Report for 2003KS31B: Reduced Irrigation Allocations in Kansas from Grain Yield -- ET Relationships and Decision Support Model

Publications

- Conference Proceedings:
  - Klocke, N.L., C. Hunter, Jr., M. Alam, 2003. Application of a linear move sprinkler system for limited irrigation research. 2003. ASAE Paper No. 032012. July, 2003, Las Vegas, NV, 13 pp.
  - Klocke, N. L., Schneekloth, J. P., Melvin, S. R., Clark, R. T., and Payero, J. O. 2004. Field scale comparison of limited irrigation strategies. American Society of Agricultural Engineers Paper No. 042280. Aug. 2004.13 pp.
  - Melvin, S. R., Payero, J. O., Klocke, N. L. ,and Schneekloth, J. P., 2004. Irrigation management strategies for corn to conserve water. In: Proceedings Central Plains Irrigation Short Course & Exposition Proceedings. Feb. 17-18, 2004. Kearney, NE. pp 37-44.
  - Klocke, N.L., G. A. Clark, S. Briggeman, L.R. Stone, and T.J. Dumler. 2004. Crop water allocator for limited irrigation. In Proc. High Plains Groundwater Conference. Lubbock, TX. Dec. 7-9, 2004. 196-206.
  - Klocke, N.L., G.A. Clark, S. Briggeman, T.J. Dumler, and L.R. Stone. 2004. Crop water allocation program. Abstracts of: 21st Annual Water and the Future of Kansas Conference. March 11, 2004. Lawrence, KS. p.19.
  - Klocke, N.L., L.R. Stone, G.A. Clark, T.J. Dumler, S. Briggeman. 2005. Crop water allocator for limited ground water. ASAE Paper No. 052187. July 17-20, 2005. Tampa, FL. 11 pp.
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Briggeman. 2005. Optimizing water allocations and crop selections for limited irrigation. 26th Annual Irrigation Association Tech. Conf. Nov. 6-8, 2005. Phoenix, AZ. 4 pp.
    - Klocke, N.L., L.R. Stone, T.J. Dumler. 2006. Optimizing water use for irrigation under limited supplies. Abstracts of: 23rd Annual Water and the Future of Kansas Conference. March 16, 2006. Topeka, KS.
- Other Publications:
    - Klocke, N.L., R.S. Currie, and M. Brouk. 2005 Cropping systems for limited irrigation management. In Report of Progress 945. Kansas State University, AES and CES, Aug. 25, 2005, Garden City, KS.
    - Stone, L.R., A.J. Schlegel, A.H. Khan, N.L. Klocke, R.M. Aiken. 2006. Crop Yields Associated with Water Supply in the Central High Plains. In Press.
- Articles in Refereed Scientific Journals:
    - Klocke, N.L., L. R. Stone, G. A. Clark, T. J. Dumler, S. Briggeman. 2006. Water allocation model for limited irrigation. J. of App. Eng. In Agric.22:3:381-389.

Report Follows

"Reduced Irrigation Allocations in Kansas from Grain Yield--ET Relationships and Decision Support Model"

Final Report

Start Date: March 1, 2003
End Date: February 28, 2006

Principal Investigators

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Dr. Loyd R. Stone, Soil Physicist, Dept. of Agronomy
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Key Words:
Limited irrigation; Deficit Irrigation; Decision support; cropping system; Evapotranspiration; Irrigation allocation

Problem and Research Objectives

Many irrigators in Kansas are facing immediate challenges with declining water yields from their wells. Estimates show that as many as 50% of irrigation wells in western Kansas are pumping below original capacity. Irrigators in Kansas also face the possibility of shrinking water allocations with changes in water policy or simply enforcement of current water policy. Any of these scenarios will mean more limited irrigation than has been used in the past.

To make reductions in water and energy use, irrigators are considering shifts in cropping patterns. Irrigators who have shrinking water supplies need to make decisions on the most profitable cropping systems. Furthermore, they need to allocate both land and water resources to multiple crops. Irrigation scheduling decisions for irrigation managers with limited water resources are not made on a daily basis as is the case for managers of fully irrigated systems. Limited capacity irrigation managers need to schedule their applications with a fixed amount of cropping season water, due to limited well capacity or water allocation, and plan a cropping system strategy. The objective was to develop and implement an irrigation decision model that will allow irrigators to optimize water and land resources for the best mix of crops and associated water allocations.

