Ogallala Aquifer
Funded by USDA ARS Research Initiative
A research consortium between USDA-Agricultural Research Service, Kansas State University, Texas AgriLife Research and Extension, Texas Tech University, and West Texas A&M University

Project Plan from FY2015
(Fiscal Years 2016-2017)

Research Priority Area: Objective 1: Reducing Irrigation Withdrawals

1) Title: Increasing Water Productivity through Advanced Irrigation Scheduling

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Collaborators/Cooperators

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Research Location: Kansas State University sites at Colby and Garden City, Kansas, Texas AgriLife, Halfway, Texas and USDA-ARS-CPRL at Bushland, Texas,

Summary-Abstract:
Irrigation scheduling is by no means a new research topic and there are many good methods that would improve irrigated water management in the Ogallala region. However, irrigator acceptance of science-based irrigation scheduling has been dismal. The PIs propose to tackle this complex problem, by developing more robust and easier-to-use methods that to a great extent will succeed by improving irrigator confidence in the irrigation scheduling decision (i.e., when and how much to irrigate). Several approaches are being proposed, but an added benefit of this multipronged approach will be that the PIs can continue to build and modify their approaches based on results from their fellow PIs. Many of the approaches concentrate on providing better information to the irrigator to make the irrigation scheduling decision while others make efforts to make irrigation scheduling decisions less complicated as perceived by the irrigator. Joint efforts are proposed by KSU, Texas A&M AgriLife Research and the USDA-ARS CPRL who have had a long history of cooperative research.

Project Narrative
Objectives:
1. Develop and perform initial evaluation of a "juried" approach to weather-based irrigation scheduling for corn at Colby and Garden City, Kansas where soil water sensors and plant canopy temperature parameters are used as additional "evidence" as irrigation triggers.
2. Conduct field studies with cotton and analyze 20 years of previous results with grain sorghum at Halfway, Texas to further develop operational criteria for interactive visual (dashboard) approach to irrigation scheduling currently under development at Texas A&M Agri-Life Research.
3. Develop decision support algorithms that integrate plant and soil water sensing as well as weather data to manage irrigation timing or scheduling for cotton and corn at Bushland Texas.

4. Refine crop coefficients for subsurface drip irrigation of cotton and corn by improving determination of evaporative component of ET and thus improve weather-based irrigation scheduling when using SDI.
5. Compare strengths and weaknesses of the various approaches and suggest improvements to irrigation scheduling protocols.

These objectives address OAP Subobjective 1 (Develop and evaluate strategies to reduce irrigation by 20% by 2020) by developing irrigation scheduling approaches that are more likely to be acceptable to irrigators and that can be adopted in the near timeframe. An earlier review by Howell (2001) indicated crop water productivity (i.e. water use efficiency) is generally maximized at approximately 80% of full irrigation. The proposed research will improve the confidence of irrigators with regard to sufficiency of irrigation, saving water step-by-step throughout the season. Specifically, the project will provide scientifically sound and robust approaches to irrigation scheduling.

Rationale/Literature Review/ Conceptual Framework:

Science-based irrigation scheduling has existed for approximately 60 years with one of the earlier discussions of the topic made by van Bavel (1956) of using evapotranspiration to estimate soil water conditions and for timing of irrigation. Although there is a wide body of literature on irrigation scheduling in reference books, journal articles, symposium proceedings, and extension publications, effective methods have not been well adopted by irrigators.

Lack of adoption was recognized many years ago as a key problem to advancing irrigation scheduling. Behavior patterns and attitudes of irrigators were identified as more significant barriers to adoption than reliability and accuracy of scheduling methods (Shearer and Vomacil, 1981). They further concluded it was difficult to get long-term acceptance of irrigation scheduling without continuing technical support from cooperative extension or others. Still, when asked in an extensive 1990 survey, the most strongly preferred water saving management practice indicated by High Plains irrigators was irrigation scheduling with over 53% willing to adopt this practice voluntarily (Kromm and White, 1990). They also found little to no differences in acceptance in north to south counties within the High Plains. This suggests that irrigators are willing to consider improved scheduling methods. Technology to help irrigators handle the “Big Data” required for irrigation management, advances in automated control of irrigation systems, and/or autonomous irrigation scheduling programs may help overcome the implementation barrier.

Although irrigator adoption of science-based irrigation scheduling has been dismal, recent research has shown that more robust user-friendly irrigation scheduling methods that integrate a combination of weather-, soil-, and plant-based measurements may have greater potential for adoption. Pressurized irrigation systems are the norm in the region, being used on greater than 85% of irrigated land and are increasing. These pressurized irrigation systems are well suited to integrated irrigation scheduling methods because they are more amenable to control than older gravity systems, but their potential for improving WUE and reducing leaching is largely untapped due to lack of appropriate irrigation scheduling and control.

