A	W	C	Sf
04/27/06				1.5		1.5	1.5		
05/18/06			1.5	1.5		1.5	1.5		
06/01/06					1.5		1.5		
06/15/06			1.5	1.5		1.5	1.5		1.5
06/22/06			1.5	1.5		1.5			1.5
07/03/06			3.0	3.0		3.0			
07/13/06			2.0	2.0		2.0			
07/21/06			2.0	2.0	2.0	2.0		2.0	
07/27/06			2.2	2.2	2.2	2.2		2.2	
08/03/06			1.5		1.5			1.5	1.5
08/10/06			1.5	1.5		1.5			1.5
08/18/06			1.5	1.5	1.5	1.5		1.5	1.5
08/24/06			1.5	1.5	1.5	1.5			
TOTAL			19.7	19.7	10.2	19.7	6.0	7.2	7.5

1070 - 2007

Applied Irrigation Amounts and Timing 2007

	Cropping System 1		Cropping System 2		Cropping System 3		Cropping System 4		
Date	W	F	C	A	C	A	W	C	Sf
05/25/07			1.5		1.5		1.5	1.5	1.5
06/13/07				2.0		2.0	2.0		
06/20/07			1.8	1.8	1.8	1.8	1.8	1.8	
06/28/07			2.0	2.0		2.0			
07/11/07			2.0	2.0					
07/19/07			2.0	2.0	2.0			2.0	2.0
07/25/07			1.5	1.5	1.5			1.5	1.5
08/16/07			1.5	1.5	1.5	1.5		1.5	
08/23/07			1.0	1.0		1.0			1.0
08/29/07			1.0	1.0		1.0			
TOTAL			14.3	14.8	8.3	9.3	5.3	8.3	6.0

1070 - 2008

Applied Irrigation Amounts and Timing 2008

	Cropping System 1		Cropping System 2		Cropping System 3		Cropping System 4		
Date	W	C	C	A	C	A	W	C	Sf
05/11/08	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
06/04/08			1.5	1.5	1.5	1.5	1.5	1.5	1.5
06/12/08			1.0	1.0		1.0	1.0		
06/18/08			1.0	1.0		1.0			
06/26/08			1.5	1.5					
07/03/08			1.5	1.5		1.5			
07/10/08			1.5	1.5		1.5			
07/17/08			1.5	1.5					1.5
07/24/08			1.5	1.5	1.5			1.5	1.5
07/31/08			1.5	1.5	1.5			1.5	1.5
08/07/08			1.0	1.0	1.0			1.0	1.0
08/15/08			1.0	1.0	1.0			1.0	
TOTAL	1.5	1.5	16.0	16.0	8.0	8.0	4.0	8.0	8.5

1070 - 2009

Applied Irrigation Amounts and Timing 2009

	Cropping System 1		Cropping System 2		Cropping System 3		Cropping System 4		
Date	W	C	C	A	C	A	W	C	M
05/20/09		0.5	0.5	0.5	0.5	0.5	0.5	0.5	
07/01/09			1.0	1.0	1.0		1.0	1.0	1.0
07/08/09			0.5	0.5					0.5
07/16/09			1.5	1.5					1.5
07/23/09			1.5	1.5					
07/30/09			0.5	0.5					
08/06/09			1.5	1.5	1.5			1.5	
08/13/09			1.5	1.5	1.5			1.5	
08/20/09			1.5	1.5	1.5			1.5	
08/27/09			1.5	1.5	1.5			1.5	
TOTAL	0.0	0.5	11.5	11.5	7.5	0.5	1.5	7.5	3.0

1070 - 2010

Applied Irrigation Amounts and Timing 2010

	Cropping System 1		Cropping System 2		Cropping System 3		Cropping System 4		
Date	W	C	C	A	C	A	W	C	Fs
06/11/10			1.0	1.0		1.0	1.0		
06/24/10			1.0	1.0		1.0	1.0		1.0
07/01/10			1.0	1.0		1.0			
07/08/10			1.0	1.0		1.0			
07/17/10			1.5	1.5	1.5	1.5		1.5	
07/22/10			1.5		1.5			1.5	1.5
07/29/10			1.5	1.5	1.5	1.5		1.5	
08/05/10			1.25	1.25	1.25	1.25		1.25	
08/12/10			1.5	1.5	1.5	1.5		1.5	
08/19/10			1.25	1.25		1.25			
08/26/10			1.25	1.25		1.25			
09/02/10			1.0	1.0	1.0	1.0		1.0	
09/16/10			1.0	1.0		1.0			
10/06/10				1.0		1.0			
TOTAL	0.00	0.00	15.75	15.25	8.25	15.25	2.00	8.25	2.50

Table 4. Crop yield summary for the CSU-ARDEC demonstration site for 2005 - 2010.

IWOP 1070 2005-2010 Average Yield

			Yields						
Rotation	**Crop**	**Units**	**2005**	**2006**	**2007**	**2008***	**2009**	**2010****	**Average**
Limited Grass Forage	W/B/M	tons/acre				1.0			**1.0**
Limited Forage	Fs	tons/acre					2.0	1.3	**1.6**
Limited Grain	W	bu/acre		44.2	32.8	*	62.9	52.3	**48.1**
Limited Grain	C	bu/acre	163.4	120.6	101.4	179.6	190.0	153.0	**151.3**
Limited Grain	Sf	tons/acre				1.8			**1.8**
Limited Grain	Sf	lbs/acre	***1551.3	2546.9	1769.5	**			**2158.2**
Limited Forage	C	bu/acre	162.5	141.8	134.9	166.2	185.0	161.0	**158.6**
Limited Forage	A	tons/acre		4.1	3.5	2.1	3.5	2.6	**3.2**
Full Irrigation	C	bu/acre	236.5	176.6	185.6	172.7	215.0	195.68	**197.0**
Full Irrigation	A	tons/acre		3.4	3.8	3.8	5.6	2.6	**3.8**
Dryland	C	bu/acre			24.4	54.8	67.0	45.1	**47.8**
Dryland	W	bu/acre		44.0	22.4	26.9	48.1	43.7	**37.0**

*No grain yields were taken due to low germination at planting.

**Due to Hail, Insect, and Bird damage no grain yield was taken from the oil sunflowers.

***In 2005 confection sunflowers were grown, 2006-2008 oil sunflowers were produced

****2010 Alfalfa Establishment Year

W = Wheat

C = Corn

A = Alfalfa

Sf = Sunflower

W/B/M = Wheat/Barley/Millet

Fs = Forage Sorghum

Table 5. Evapotranspiration (ET) summary by contribution for the CSU-ARDEC demonstration site for 2006 - 2010 and the four year average.

IWOP 1070 2006-2010 ET

Rotation	Crop	Irrigation	Precip.	Δθ	ET
			2006		
Limited Grain	W	5.7	1.3	3.8	10.8
Limited Grain	C	6.8	2.1	-0.2	8.8
Limited Grain	Sf	7.1	1.9	9.7	18.7
	Avg.	**6.6**	**1.8**	**4.4**	**12.8**
Limited Forage	C	9.7	2.1	1.8	13.6
Limited Forage	A	18.7	2.5	0.6	21.9
	Avg.	**14.2**	**2.3**	**1.2**	**17.7**
Full Irrigation	C	18.7	2.1	1.0	21.8
Full Irrigation	A	18.7	2.5	1.2	22.4
	Avg.	**18.7**	**2.3**	**1.1**	**22.1**
Dryland	W	0.0	1.3	6.2	7.5
	Avg.	**0.0**	**1.3**	**6.2**	**7.5**
			2008		
Limited Grass Forage	W	9.00	10.79	-7.47	12.3
Limited Grain	C	8.00	9.36	-2.91	14.4
Limited Grain	W/B/M	5.50	8.86	1.93	16.3
	Avg.	**7.5**	**9.7**	**-2.8**	**14.4**
Limited Forage	C	8.00	9.36	0.45	17.8
Limited Forage	A	8.0	9.4	-1.2	16.2
	Avg.	**8.0**	**9.4**	**-0.4**	**17.0**
Full Irrigation	C	16.00	9.36	1.95	27.3
Full Irrigation	A	16.0	9.4	-3.9	21.5
	Avg.	**16.0**	**9.4**	**-1.0**	**24.4**
Dryland	W	1.50	8.39	5.47	15.4
Dryland	C	1.50	9.36	1.24	12.1
	Avg.	**1.5**	**8.9**	**3.4**	**13.7**
			2010		
Limited Grass Forage	W	2.00	13.48	3.59	17.1
Limited Grain	C	8.25	5.06	6.42	19.7
Limited Grain	Fs	2.50	1.43	2.61	6.5
	Avg.	**4.3**	**6.7**	**4.2**	**15.1**
Limited Forage	C	8.25	5.06	4.04	17.4
Limited Forage	A	15.3	9.4	*	*
	Avg.	**11.8**	**7.2**	**4.0**	**23.0**
Full Irrigation	C	15.75	5.06	4.80	25.6
Full Irrigation	A	15.3	9.4	*	*
	Avg.	**15.5**	**7.2**	**4.8**	**27.5**
Dryland	W	1.50	13.48	2.51	17.5
Dryland	C	0.00	5.03	4.15	9.2
	Avg.	**0.8**	**9.3**	**3.3**	**13.3**