Past irrigation management research has demonstrated that annual grain crops respond best to water applications during flowering and seed fill growth periods. No-till management systems, which leave crop residues on the surface, have been beneficial in increasing off-season capture and retention of precipitation, reducing soil water evaporation, and reducing runoff in sprinkler irrigation. This project is designed to combine the best irrigation and crop residue management techniques into one management system. The products of this project are grain yield-water use and grain yield-irrigation relationships.

The answers to these questions are not straightforward and have many economic and policy-based implications. In order to help agricultural irrigators with these questions and to improve on their beneficial use of limited water resources, the objectives are:

1. Develop a computerized tool for irrigators to assist in their decisions regarding the best use of limited water supplies or reduced water allocations.
2. Measure irrigation and grain yield relationships for corn, wheat, soybean, grain sorghum, and sunflower crops using current varieties and no-till management to support the continued implementation of the decision tool.

Methodology

Objective 1:

A crop water allocator (CWA) has been developed to assist in planning cropping patterns and targeting irrigation to those crops. It is an economic model that will predict the net returns of possible cropping options. Net returns are to land, management, and irrigation equipment since only operating costs are subtracted from gross income. The model uses crop yield and irrigation relationships that were generated from the Kansas Water Budget, a water balance simulation model for western Kansas. The Kansas Water Budget used yield-evapotranspiration relationships for each crop. Through simulations with rainfall patterns across western Kansas and irrigation management assumptions, yield-irrigation irrigation relationships were formulated. Example output yield-irrigation relationships for corn are in figure 1. Each broken line represents annual rainfall for an area across the region. Diminishing-return relationships of yield with irrigation applied were typical for all crops used in CWA (corn, grain sorghum, wheat, soybean, sunflower, and alfalfa). Crop production and irrigation costs can be completely controlled by the user with inputs to CWA, or the user can rely on default values from Kansas State surveys of typical farming operations in western Kansas.

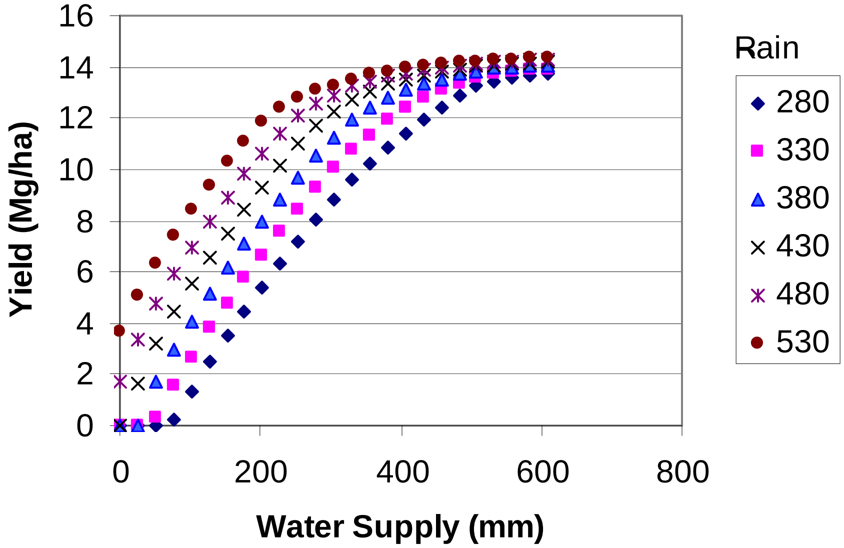

Fig.1. Corn yield in response to irrigation for annual precipitation zones in western Kansas.

The user first selects possible proportions of land considered for potential rotation of crops and/or fallow. The percentages of land splits could be: 50-50, 75-25, 33-33-33, 50-25-25, and 25-25-25-25. The user can select more crops than selected number of land splits for consideration by the program. The program will consider all possible combinations of crops and water allocations. The crop species, maximum crop yields, irrigation water costs, crop production costs, and water allocation for the season (gross irrigation) are then entered. The program then iterates, by 10% increments of the water allocation, all possible net income solutions. By changing one input value at a time, subsequent runs of the model can give the user indications of the sensitivities of net returns to commodity prices, production cost inputs, crop selections, and land allocations.

