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CENTER PIVOT EVALUATION AND DESIGN

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INTRODUCTION

The Center Pivot Evaluation and Design Program (CPED) is a simulation model. It is based on the first model presented by Heermann and Hein (1968) which was verified with field data. Their simulation model required input of the sprinkler location, discharge, pattern radius and an assumed stationary pattern shape of either triangular or elliptical. The application depth versus distance along a radial line from the pivot was determined and application rates at a specified distance from the pivot were determined. The hours per revolution were input and each tower was assumed to move at a constant speed for the complete circle. Kincaid, Heermann and Kruse (1969) used the model to calculate potential runoff for different system capacities and infiltration rates. Kincaid and Heermann (1970) added the calculation of the flow resistance and verified with measured pressure distribution along the center pivot lateral. Chu and Moe (1972) studied the hydraulics of a center pivot system and developed a quick approximation for determining the pressure loss from the pivot to the outer end of the lateral as a constant (0.543) times the loss that would occur if the entire discharge flowed the total length of the lateral.

The model was adapted by Beccard and Heermann (1981) to include the effect of topographic differences in the resulting application depths along radii of the center pivot in non level fields. The model included the pump and well characteristics and calculated the hydraulic equilibrium point as the system moved to different positions on a rough terrain. The model was exercised to determine the uniformity changes when converting from high pressure to low pressure on rough terrain. Edling (1979), and James (1984) also used simulation models to study the performance of center pivot systems on variable topography and with different pressures.

The current simulation model has been expanded to include donut shaped stationary patterns that can be used to represent many of the low pressure spray heads. The start-stop of the electric motors and the speed variation in hydraulic drives can also effect the uniformity in the direction of travel (Heermann and Stahl, 1986). The input of the start-stop sequence for each tower replaces the assumption of a constant speed and the variability of application depths in the direction of travel has been simulated.

EXAMPLES OF SIMULATION EVALUATION

The uniformity of application depths can be calculated by inventorying the sprinkler head models, nozzles sizes and distance from the pivot. The pump curve and drawdown, or pivot pressure, or discharge is also needed. Figure 1 illustrates a simulation as designed and the distribution if the sprinkler heads were reversed between 2 towers made at the time of installation. The application rate and potential runoff are illustrated in Figure 2.

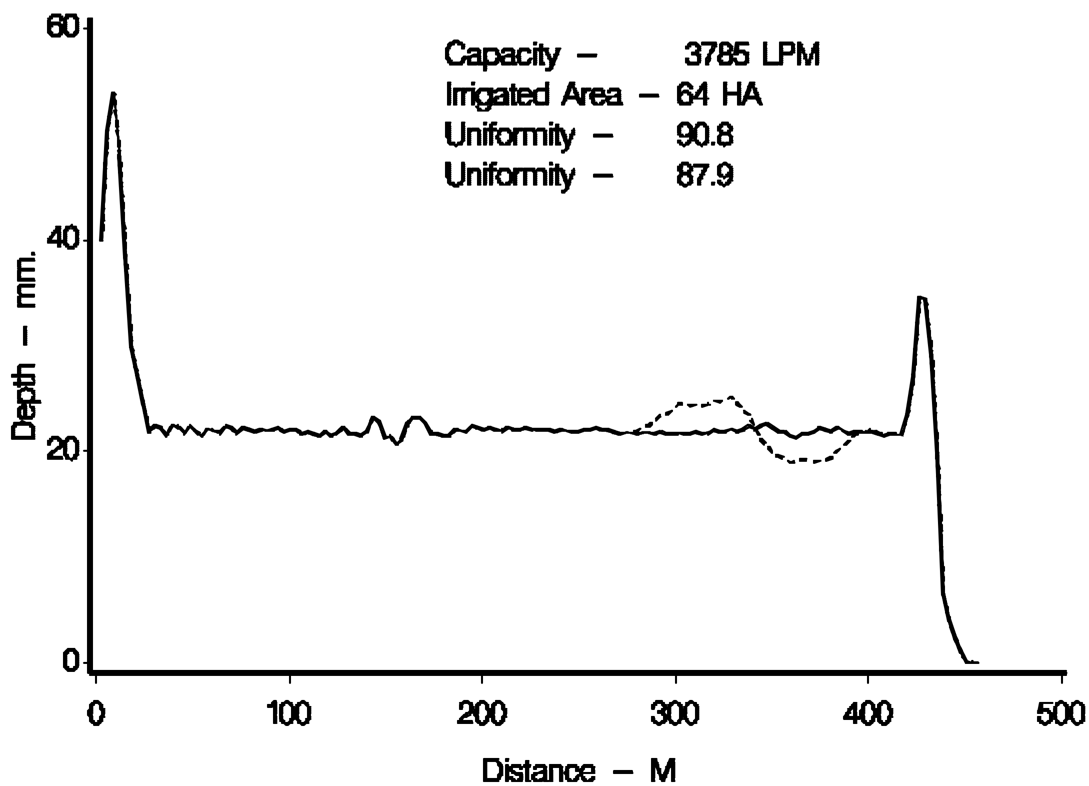


Figure 1. Typical center pivot as designed (CU = 90.8) and with 10 sprinkler heads incorrectly installed shown as a dashed line (CU = 87.9).