Rotation	Crop	Irrigation	Precip.	Δθ	ET
			2007		
Limited Grain	W	5.0	5.3	1.1	11.4
Limited Grain	C	7.8	7.8	-2.1	13.5
Limited Grain	Sf	5.7	7.2	1.7	14.6
	Avg.	**6.2**	**6.8**	**0.2**	**13.2**
Limited Forage	C	7.8	7.8	-0.5	15.2
Limited Forage	A	8.3	5.5	-4.7	9.0
	Avg.	**8.0**	**6.6**	**-2.6**	**12.1**
Full Irrigation	C	13.5	7.2	1.2	21.9
Full Irrigation	A	13.8	5.5	-9.7	9.6
	Avg.	**13.6**	**6.3**	**-4.2**	**15.7**
Dryland	W	0.0	5.3	2.3	7.6
	Avg.	**0.0**	**5.3**	**2.3**	**7.6**
			2009		
Limited Grass Forage	W	1.50	10.36	0.79	11.2
Limited Grain	C	9.50	5.88	6.29	21.7
Limited Grain	Fs	5.00	5.88	6.10	17.0
	Avg.	**5.3**	**7.4**	**4.4**	**17.1**
Limited Forage	C	9.50	5.88	3.55	18.9
Limited Forage	A	0.5	11.2	3.4	15.2
	Avg.	**5.0**	**8.6**	**3.5**	**17.1**
Full Irrigation	C	13.50	5.88	1.35	20.7
Full Irrigation	A	11.5	11.2	-1.4	21.3
	Avg.	**12.5**	**8.6**	**0.0**	**21.0**
Dryland	W	0.00	10.36	0.38	10.7
Dryland	C	0.50	4.99	6.43	11.9
	Avg.	**0.3**	**7.7**	**3.4**	**11.3**
			Five Year Average		
Limited Grain	W	4.6	8.3	0.4	12.6
Limited Grain	C	8.1	6.0	1.5	15.6
Limited Grain	Sf/Fs	5.2	5.0	4.4	14.6
	Avg.	6.0	6.4	2.1	14.3
Limited Forage	C	8.7	6.0	1.9	16.6
Limited Forage	A**	10.1	7.2	-0.5	15.6
	Avg.	9.4	6.6	0.7	16.1
Full Irrigation	C	15.5	5.9	2.0	23.5
Full Irrigation	A**	15.0	7.2	-3.4	18.7
	Avg.	15.3	6.5	-0.7	21.1
Dryland	W	0.6	7.8	3.4	11.7
Dryland	C	0.4	5.2	4.1	9.7
	Avg.	**0.5**	**6.5**	**3.7**	**10.7**

*2010 Alfalfa Establishment
**Four Year Average
W = Wheat
C = Corn
A = Alfalfa
Sf = Sunflower
Fs = Forage Sorghum
W/B/M = Wheat/Barley/Millet

Table 6. Average crop yield, evapotranspiration (ET), and water use efficiency (WUE) summary for the CSU-ARDEC demonstration site for 2006 - 2010.

		Five Year Average		
Rotation	**Crop**	**Yield**	**ET**	**WUE**
		tons/ac	**inches**	**tons/ac/in**
Limited Forage**	A	3.15	15.6	0.2
Full Irrigation**	A	3.83	18.7	0.2
Limited Grass Forage*	Fs	1.29	13.3	0.1
		bu/ac		**bu/ac/in**
Limited Grain	C	151	15.6	9.7
Limited Forage	C	159	16.6	9.6
Full Irrigation	C	197	23.5	8.4
		lbs/ac		**lbs/acre/in**
Limited Grain *	Sf	2158	16.6	129.7
		bu/ac		**bu/ac/in**
Limited Grain	W	48	12.6	3.8
Dryland	W	37	11.7	3.2

*Two year average.

**Four year average.

W = Wheat

C = Corn

A = Alfalfa

Sf = Sunflower

Fs = Forage Sorghum

Figure 1. Photos illustrating the sprinkler irrigation demonstration site at the CSU ARDEC location.

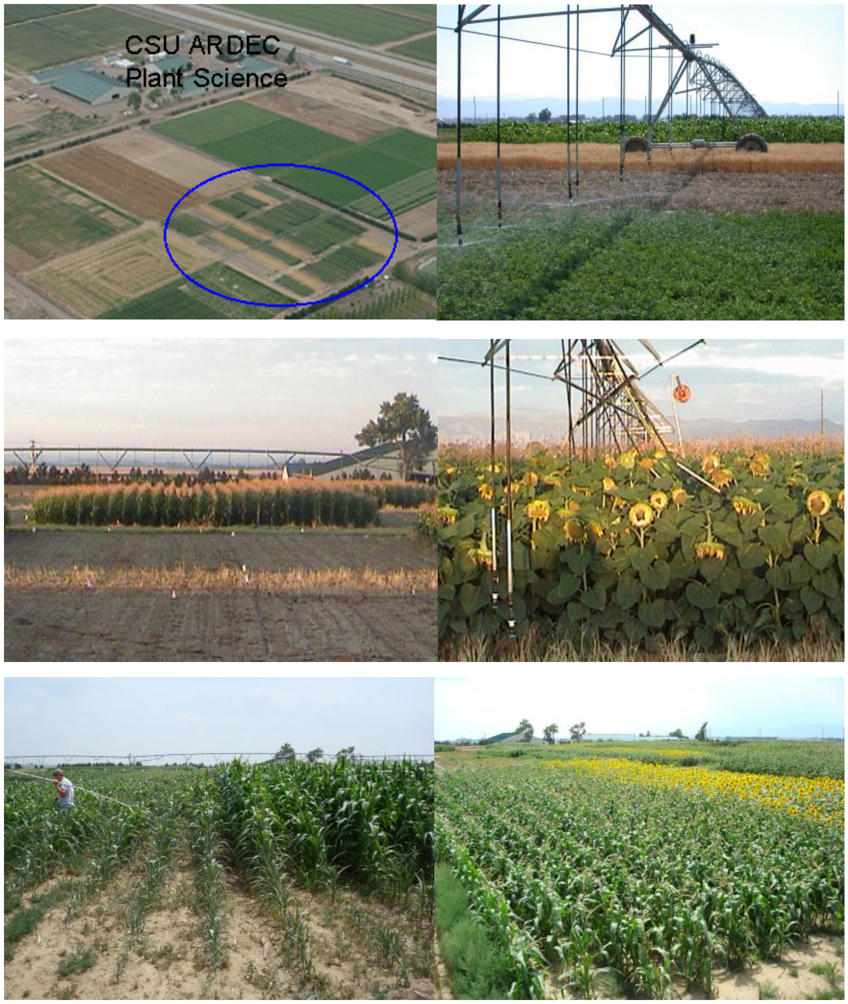


Figure 2. Demonstration plot map and layout for the Sprinkler Irrigation site at CSU-ARDEC

Irrigation Water Optimization Program
ARDEC Field 1070 Linear Irrigated

N^

Rep 1

Plot	501	502	503	504	505	506	507	508	509
Cropping System	1	1	2	2	3	3	4	4	4
2005	W	F	A	C	C	A	W	Sf	C
2006	F	W	A	C	C	A	C	W	Sf
2007	W	F	A	C	C	A	Sf	C	W
2008	C dry	W	A	C	C	A	W	Sf	C
2009	W	C dry	A	C	C	A	C	W	Fs
2010	C dry	W	C	A	A	C	Fs	C	W