Objective 2:

The experimental field was subdivided into six (1.2 ha each) cropped strips that were irrigated by a 4-span linear move sprinkler irrigation system. The cropping sequence was corn-corn-soybean-winter wheat-grain sorghum-sunflower. The soil was a silt loam with pH 8.3 and slope of less than 1%. The six irrigation treatments, replicated four times, ranged in water application from a season total of 76 mm to full atmospheric demand. Irrigation frequency was limited to no more than 50 mm per week. If rainfall was sufficient to fill the soil profile to field capacity, irrigation was not applied. The extra irrigation allocation was rolled over to the next growth stage. If there was extra allocation at the end of the year, it was not carried over to the next year. The study area was not pre-irrigated and the same irrigation treatment followed on another from year to year. Dry plots followed dry plots and wet plots followed wet plots.

Soil water was measured once every two weeks with the neutron attenuation method in increments of 0.3 m to a depth of 2.4 m. There was one sampling site per plot. These measurements were used to calculate evapotranspiration for each two-week period from a water balance of soil water, net irrigation, and rainfall.

Work Accomplished

Objective 1:

Crop Water Allocator (CWA) was released on the World Wide Web during December 2004 at www.oznet.ksu.edu/mil. It is available to users to download to their individual computers. Individual farmers as users of the program can guide outcomes by their own preferences and strengths. The program is sensitive to commodity prices and maximum yields which can influence results based on user inputs. Water policy agencies are reviewing CWA for application in risk management programs. The crop insurance industry is considering more options for limited irrigation cropping sequences under insured programs. Colorado is considering feasibility of rotation of fallowed water rights in cropping sequences.

Output from CWA gives irrigators who are planning strategies for their limited water, and those working in water professions the opportunity to examine trends. For example, multiple runs of the model allow the user to examine combined effects of water allocation, commodity prices, maximum yields, irrigation costs, and production costs. Figure 2 shows the results of series of CWA outputs of net returns over a range of water allocations. The first line generated for figure 2 was the “reference” scenario. The inputs for the reference scenario were typical for no-till management in western Kansas during 2006. The water costs were based on $0.70/ha-mm and the commodity prices and maximum expected crop yields with no water restrictions are in table 1. The annual rainfall was 430 mm and the land split was 33-33-33. The CWA could choose among row crops (corn, soybean, sunflower, grain sorghum, and wheat) for crop rotations. Alfalfa was excluded from consideration.

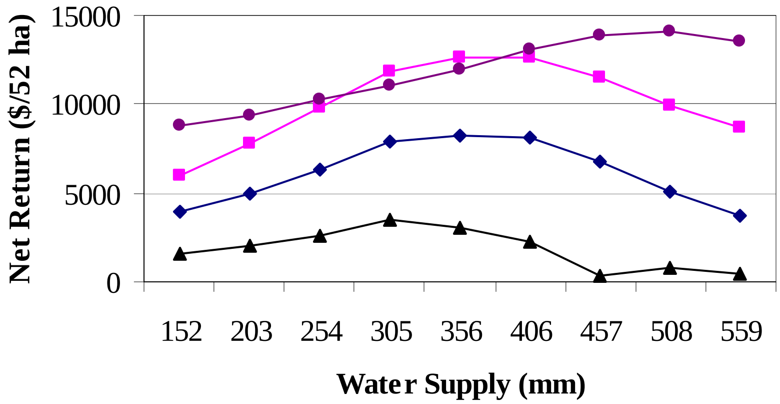

Figure 2. Trends in net return to land, management, and irrigation equipment predicted by CWA for 2006 reference (row crop) scenario, a "high" soybean price ($0.22 vs. $0.18/kg for reference) a "high" pumping cost ($0.16 vs. $0.11/ha-mm for reference), and alfalfa scenario.