Approach and Research Procedures:

General procedures:

The cropping systems to be studied in this joint proposal include corn, cotton, and grain sorghum and will be planted in the spring at an appropriate timing at the various locations (Colby, Kansas; Garden City, Kansas; Bushland, Texas; and Halfway, Texas. Irrigation will be by lateral move sprinkler (LMS) systems or subsurface drip irrigation (SDI) systems. Irrigation will be scheduled only as needed according to weather- soil- based, plant-based, or some combination of these three methodologies to be described in the specific procedures. Soil water will be measured in the complete root zone periodically throughout the season through neutron attenuation for correlation with other irrigation scheduling parameters, to help quantify periods of water stress, and to determine crop water use. Weather data will be measured using automated weather stations that exist on all of the sites and phenological and growth stage data will be recorded throughout the growing season. Crop yield will be determined by harvesting a representative sample at physiological maturity.

No comprehensive economic analysis is planned for his study as the primary focuses are exploration of new combined irrigation scheduling methods and more rigorous, physically-based approaches of existing methods for additional robustness by adding auxiliary information to improve irrigator confidence in irrigation scheduling. Given the progress, the PIs anticipate refining irrigation scheduling methods in the next two years; and it is likely subsequent work would evaluate more complete irrigation scheduling procedures and at that time would more strongly benefit from economic analysis.

Specific Procedures:

COLBY AND GARDEN CITY, KANSAS:

Field experiments will be conducted with field corn (maize) at Colby, Kansas on a Keith silt loam and at Garden City, Kansas on a Ulysses silt loam. Primarily, weather-based ET irrigation scheduling will be used with the development of additional "triggers" for soil water sensors and plant water stress measurements to serve as additional data to improve robustness.

At Colby, Kansas, the study will be conducted on an existing SDI system with dripline spacing of 1.5 m centered between adjacent pairs of 0.75 m crop rows and with an emitter spacing of 0.3 m along the row. Each of the 8 treatments will be replicated 4 times in a complete randomized block design (CRB). Plot size will be approximately 60 m long and 6 m wide. The frequency of irrigation events could be as often as daily as determined by the irrigation scheduling treatment triggers. Irrigation scheduling treatments will start with 2 weather-based ET treatments designed to replenish the accumulated calculated corn water use minus effective precipitation, but will be limited to either 7.5 or 4.5 mm/d irrigation capacities. The different irrigation capacities are being used to evaluate relative performance of the irrigation scheduling treatments and to allow cross correlations of the irrigation triggers at differing water levels. It should also be noted that the limited 4.5 mm/d irrigation scheduling capacity will likely experience numerous irrigation "pulled triggers" for irrigation events that will not be conducted due to the lack of irrigation capacity. Thus, the effect of lower-capacity systems with these advanced irrigation-scheduling techniques will be thoroughly evaluated. Two additional treatments with the same limitations in irrigation capacities will add the usage of Watermark soil matric potential sensors (SMP) sensors installed at 0.3, 0.6 and 0.9 m depth under the corn row. When the average SMP within the rooting depth is drier than 70 kPa and/or the ET-based schedule would trigger irrigation, an irrigation event will be performed. Continuous daily measurements of SMP from the Watermark sensors will be correlated with ET-based irrigation triggers at the end of each season, along with analysis of the overall treatment corn grain yield, and water use efficiency to help determine if the SMP trigger value should be changed for subsequent years of the study. This inter-year adjustment procedure will be only be conducted with the results from the greater irrigation capacity (7.5 mm/d). As an example, if an SMP-added treatment resulted in appreciably more irrigation event triggers, but no appreciable change in corn yield and thus less water use efficiency, then the SMP trigger would be adjusted to a drier value (greater than original 70 kPa). If conversely, an SMP-added treatment resulted in appreciably greater yield, then there might be rationale to examine an even wetter SMP in future years. This latter scenario also may suggest refinements to the ET-based schedule are warranted or weather data quality should be checked. Ideally, over time the goal would be for SMP trigger to match the ET-based trigger. Additionally, Acclima model TDR-315 volumetric water content (VWC) sensors will be installed at the 0.3 and 0.6 m depth for one of these soil water treatments to evaluate their potential as an alternative soil water sensor. In additional 2 treatments would instead use the integrated crop water stress index (iCWSI) daily threshold value of 100 for corn as the added trigger to the ET-Based irrigation scheduling treatments. Inter-year evaluations and adjustments of the trigger iCWSI values similar to those described for the SMP triggers would be conducted. A final 2 treatments would add both the SMP and iCWSI triggers to the ET-based irrigation schedules for the 2 different irrigation capacities. For these latter treatments, any combination of 2 or more of the triggers "being pulled" will call for an event. Although, there are many permutations of how the event triggers could be set or combined, it is believed these treatments represent a good cross section of potential strategies (or alternatively termed, streams of evidence) to examine for irrigation scheduling.