Rep 2

Plot	601	602	603	604	605	606	607	608	609
Cropping System	2	2	3	3	4	4	4	1	1
2005	C	A	A	C	W	Sf	C	F	W
2006	C	A	A	C	C	W	Sf	W	F
2007	C	A	A	C	Sf	C	W	F	W
2008	C	A	A	C	W	Sf	C	W	C dry
2009	C	A	A	C	C	W	Fs	C dry	W
2010	A	C	C	A	Fs	C	W	W	C dry

Rep 3

Plot	701	702	703	704	705	706	707	708	709
Cropping System	2	2	3	3	4	4	4	1	1
2005	A	C	C	A	W	Sf	C	F	W
2006	A	C	C	A	C	W	Sf	W	F
2007	A	C	C	A	Sf	C	W	F	W
2008	A	C	C	A	W	Sf	C	W	C dry
2009	A	C	C	A	C	W	Fs	C dry	W
2010	C	A	A	C	Fs	C	W	W	C dry

Rep 4

Plot	801	802	803	804	805	806	807	808	809
Cropping System	4	4	4	2	2	1	3	3	1
2005	C	Sf	W	A	C	F	W	A	C
2006	Sf	W	C	A	C	W	F	A	C
2007	W	C	Sf	A	C	F	W	A	C
2008	C	Sf	W	A	C	W	C dry	A	C
2009	Fs	W	C	A	C	C dry	C	A	W
2010	W	C	Fs	C	A	W	A	C	C dry

Cropping Sy
1 = WF (Dry)2005-2007 WC (Dry)2008-2010
2 = CA (Fully Irrigated)
3 = CA (Conservation)
4 = WCSf (Rotation)

W = Wheat
C = Corn
A = Alfalfa
Sf = Sunflower
Fs = Forage Sorghum

Plots: 30' x 85'

On an annual basis, at IWOP 1070, there are:
0.94 acres of corn
0.47 acres of alfalfa
0.47 acres of wheat
0.23 acres of sunflowers/forage sorghum

Figure 3. Photos illustrating the furrow irrigation demonstration site at the CSU ARDEC location.

Figure 4. Demonstration plot map and layout for the 2005 - 2007 and 2008 - 2013 Furrow Irrigation site at CSU-ARDEC

Irrigation Water Optimization Program
ARDEC Kerbel Field Furrow Irrigated

N^

Rep 1

Plot	101	102	103	104	105	106	107	108	109
Cropping System	4	4	4	1	1	3	3	2	2
2005	W	C	Sf	W	F	C	A	A	C
2006	C	Sf	W	F	W	C	A	A	C
2007	Sf	W	C	W	F	C	A	A	C

Rep 2

Plot	201	202	203	204	205	206	207	208	209
Cropping System	2	2	1	1	3	3	4	4	4
2005	A	C	W	F	C	A	Sf	C	W
2006	A	C	F	W	C	A	W	Sf	C
2007	A	C	W	F	C	A	C	W	Sf

Rep 3

Plot	301	302	303	304	305	306	307	308	309
Cropping System	3	3	4	4	4	1	1	2	2
2005	A	C	W	Sf	C	W	F	A	C
2006	A	C	C	W	Sf	F	W	A	C
2007	A	C	Sf	C	W	W	F	A	C

Rep 4

Plot	401	402	403	404	405	406	407	408	409
Cropping System	3	3	2	2	1	1	4	4	4
2005	C	A	A	C	W	F	Sf	C	W
2006	C	A	A	C	F	W	W	Sf	C
2007	C	A	A	C	W	F	C	W	Sf

Cropping System
1 = WF (Dry)
2 = CA (Fully Irrigated)
3 = CA (Conservation)
4 = WCSf (Rotation)

W = Wheat
C = Corn
A = Alfalfa
Sf = Sunflower

Plots: 30' x 300'

On an annual basis, between both IWOP locations, there are:
3.3 acres of corn
2.2 acres of alfalfa
2.2 acres of wheat
1.1 acres of sunflowers

Irrigation Water Optimization Program
ARDEC Kerbel Field Furrow Irrigated

N^

Rep 1

Plot	H - 1	H - 2	H - 3	H - 1	H - 2	H - 3
Cropping System	5	5	5	6	6	6
2008	C	C	C	C	C	C
2009	S	S	S	S	S	S
2010	C	C	C	C	C	C
2011	S	S	S	S	S	S
2012	C	C	C	C	C	C
2013	S	S	S	S	S	S

Plots: 45' x 630'

Rep 2

Plot	H - 1	H - 1	H - 1	H - 1	H - 1	H - 1
Cropping System	7	7	7	8	8	8
2008	S	S	S	S	S	S
2009	C	C	C	C	C	C
2010	S	S	S	S	S	S
2011	C	C	C	C	C	C
2012	S	S	S	S	S	S
2013	C	C	C	C	C	C

Plots: 45' x 300'

Cropping System
5 = CS (Fully Irrigated)
6 = CS (Limited Irrigation)
7 = SC (Fully Irrigated)
8 = SC (Limited Irrigation)

S = Soybean
C = Corn

On an annual basis, at IWOP Kerbel, there are:
3.9 acres in Rep 1
1.9 acres in Rep 3

Figure 5. Photo and plot map and layout of the alfalfa limited irrigation demonstration in Berthoud, CO.

NCWCD Water Optimization Alfalfa Plot Layout

	290'	290'	290'	
	15'		15'	
216'	Full Irrigation	Stop Irr. After 2nd	Stop Irr. After 1st	4' 51'
	Spring and Fall Irr.	Full Irrigation	Stop Irr. After 2nd	4' 51'
	Stop Irr. After 1st	Spring and Fall Irr.	Full Irrigation	4' 51'
	Stop Irr. After 2nd	Stop Irr. After 1st	Spring and Fall Irr.	51'
		900'		

Figure 6. Timing of irrigation events for the different irrigation systems demonstrated for the corn crop under sprinkler irrigation at CSU ARDEC in 2006 - 2010.