Table 1. Input values for CWA reference example

Crop	Commodity Price	Maximum Yield
Corn	$0.094/kg	12.5 Mg/ha
Sorghum	$0.084/kg	7.5 Mg/ha
Soybean	$0.18/kg	4.1 Mg/ha
Wheat	$0.13/kg	4.7 Mg/ha
Sunflower	$0.24/kg	3.0 Mg/ha
Alfalfa	$0.083/kg	15.7 t/ha

First, the reference inputs were used to execute the CWA at each water supply amount to construct the points for the reference line in figure 2. When the water supply was from 300 to 500 mm, CWA selected continuous corn, but CWA selected corn-wheat rotation when the water supply was from 150 to 250 mm. Second, the soybean price was increased from $0.18 to $0.22/kg. All other reference inputs remained constant. The result was the "high" soybean line in figure 2. CWA did not select soybeans for the reference scenario, but exclusively selected soybeans for water supplies 200-560 mm. Third, the soybean price returned to $0.18/kg and the irrigation cost was increased from $0.11 to $0.16/ha-mm. This is a typical range of pumping costs reported for natural gas and diesel during 2005. CWA selected corn and wheat rotations for 150 to 250 mm water supplies, continuous corn for 300 to 400 mm, and corn-fallow rotations for 460 to 560 mm water supplies. The increased energy costs penalized high water use to the point of reducing irrigated acres. If pumping costs were to increase to $0.19/ha-mm, CWA would predict no net return from this scenario. Fourth, the pumping cost was returned to $0.70/ha-mm and alfalfa was considered for selection along with the row crops and fallow. In this selection, alfalfa was chosen exclusively over the row crops and fallow, even at the lowest water supply. When water was very limited, water was applied at full irrigation to part of the field and a nearly dryland on the rest of the field.

The CWA model allows irrigators, county agents, consultants, or water planners to evaluate combinations of land allocations, cropping systems, and water allocations for optimum economic return. The CWA model is user friendly and can be executed with a few basic inputs. However, more experienced users can modify default input and production costs to match field specific scenarios. As water resources become more limited, programs such as the CWA model can be used to help plan for future farming operations or to assess potential impacts of changes in water policy.

Objective 2:
Grain yield response to irrigation for 2004 and 2005 is shown in figures 3 and 4. Grain sorghum and sunflower yields were the similar for all irrigation treatments. The lowest application (76 mm) was sufficient for optimum yields both years. Grain yields were less in 2005 than 2004 because of hail damage (July 4, 2005). Wheat yields responded slightly to irrigation in 2005, but not at all in 2004. Favorable spring rain in 2004 assisted the drier wheat plots. Corn yields respond to additional irrigation both years. Favorable growing conditions and rainfall in 2004 (430 mm from May 1-September 30, 2004) produced maximum yields with 250 mm of irrigation. Again in 2005 maximum corn yields were produced with 250-280 mm of irrigation even though hail affected the crop and rainfall was less (330 mm from May 1-September 30, 2005).

The grain yield responses to irrigation in figures 1 and 2 are based on how the water was managed on a year-around basis. Irrigation was reduced from conventional practices (normally 400-460 mm) because there was soil water available from the off-season and irrigation was managed according to atmospheric demand and soil water availability. Extra water came from snow trapped and retained by standing crop residue. Precipitation infiltrated where it fell. Soil

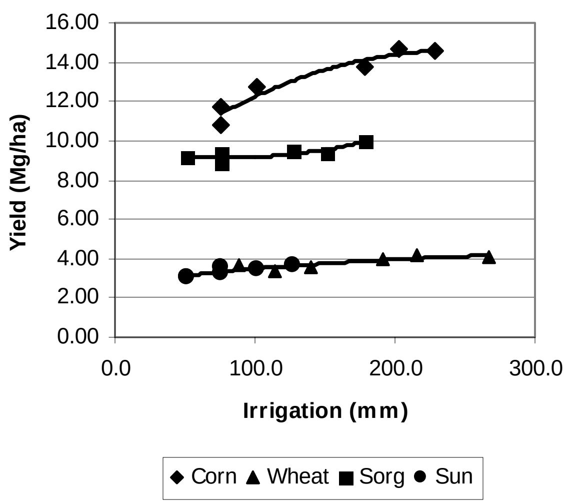

Figure 1. 2004 crop yield-irrigation relationships for crops grown at Garden City, Kansas, SWREC, Kansas State University.