At the Garden City, Kansas, location, an existing four-span (44 m span width) lateral move sprinkler irrigation system modified to apply irrigation water in any desired treatment combination will be used. The experimental design will be CRB with 6 treatments and 4 replications. Plot sizes will be 14 x 28 m making a total area of approximately 2.7 acres including borders. Due to space limitations, the latter 2 treatments involving all three triggering mechanisms will not be examined at Garden City. However, an ex post facto analysis can be performed of the other 6 treatments to evaluate the potential frequency and overall number of events matching the three-trigger criterion. Event frequency will be twice every 5 days based on the frequency and number of irrigation scheduling triggers. Each irrigation event will be set at 25 mm/event since small application amounts result in appreciable evaporation losses. The model Acclima TDR-315 soil water sensors will be compared to the CS655 soil water sensors that are currently being evaluated in the Garden City experiments.

HALFWAY, TEXAS

In the southernmost region of the Ogallala, irrigation capacities are already greatly limited, so a predefined irrigation schedule is not only a practical but also a logical approach to gain irrigator acceptance of irrigation scheduling. However, the innovation proposed here is to adjust that predefined schedule with new information as the season progresses (i.e., new information is provided to the irrigator's dashboard which is currently under development).

The primary research question relates to efficiency of soil profile irrigation water storage with SDI early in the year when irrigation capacity is greater than ETc. Two field studies with cotton are proposed to augment earlier irrigation management data for cotton. In the first field study conducted under SDI (0.75 m dripline spacing), four approaches to deficit irrigation replicated three times in a RCB design will be evaluated: 1) minimal irrigation for plant establishment, no irrigation during vegetative period, 3.8 mm/d during reproductive and maturation periods; 2) irrigation at 3.8 mm/d during preplant for up to 30 days, no irrigation during vegetative period, 3.8 mm/d during reproductive and maturation periods; 3) minimal irrigation for plant establishment, 3.8 mm/d during vegetative, reproductive, and maturation periods; and 4) minimal irrigation for plant establishment with no further irrigation after plant establishment. The first study will be coordinated with a second study currently supported by OAP. In the second SDI (1.5 m dripline spacing) field study, seven irrigation treatments replicated four times in a CRB design will be evaluated. The treatments include: 1) Preseason irrigation of 100 mm, 2.5 mm/d during vegetative period and 5 mm/d during reproductive and maturation period; 2) Preseason irrigation of 50 mm, no irrigation during vegetative period and 5 mm/d during reproductive and maturation period; 3) Preseason irrigation of 100 mm, no irrigation during vegetative period and 5 mm/d during reproductive and maturation period; 4) Preseason irrigation of 100 mm, 5 mm/d during vegetative through maturation period; 5) Preseason irrigation of 50 mm, 2.5 mm/d irrigation during vegetative period and 5 mm/d during reproductive and maturation period; 6) Preseason irrigation of 50 mm, 5 mm/d during vegetative through maturation period; and 7) Preseason irrigation of 50 mm with no further irrigation the rest of season. These data are useful in establishing effective criteria for allocating limited water resources throughout the cotton growth cycle.

A third effort will concentrate on developing the framework criteria for an irrigation dashboard approach for grain sorghum by analyzing irrigated grain sorghum research that was conducted over a 20-year period at Halfway, Texas. This effort will require determining what would be a realistic predefined schedule for adequate grain sorghum production given the water constraints of present day in this region.

BUSHLAND, TEXAS

Experiments at Bushland will involve research in the large weighing lysimeter fields contrasting SDI and MESA irrigation systems; under a lateral move sprinkler outfitted with MESA, LEPA, LESA and SDI, the latter under plugged drop hoses; and under a center pivot system equipped with LESA and running a beta version of the Bushland Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) system. Crops will be cotton and corn, corn only under the center pivot.