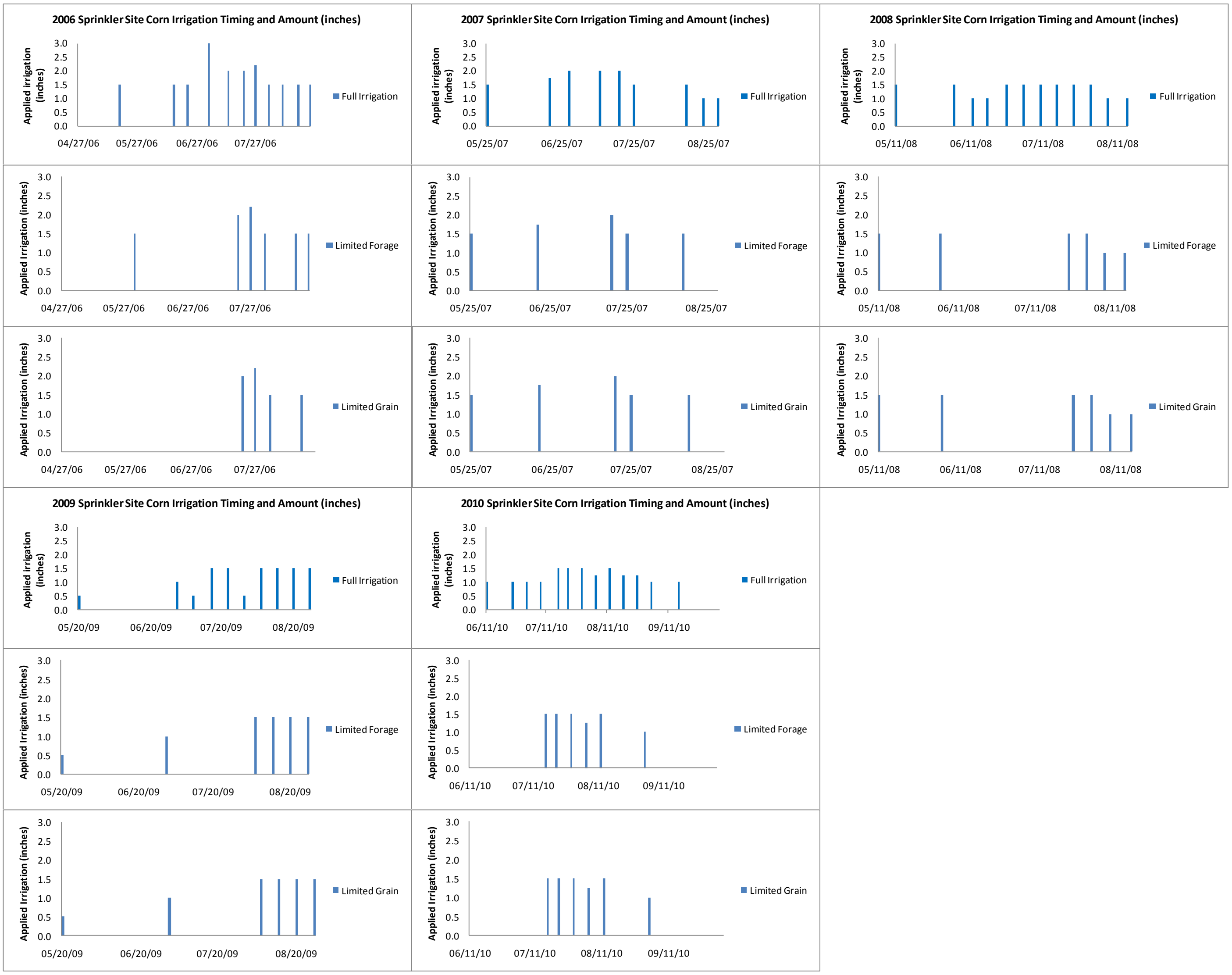


Figure 7. Calibration of CPN neutron density gauge for determining soil water content at the CSU ARDEC demonstration site.

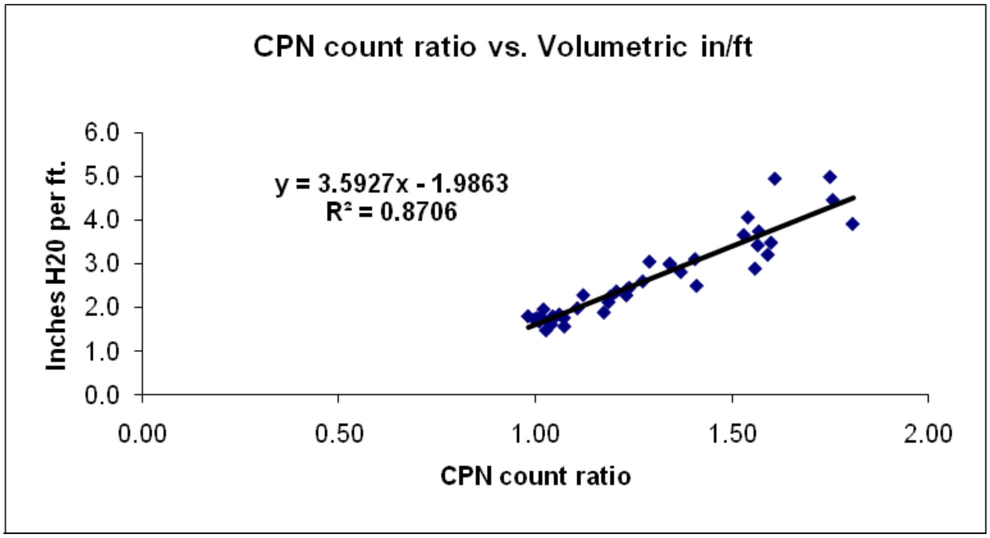


Figure 8. Cumulative annual precipitation in inches including long term historical averages for the CSU-ARDEC demonstration site.

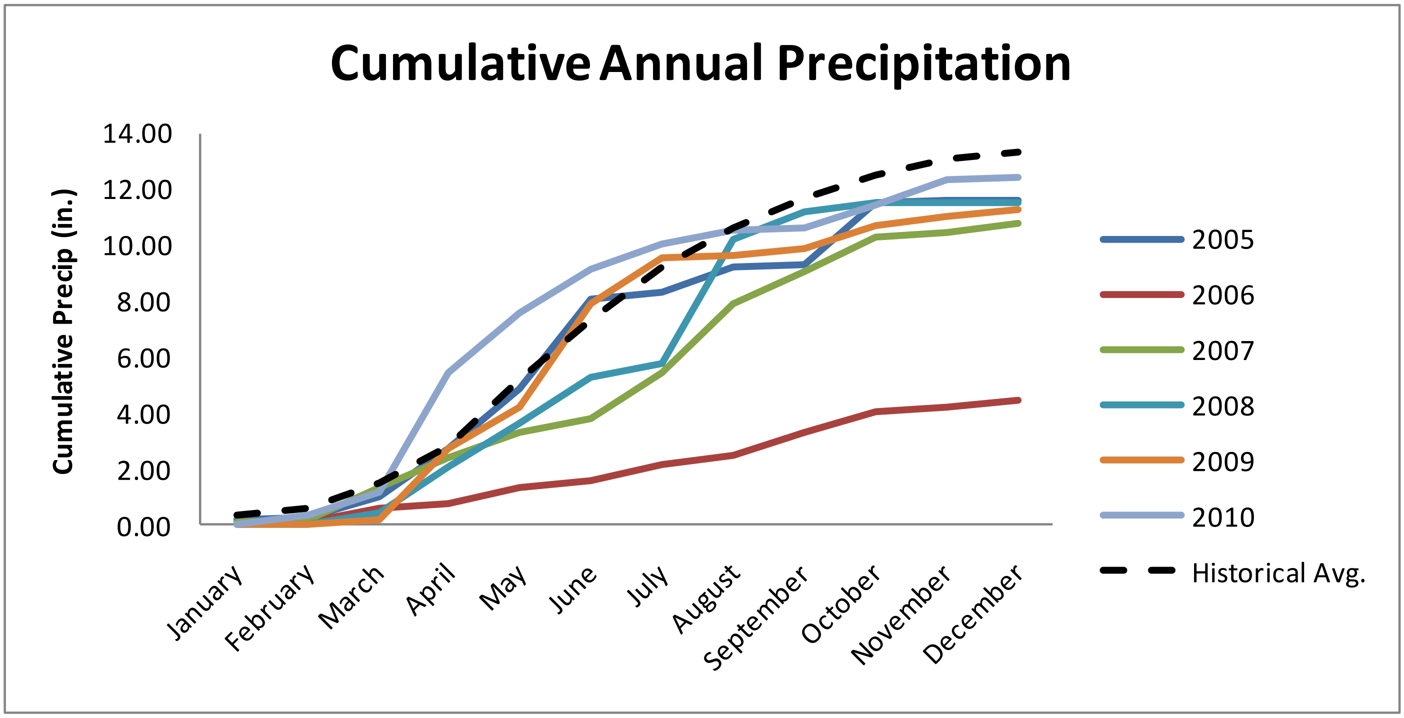


Figure 9. Sprinkler site corn grain yields 2005 - 2010 in bushels per acre for the CSU-ARDEC demonstration site.