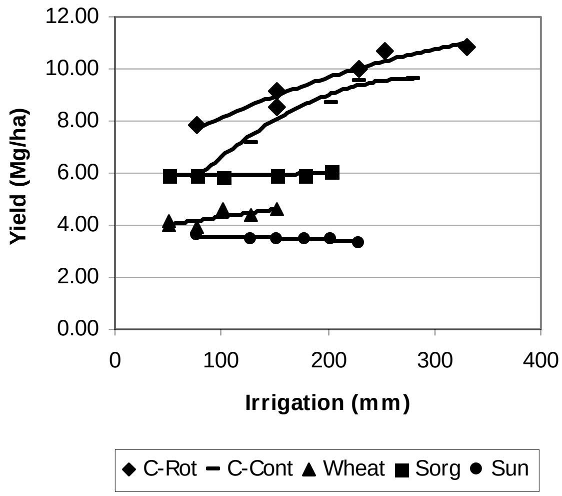

Figure 4. 2005 crop yield-irrigation relationships for crops grown at Garden City, Kansas, SWREC, Kansas State University.

water evaporation was reduced starting from harvest of the previous crop through the entire growing season by untilled crop residue. Water application on fully irrigated plots was managed to meet and not exceed atmospheric demand for water. Soil water status was measured bi-weekly and monitored for management decision. All of these factors worked together to reduce crop irrigation needs.

Table 2 has the summary data for the cropping systems research at Garden City for 2004 and 2005. The soybean crop was completely destroyed in a hail storm in early July, 2005. Corn was not in a rotation following sunflower during 2004. Irrigation treatments from 1 to 6 indicate irrigation gradations from meeting full ET demand (1) to very limited applications of 76 mm (6). The driest treatment (7) was only rainfed. Only continuous corn data are presented. Gain yields usually decreased with decreasing irrigation. This was not true for soybean in 2004, sorghum in

Table 2. Crop yield, crop evapotranspiration (ETc), water use efficiency (Y/ETc), and irrigation water use efficiency (IWUE) for crops in the cropping systems research at SWREC, Garden City, KS.

Irrigation Treatment*	Yield (kg/m^2)	ETc (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)	Irrigation Treatment*	Yield (kg/m^2)	ETc Rate (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)
a. Corn-2004					b. Soybean-2004				
1	1.51a	4.04a	2.75a	6.99c	1	0.31a	4.50a	0.61b	1.72c
2	1.48a	4.00a	2.68a	7.78c	2	0.28a	4.45ab	0.56b	1.82c
3	1.40ab	3.93 a	2.60ab	8.51c	3	0.31a	4.38abc	0.62b	2.39c
4	1.30bc	3.70ab	2.57ab	11.54b	4	0.27a	3.88dc	0.63b	3.60b
5	1.19c	3.54b	2.50ab	13.8a	5	0.29a	3.95bcd	0.67ab	5.76a
6	1.04d	3.46b	2.22b	13.8a	6	0.32a	3.73d	0.76a	6.19a
$LSD_{0.05}$**	0.11	0.35	0.40	1.70	$LSD_{0.05}$	0.06	0.53	0.13	0.79

Table 2. Continued.