Soil water content will be determined periodically (weekly or monthly as needed) to depths of 2.4 m in 0.2-m increments using field calibrated neutron probes (Evett, 2008) to provide data for irrigation scheduling and for solution of the soil water balance to determine crop ET (ETc). Soil water content will also be determined automatically on an hourly basis using a wireless soil water sensor system based on Acclima TDR-315 sensors and Campbell Scientific CR206X wireless dataloggers. The TDR-315 sensors will provide time domain reflectometry (TDR) waveforms, apparent permittivity values, soil temperature and bulk electrical conductivity and soil water content. Data obtained wirelessly will be integrated into irrigation scheduling systems.

Crops will be managed for high yield according to best management practices for the northern Texas Panhandle. Irrigation management will aim for a range of water stress conditions ranging from mild to severe depending on the experiment.

Weighing Lysimeter Experiments

Experiments on the large weighing lysimeter fields will involve two fields and lysimeters irrigated using mid elevation spray application (MESA) and two fields and lysimeters irrigated using subsurface drip irrigation (SDI) as described by Evett et al. (2015). Weekly neutron probe water content determinations will be made in eight access tubes arranged in the field around each lysimeter and two access tubes within each lysimeter. Hourly soil water content determinations will be made using a wireless sensor network installed in the field around one (the northeast, NE) lysimeter using 48 Campbell Scientific model CS-655 sensors and 48 Acclima model TDR-315 sensors. A whole-field soil water content will be reported hourly by the COSMOS sensor located at the NE lysimeter. In this sub-experiment, these four soil water sensing systems will be contrasted with each other and with the weighing lysimeter determination of soil water storage changes in order to determine their relative accuracy and usefulness for irrigation scheduling. Within-canopy and above-canopy humidity data from another OAP research project, led by Dr. Xiaomao Lin, will be used in the analysis of the COSMOS sensor neutron count and calibration of the sensor to account for the interference of humidity on COSMOS soil water estimates.

The lysimeters and fields will be cropped and operated, other sensors will be deployed and ETc will be determined using methods described thoroughly in Evett et al. (2012a,b), including microclimatological sensing systems at each lysimeter and at the adjacent grass weather station. Plant characteristics will be measured biweekly throughout the cropping season and at harvest. Soil and plant temperatures within the lysimeters will be measured using wireless infrared thermometers and thermal imagers. Soil water evaporation will be measured using microlysimeters in the lysimeter fields for multiple periods of several days at different growth stages during the growing season using methods reported by Agam et al. (2012). Reference evapotranspiration for both short (grass) and tall (alfalfa) crops will be computed using the microclimatological data, and dual crop coefficients will be determined using methods of Tolk and Howell (2001) as described in Chapter 7 of the FAO 56 manual, including the soil water stress approach of Chapter 8 (Allen et al., 1998). Weighing lysimeter data will specifically be used to determine evaporation from bare soil during pre-plant and post-plant periods until crop emergence and achievement of non-negligible leaf area. Crop water productivity (water use efficiency) will be determined based on yield and ETc. Contrasts between SDI and MESA irrigation application methods will involve yield, water use and water use efficiency. Evapotranspiration data from the NE weighing lysimeter and surrounding neutron probe measurements will be compared with ET derived from eddy covariance systems in the cooperative OAP project with Dr. Lin.

<u>ISSCADA System Trials</u>
Experiments will be conducted under a six-span variable rate irrigation (VRI) center pivot system in order to demonstrate the effectiveness of wireless sensor networks of infrared thermometers (IRTs)(Dynamax, Inc.) mounted on the moving lateral and soil water sensors (Campbell Scientific CS-655 and Acclima TDR-315) installed in the field, similar to the work of O'Shaughnessy et al. (2013). The field will be divided into six pie-shaped sectors (28°) with plots widths of 18 m. Irrigation methods and treatment levels will be randomized radially and concentrically in a RCB design with six replications. Treatments will include two irrigation-scheduling methods (manual and automatic) and four irrigation treatment levels of 100%, 75%, 50% and 25% replenishment of soil water depletion to field capacity as determined by weekly neutron probe readings or decision support algorithms. Two IRTs will be located at the border of each concentric plot, pointed forward of the drop hoses and downwards over the crop at an oblique angle. Two soil water sensing nodes (CS-655 and TDR-315) each composed of three soil water sensors will be installed at 3 depths of 0.15, 0.30 and 0.45 cm in three of the 100% automatic-control plots. Decision support for automatic irrigation scheduling will be established from plant (O'Shaughnessy et al., 2013) and soil water sensor feedback in the 100% automatic-control plots. The decision support algorithm will include an iCWSI threshold of 100 and soil water sensing will be used as a closed loop feedback for triggering (SWC < 50% MAD) or withholding an irrigation (SWC > 50% MAD). Plant sampling (height and width measurements) will be performed every two weeks. Samples will be hand-harvested from 10 m^2 subplots near the neutron access tubes and crop response of grain and biomass yields, ETc, and WUE will be reported for each method and treatment level. Similarities and differences between the two types of soil water sensors will also be discussed. Sensor and crop response data will be analyzed after the first year to refine the decision support algorithm for the second year.