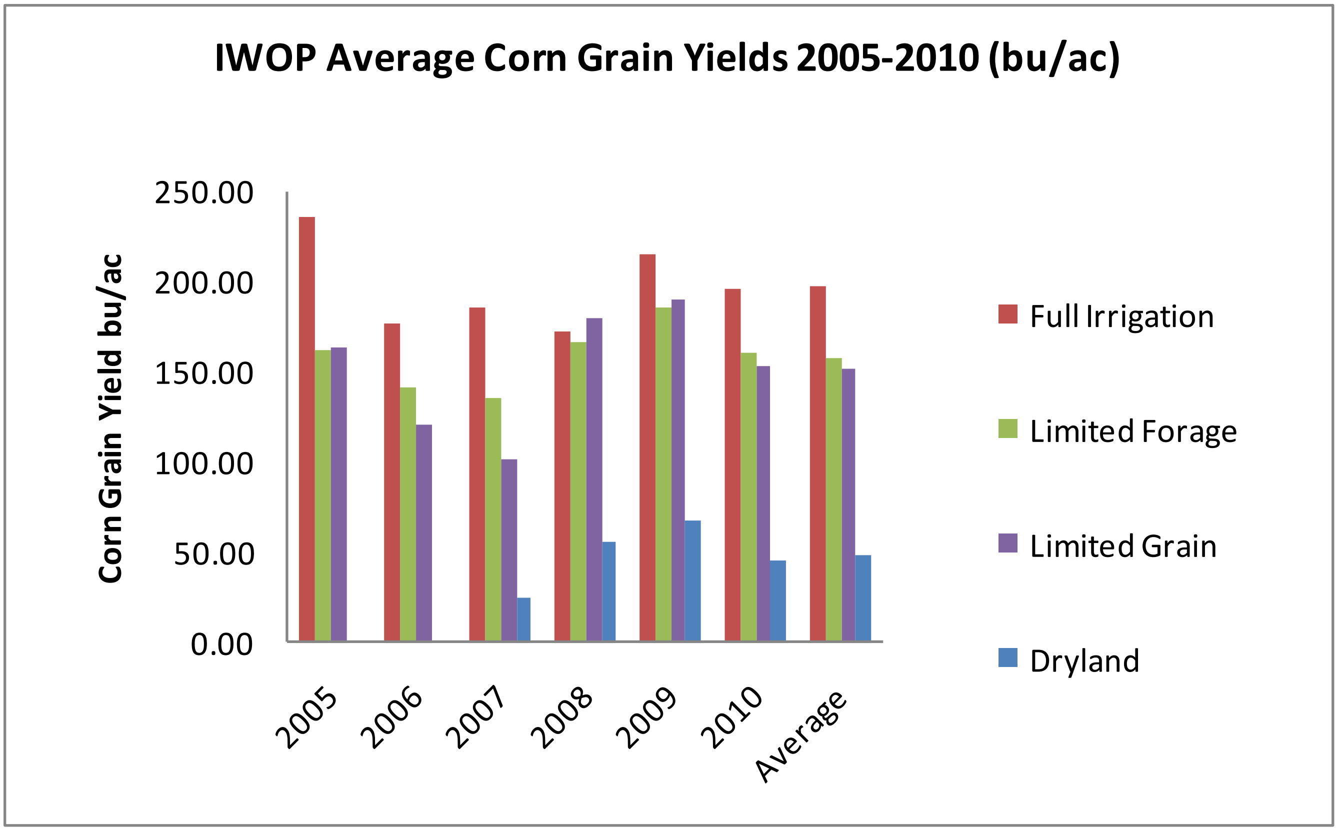


Figure 10. Sprinkler site corn silage yields 2005 - 2010 and sunflower silage yield 2008 in tons per acre for the CSU-ARDEC demonstration site.

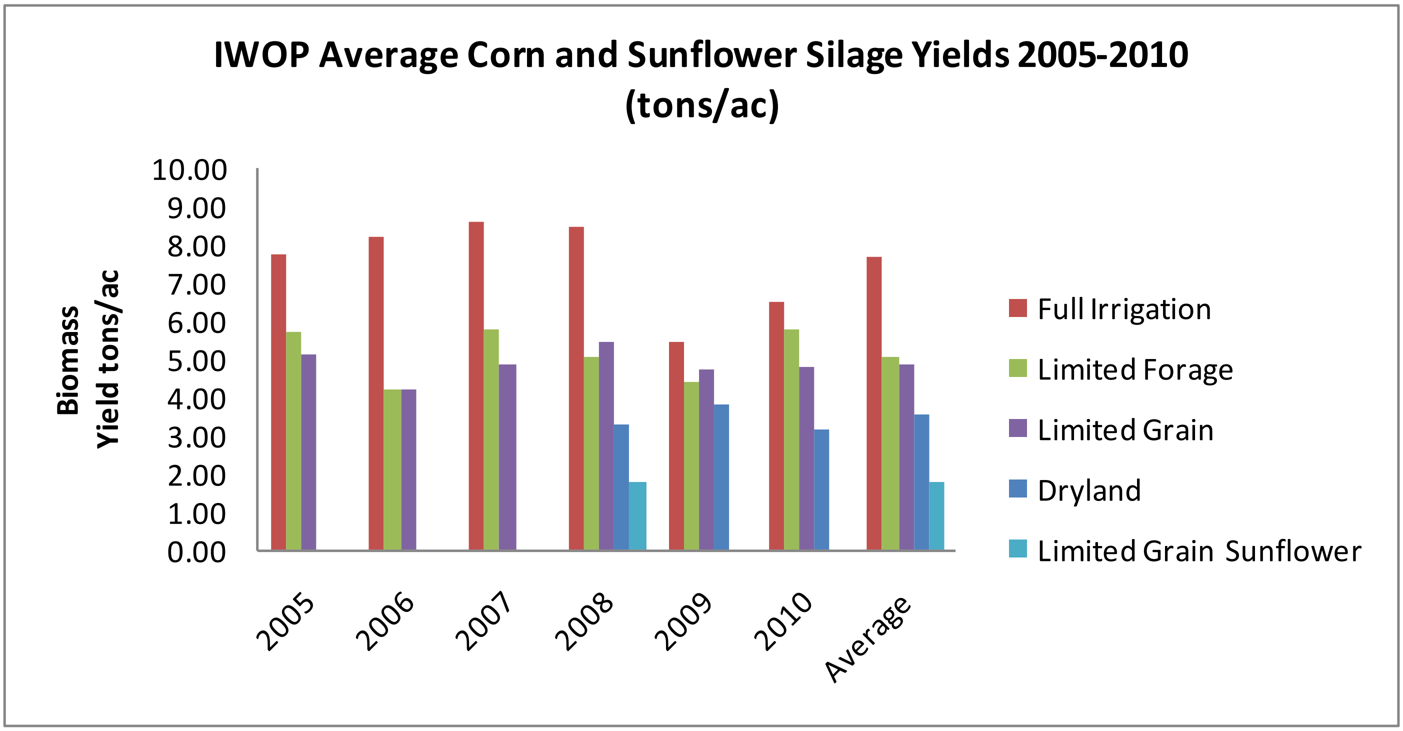
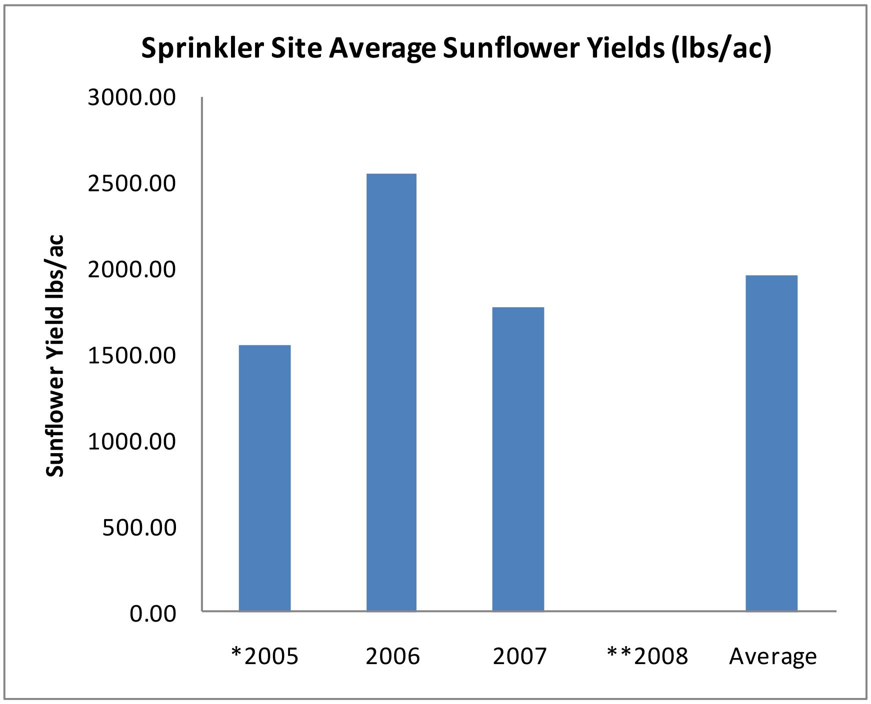