Irrigation Treatment*	Yield (kg/m^2)	ETc (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)	Irrigation Treatment*	Yield (kg/m^2)	ETc Rate (mm/day)	Y/ETc (kg/m^3)	IWUE (kg/m^3)
c. Corn after Sunflowers-2005					d. Corn after Corn-2005				
1	1.09a	6.20a	1.69bc	3.30c	1	0.96a	6.20a	1.57ab	3.45d
2	1.07a	5.30b	1.94a	4.20b	2	0.95a	5.55b	1.73a	4.18cd
3	1.00ab	5.55b	1.73abc	4.37b	3	0.87a	5.63b	1.56ab	4.29c
4	0.92bc	4.85c	1.83ab	6.03a	4	0.85ab	5.03c	1.71ab	5.56b
5	0.85cd	5.35b	1.53c	5.58a	5	0.72bc	5.00c	1.44bc	5.65b
6	0.78cd	4.60c	1.65bc	----	6	0.58c	4.80c	1.24c	7.64a
7	0.71d	3.83d	1.75abc	----	----	----	----	----	----
$LSD_{0.05}$	0.14	0.45	0.24	0.72	$LSD_{0.05}$	0.15	0.40	0.29	0.83
e. Wheat-2004					f. Wheat-2005				
1	0.41ab	6.00a	0.87c	1.52e	1	0.46a	4.00a	1.07a	3.03c
2	0.42a	5.43ab	1.01bc	1.94de	2	0.44abc	3.73ab	1.08a	3.44c
3	0.34ab	5.20bc	0.99bc	2.09cd	3	0.46ab	3.73ab	1.14a	4.51b
4	0.35b	4.80cd	0.94bc	2.53bc	4	0.39c	3.50bc	1.03a	5.14b
5	0.35b	4.30de	1.03bc	3.02b	5	0.42abc	3.38c	1.12a	8.16a
6	0.36ab	4.13e	1.12b	4.08a	6	0.40bc	3.25c	1.12a	7.82a
7	0.38ab	3.46f	1.39a		7	0.30d	3.40c	0.78b	
$LSD_{0.05}$	0.06	0.61	0.19	0.51	$LSD_{0.05}$	0.06	0.32	0.15	0.91
g. Sorghum-2004					h. Sorghum-2005				
1	1.00a	5.85a	1.88ab	5.64d	1	0.61a	5.42a	1.11ab	2.99e
2	0.94b	5.85a	1.75b	6.13d	2	0.59a	5.38ab	1.10ab	3.34e
3	0.95ab	5.83a	1.80ab	7.44c	3	0.59a	5.20b	1.14ab	3.90d
4	0.89b	4.60b	1.86ab	11.70b	4	0.59a	4.88c	1.20ab	5.78c
5	0.92b	4.45bc	2.00a	18.02a	5	0.60a	4.85c	1.22a	7.81b
6	0.94b	4.23c	1.89ab	12.28b	6	0.59a	4.60d	1.27a	11.65a
----	----	----	----	----	7	0.49b	4.40d	1.03b	
$LSD_{0.05}$	0.07	0.37	0.20	0.70	$LSD_{0.05}$	0.07	0.22	0.17	0.53
i. Sunflower-2004					j. Sunflower-2005				
1	0.36a	5.75a	0.72a	2.86c	1	0.34a	6.15ab	0.60ab	1.46d
2	0.34ab	5.78a	0.68a	3.39c	2	0.35a	6.58a	0.58b	1.70d
3	0.36ab	5.43ab	0.74a	4.24b	3	0.35a	5.83b	0.66ab	1.96cd
4	0.33ab	5.43ab	0.69a	4.65b	4	0.35a	5.95ab	0.65ab	2.29cb
5	0.31ab	5.03b	0.72a	6.08a	5	0.35a	5.55b	0.70ab	2.75b
6	0.31b	4.98b	0.70a	6.10a	6	0.36a	5.48b	0.73a	4.71a
$LSD_{0.05}$	0.05	0.67	0.14	0.76	$LSD_{0.05}$	0.07	0.71	0.15	0.57

* Treatment 1=full irrigation; 7=Dryland.
**LSD= least significant difference for alpha=0.05.
***data with the same letters are not significantly different within each column for each crop-year.

2005 and sunflower in 2005. In these instances, there were no significant yield differences among irrigation treatments. Crop evapotranspiration (ETc), measured with the water balance method, generally increased with added irrigation. Irrigation treatments with less water applied than treatment 1 were under a gradation of water stress at times during the growing season. The separation in ETc among treatments in terms of significant difference was not consistent. Although 2004 had less growing season rainfall than 2005 (330 vs. 530 mm), ETc differences for irrigation treatment were not consistent across the crops. Water use efficiency (Y/ETc) generally decreased with less irrigation in 2005 and increased with less water in 2004. As noted, the two years were different in terms of water available from rainfall. Irrigation water use efficiency (IWUE) increased with decreasing irrigation. This indicates less grain yield was returned from irrigation with increasing irrigation, which is a diminishing return effect (see figures 3 and 4).