<u>Irrigation Application Method Comparisons</u>
Crop yield, ET, crop coefficients, and crop water productivity will be compared for different irrigation application methods and different irrigation application rates in small plot studies described in Colaizzi et al. (2010). Crops will include alternating years of new varieties of corn and cotton, anticipated or shown to be drought- and cold-tolerant, respectively (e.g., Hao et al., 2015). ET and crop coefficients (including the soil water stress coefficient; Allen et al., 1998) will be determined by a soil water balance, where changes in the soil water profile to 2.4 m will be measured by a field-calibrated neutron probe. Irrigation application methods will include MESA, LESA, LEPA, and SDI. Irrigation application rates will include 0, 25, 50, 75, and 100% of full crop ET measured by neutron probe. The neutron probe will also provide the basis of irrigation scheduling. Irrigations will be triggered when soil water in the 100% plots reach an average soil water deficit of 25 mm. Irrigation will be applied to all plots at the same time beginning in morning hours, where the 100% plots are irrigated in 25 mm increments and other plots in

proportionately less increments. These irrigation amounts typically require 2 h to irrigate the MESA, LESA, and LEPA plots, and 12 h to irrigate the SDI plots. The MESA, LESA, and LEPA plots are irrigated by lateral move. Irrigation by lateral move occurs only during mid-morning hours when atmospheric demand is intermediate during the 24 h period; this compensates for differences in application efficiency during day and nighttime hours, which occurs for commercial center pivots operated continuously (i.e., 24 h).

Schedule and Timelines:

October 1, 2015 through April 30, 2016:

Prepare field sites and acquire materials and supplies.

May-June 2016:

Establish field plots, plant crops, install neutron access tubes, and other sensors.
Read initial soil water.

June 2016 through September 2016:

Irrigate plots according to procedures.
Periodically measure crop phenology, soil water and plant-based scheduling parameters.
Collect and evaluate weather data for reliability.

September-October 2016

Harvest crop samples at physiological maturity for yield determination.
Measure soil water at physiological maturity to aid in determination of seasonal water use.

October 2016 through April 30, 2017

Analyze and summarize first year's field results.
Develop plan to handle any needed scheduling trigger adjustments and anomalies.
Prepare field sites.

May 2017:

Establish field plots, plant crops, install neutron access tubes, and other sensors.
Read initial soil water.

June 2017 through September 2017:

Irrigate plots according to procedures.
Periodically measure crop phenology, soil water and plant-based scheduling parameters.
Collect and evaluate weather data for reliability.

September-October 2017

Harvest crop samples at physiological maturity for yield determination.
Measure soil water at physiological maturity to aid in determination of seasonal water use.

October 2017 through March 1, 2018

Analyze second year's results and compare to first year's results.
Analyze combine results and prepare reports.
Make presentations at regional or national meetings.
Complete project with journal publications and with presentations

Expected Outcomes:

Improved irrigation scheduling that is both more robust and easier to implement at the farm level will be adopted by irrigators wishing to optimize irrigated land area.

Improved scheduling will allow irrigators to approach the optimum yield at 80% of full irrigation that is the norm from research studies (Howell, 2001).

Dual crop coefficients for SDI irrigation scheduling of corn and cotton will be developed, leading to more accurate and water efficient irrigation scheduling.

New soil water sensors will be field tested and verified for use in irrigation scheduling.

A wireless soil water sensor network using the new sensors will be integrated into the patented ARS ISSCADA system, which is being transferred for commercialization to producers through a CRADA.

Crop water productivity as a function of deficit irrigation and irrigation application method will be better understood, leading to recommendations to producers for choice of irrigation application systems and scheduling methods that produce more crop per unit of water applied.

Results will be disseminated through regional Texas A&M AgriLife Extension programs to assist local producers with agronomic decisions directly affecting production economics and resource management. Similarly, the results in Kansas will be disseminated through local and regional meetings. Kansas helps to plan and coordinate the three state Central Plains Irrigation Conference held annually in mid to late February and the results of this study would be appropriate for this forum as well. Some ARS technology advances will be disseminated to producers through Cooperative Research and Development Agreements (CRADAs) with private firms.

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