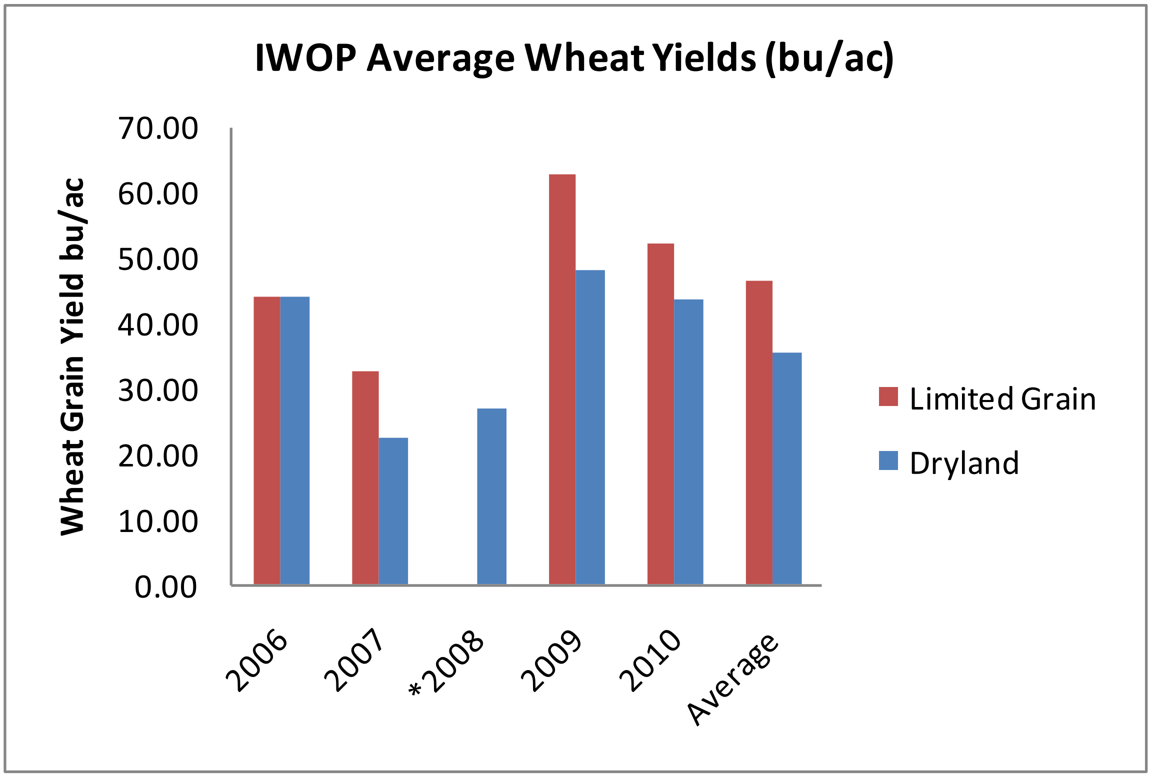
Figure 11. Sprinkler site sunflower yields 2005 - 2008 in lbs. per acre for the CSU-ARDEC demonstration site.



* Sunflowers were oil type in all years except 2005 sunflowers were confection type.

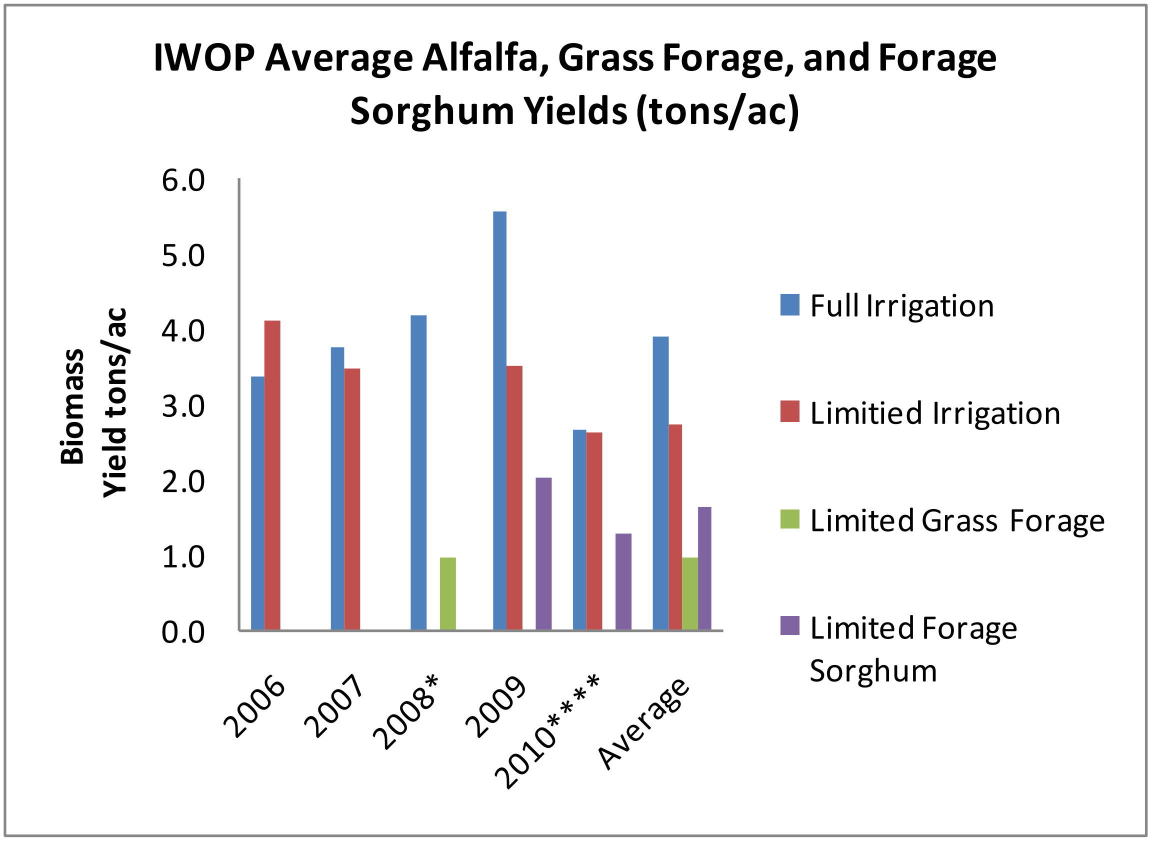
**Due to Hail, Insect, and Bird damage no grain yield was taken from the oil sunflowers. Biomass yield was determined and is reported in Figure 10.

Figure 12. Sprinkler site wheat yields 2005 - 2010 in bushels per acre for the CSU-ARDEC demonstration site.



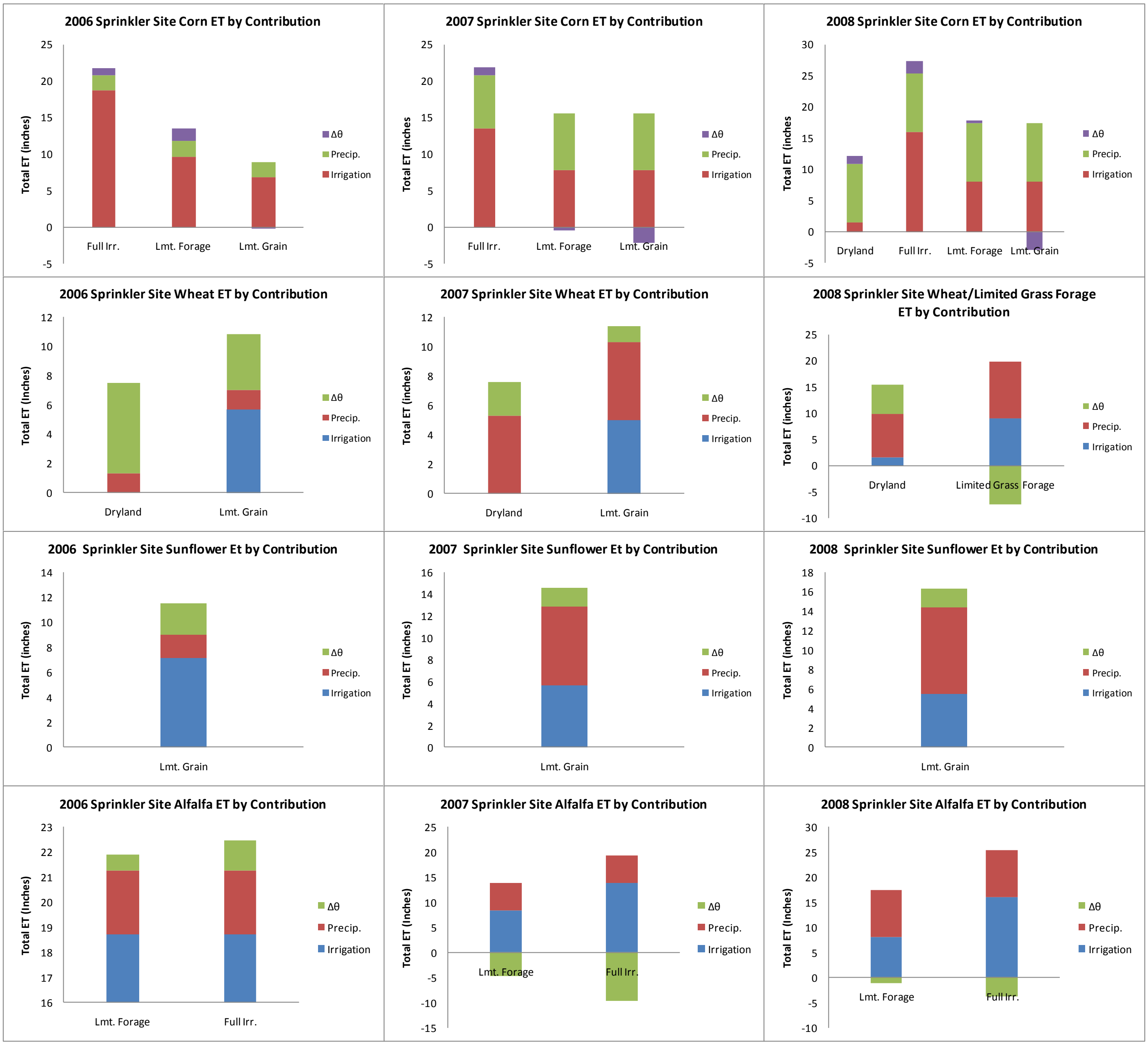
*No grain yields were taken in the Limited Grain due to low germination at planting. In lieu of grain yields, forage yields were assessed and are reported in Figure 13.