Differences in grain yield among crops opens possibilities for strategies for crop selection when well capacity is limited. Corn returned more grain with added water until it became over-watered. Economic returns follow this same trend. Wheat, sunflower, and grain sorghum yielded well with small amounts of irrigation. Results are needed for dry years, but previous research at this research center indicated that these traditional dryland crops can be sustained at optimum yields with little irrigation. The two characteristics of economic response to irrigation from corn and sustainable yields with small irrigation investments can be utilized for limited capacity wells. Planting two crops, one with lower water demand than the other, the same field increases the per-acre well capacity. This option is also enhanced with crop residue management possibilities that take advantage of the stubble like wheat produces for water savings in the next crop. Systems management, including retaining crop residues and irrigation timing, for limited water resources has the potential for reducing water applications and/or increasing crop yields. .

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Dr. Klocke presented the CWA model in a variety of settings and gave potential users its background, philosophy, operations, and application examples. Audience members included irrigators, educators, water district board members, state and federal water agency heads, US congressmen, state legislators, water scientists. The presentations included:

Presentations by Dr. Klocke at:
ASAE International Meeting, Las Vegas, NV, 2003
Kansas State University—SWREC Research Advisory Council, 2003-2006
Kansas State University—SWREC Field Day, 2004, 2005
Central Plains Irrigation Conference, Kearney, NE, 2004
Producer meeting at Healy, Kansas, 2004
High Plains Groundwater Resources Conference, Lubbock, TX, 2004
Water and the Future of Kansas, Lawrence & Topeka, KS, 2004, 2006

Kansas Water Resources Advisory Meeting, 2004
Irrigation Technology Seminar, Dodge City, 2004, 2005
Kansas Water Authority Meeting, Ft. Scott, KS, 2004
Groundwater Management District Meeting, Garden City, KS 2005
Soil Conservation District Board Meeting, Garden City, 2005
ASABE International Meeting, Tampa Bay, FL, 2005
Irrigation Association Meeting, Phoenix, AZ, 2005
Partners in Conservation, Garden City, KS, 2005
Kansas F.A.C.T Conference, Liberal, KS, 2006

Troy Dumler presented CWA in the following extension meetings:

Ag Profitability Conferences 2005-2006
- Ulysses - Feb. 2005
- Lewis – Jan. 2006
- Goodland – Feb. 2006

Irrigated Crop Production/Energy Cost Meetings 2005-2006
- Scott City (2) - Jan. 2005, Feb. 2006
- Hugoton (2) - Dec. 2004, Jan. 2006
- Dodge City – Jan. 2006
- Garden City – Feb. 2006
- Wichita – Nov. 2005
- Ulysses – Dec. 2005
- Lakin – Feb. 2005
- Cimarron – Feb. 2005

Dr. Dan Rogers, extension irrigation engineer, conducted training sessions with the CWA. These included the following sessions:

Event	Location	Format	Date	Attendance
Irrigation Management Seminars and Field Tours				
Agent Program Planning	Great Bend	Presentation	Sept	30
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Finny County Conservation District Crop Production	Garden City	Presentation	Jan 26	60
Grant County KanSched	Ulysses	Training	Jan 26	30
Kearny County: KanSched	Lakin	Training	Feb 14	4
Cheyenne County: KanSched	St. Francis	Training	Feb18	2
Grant County: KanSched	Ulysses	Training	Mar 1	5
South Central Ks: KanSched	Hutchinson	Training	Mar 31	10
Spring Action Conference	Salina	Presentation	April 6	40
MIL Software Seminar	Oberlin	Computer Training	April 26	8
MIL Software Seminar	Lakin	Computer Training	April 8	4
3-I Trade Show	Garden City	Booth	April 28-30	110

Information transfer

KBUF radio presentations for live interviews on five occasions

KSU news release used by High Plains Journal, Kansas Farmer

Klocke, N.L., Clark, G. A., Stone, L.R., Dumler, T.J., and Briggeman, S. 2004. Crop Water Allocator (CWA). [World Wide Web]. Version 1.5. www.oznet.ksu.edu/mil. Kansas State University, AES.

Activity for CWA on the Internet: 1,100 hits in 330 downloads during 2005.

Students Supported
Five college students and three college prep students were supported with part-time employment through this grant. They were exposed to various facets of water resources research from daily planning and coordination of research activities, execution of research protocols, to data processing and data quality control.