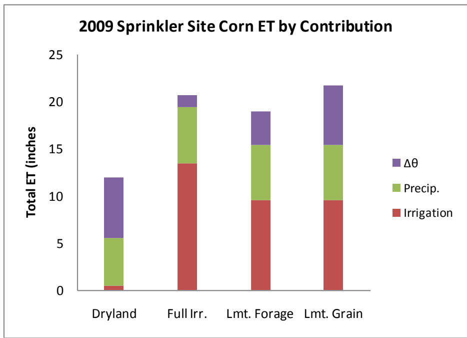
Figure 13. Sprinkler site alfalfa yields 2006 - 2010 and limited grass forage in tons per acre for the CSU-ARDEC demonstration site.

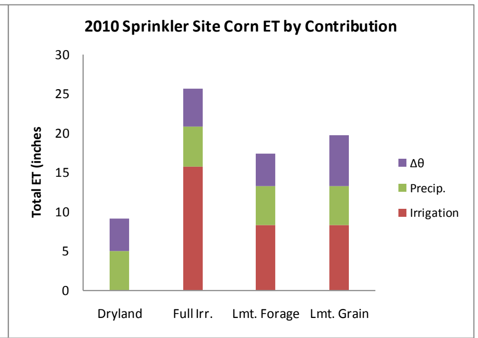


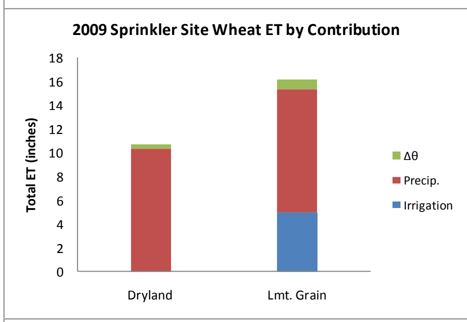
*No grain yields were taken due to low germination at planting. Barley was inner seeded and harvested for forage. Millet was planted and harvested for forage.
****2010 Alfalfa Establishment Year

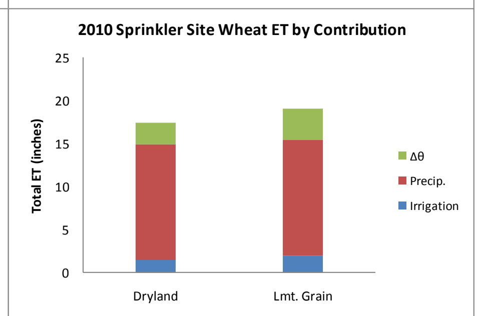
Figure 14. Evapotranspiration of corn, wheat, sunflower, and alfalfa by contribution for 2006 – 2010 grass forage for 2008 and forage sorghum for 2009-10 at the CSU-ARDEC demonstration site.

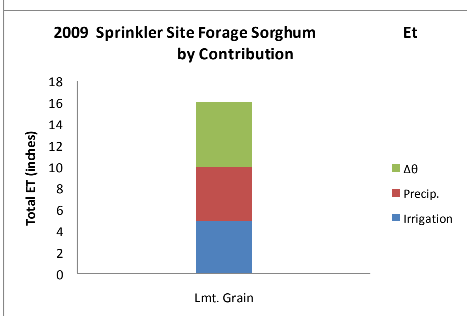


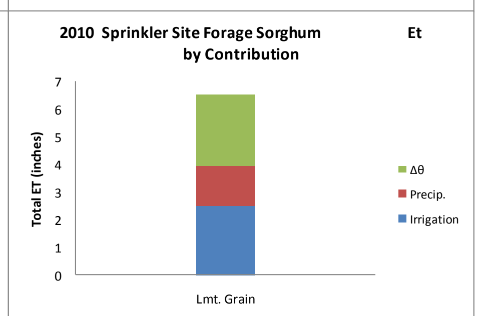

2009 Sprinkler Site Corn ET by Contribution
Total ET (inches
0
5
10
15
20
25
Dryland
Full Irr.
Lmt. Forage
Lmt. Grain
Δθ
Precip.
Irrigation

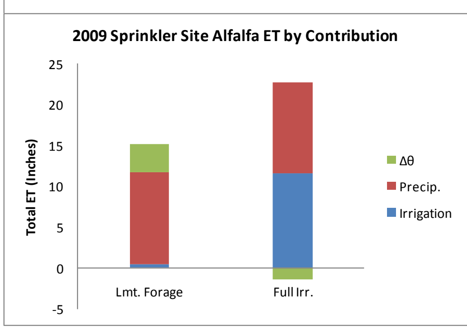

2010 Sprinkler Site Corn ET by Contribution
Total ET (inches
0
5
10
15
20
25
30
Dryland
Full Irr.
Lmt. Forage
Lmt. Grain
Δθ
Precip.
Irrigation


2009 Sprinkler Site Wheat ET by Contribution
Total ET (inches)
0
2
4
6
8
10
12
14
16
18
Dryland
Lmt. Grain
Δθ
Precip.
Irrigation


2010 Sprinkler Site Wheat ET by Contribution
Total ET (inches)
0
5
10
15
20
25
Dryland
Lmt. Grain
Δθ
Precip.
Irrigation


2009 Sprinkler Site Forage Sorghum Et by Contribution
Total ET (inches)
0
2
4
6
8
10
12
14
16
18
Lmt. Grain
Δθ
Precip.
Irrigation


2010 Sprinkler Site Forage Sorghum Et by Contribution
Total ET (inches)
0
1
2
3
4
5
6
7
Lmt. Grain
Δθ
Precip.
Irrigation


2009 Sprinkler Site Alfalfa ET by Contribution
Total ET (inches)
-5
0
5
10
15
20
25
Lmt. Forage
Full Irr.
Δθ
Precip.
Irrigation

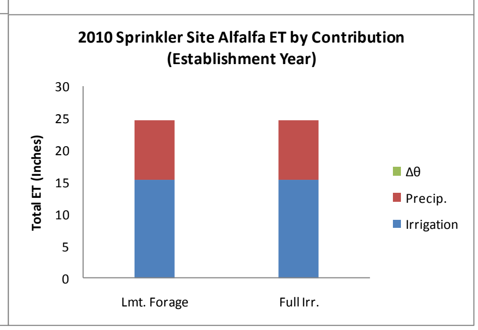
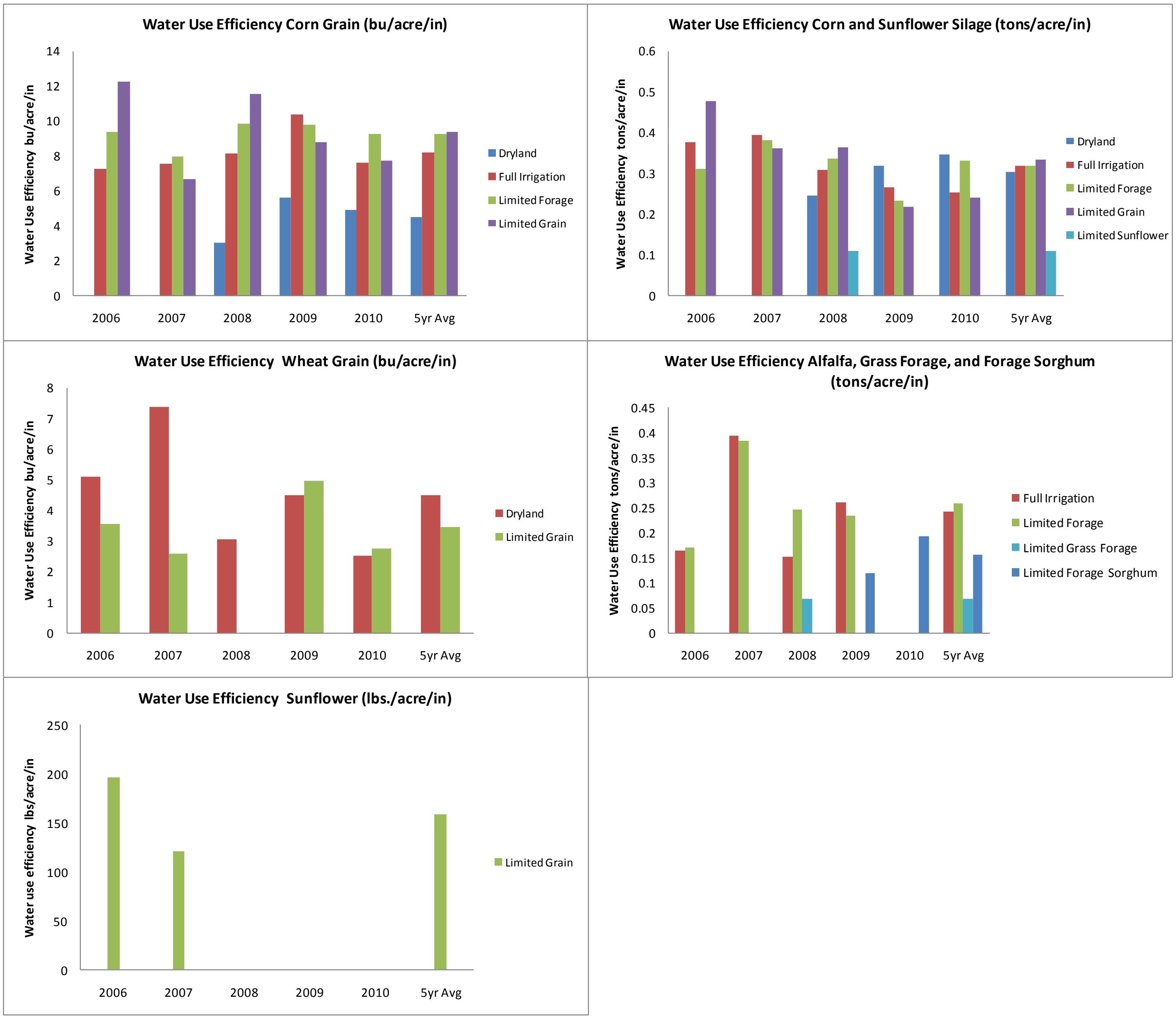

2010 Sprinkler Site Alfalfa ET by Contribution
(Establishment Year)
Total ET (inches)
0
5
10
15
20
25
30
Lmt. Forage
Full Irr.
Δθ
Precip.
Irrigation

Figure 15. Water use efficiency of corn grain, corn and sunflower silage, winter wheat, alfalfa, grass forage, forage sorghum, and sunflowers averaged for 2006 - 2010 at the CSU-ARDEC demonstration site.



SUMMARY OF EDUCATION EVENTS AND OUTREACH ACTIVITIS

Year	Program	Title - Date	Total no. of participants
2006	Workshops	Limited Irrigation Workshop, Nebraska Water Delegation	25
		NRCS Staff Irrigation Training Workshop	35
		Organized Brown Bag Coal Bed Methane Discussion	15
2006	Presentations	Rocky Mountain Agribusinsss Association, Jan 10	125
		Sterling Crop Clinic (2)	45
		Colorado Ag. Classic, Dec 7	40
		National Western Stock Show Display, Jan 9	~400
2006	Field Days	Limited Irrigation (LI) Demo. at Eckhardt Farms, LaSalle	75
		LI at ARDEC, May 1	15
		LI at ARDEC, Aug 10	90
		LI at NCWCS	250
		High Plains Water Tour at Stratton	15
		Rocky Ford Field Day, Sept 7	100
2006	K-12	“You’re All Wet” Water Education Activities All 5th Graders at Moore Core Knowledge School	75
		“Getting Seed Smart” Educational Activity All 5th Graders at Linton Elementary	60
2007	Workshops	*Soil moisture management, Burlington	20
		*Producing Corn in Dry Environments – Western North Dakota (4 sessions)	200
		*Limited irrigation crop clinic, Greeley 12/12-13	40
2007	Presentations	*Cropping w/ Limited Irrigation, 4-state irrigation council	150
		*Larimar county ag. board	25
		*Morgan county commission	
		*S. Platte Forum, Oct 24	15
		*National Western Stock	140
		Show Display, Jan 6	~250
2007	Field Days	*ARDEC Research Field Day, Aug 1	40

Year	Program	Title - Date	Total no. of participants
2007	Site tours	*NCWCD Alfalfa Field Day *Colorado Conservation Board, 06/27 *Logan County Leadership 4-H CSU Tour	20 20 12 40
2008	Workshops	*Farm Business Management Workshop, Sterling, CO, 2/26, 3/11, 3/26	12
		*Irrigation water management training w/ NRCS, 7/14-15	35
		* Irrigation Water Management Focus Group Meeting, Combined CSU & ARS, 3/6	15
		*Dryland Cropping Systems Focus Group Meetings, Eastern Colorado, 12/15-16	25
2008	Presentations	* Addressing water shortage in Colorado agriculture, Colorado Water Congress, 1/24	60
		* Limited Irrigation for water conservation, Colorado Water Cons. Board.	50
		* Limited Irrigation for water conservation, Norther Water Exec. Committee	12
		* Strategies for Reducing Consumptive Use of Alfalfa , Central Plains Irrigation Association, 1/31	55
		*Sunflower Water Use and Conservation, Colorado Sunflower Growers Assoc. 2/7	20
		*Northern Colorado Friendship Force *Cropping Systems for dryland and limited irrigation, Colorado Ag. Classic, 12/11	35 15
2008	Field Days	*Colorado Water Education Foundation, June 19	80
		*Central Colorado WCD Field Day	65
		*Lower South Platte Irrigation Research	120
2008	Site tours	*Colorado Agriculture, Tour Russian visitors for	12

2009	Workshops	Cropping Systems for Limited Irrigation, Colorado Conservation Tillage Association, 1/28	80
		Developing Cropping Systems to Address Changing Water Supply and Demand Issues, Colorado County Agent Assoc. Prof. Dev Workshop	25
		Western Great Plains Sustainable Feedstock Development Partnership – 1st Annual Conference, 9/16-17	35
2009	Presentations	Limited irrigation cropping systems research at CSU ARDEC, CAES Annual Conference, 1/06	35
		Limited Irrigation of Forage Crops, Colorado Hay and Forage Producers, 1/28	50
		A Model to Sustain Irrigated Agriculture While Meeting Increasing Urban Water Demand, Colorado Water Congress, 1/29	80
		Alternatives to Agricultural Land Dry-up, South Platte Forum, 3/10	
		Lower South Platte Irrigation Research and Demonstration Project, Colorado Water Conservation Board, 9/01	40
		Irrigation Water Optimization, 2009 Ag. Water Summit, 12/01	20
			110
2009	Invited Presentations	Forest Vegetation Management and Water Supply, Invited Presentation to USFS Regional 2 Administration, 8/14	10
2009	Field Days	Conservation Tillage for Furrow Irrigated Cropping Systems, CSU ARDEC, 8/14	40
		South Platte Irrigation Research and Demonstration Project, 8/22	60
		Bioenergy Field Tour, 9/17	
			13

TOTAL NUMBER OF PARTICIPANTS IN EDUCATIONAL EVENTS 3,600