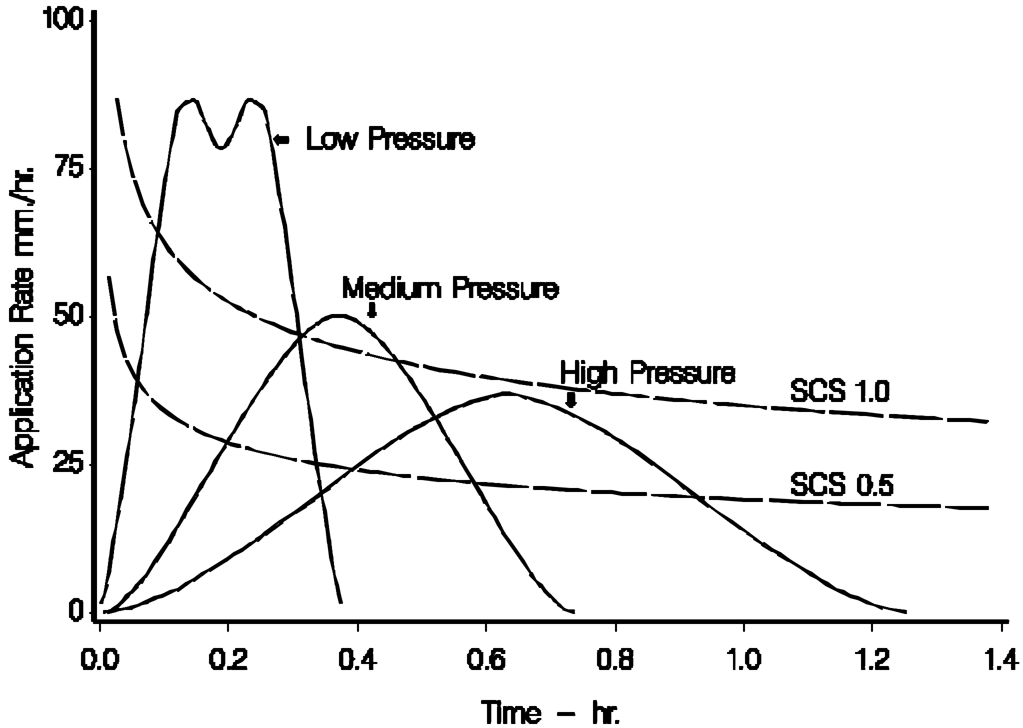


Figure 2 Example application rate curve versus 0.5 and 1.0 SCS intake curve.

EVALUATION OBJECTIVES

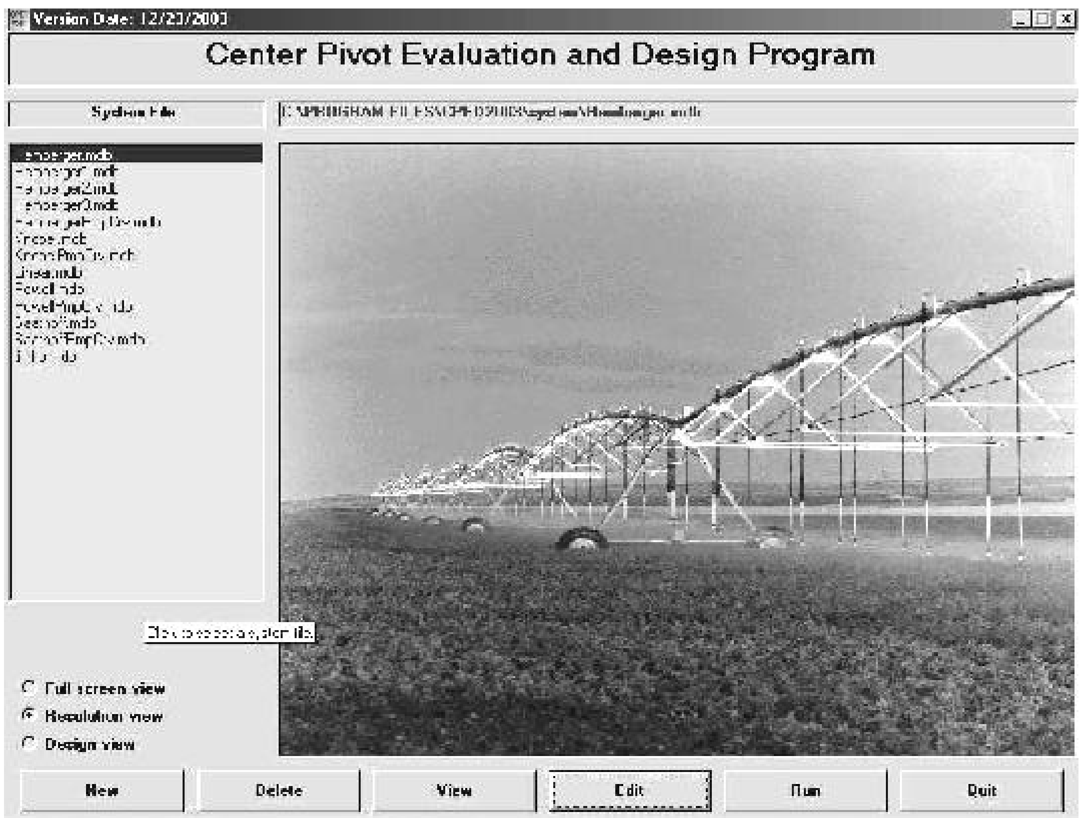
The selection or development of an evaluation standard and procedures should focus on the need for the evaluation. The USDA, Environmental Quality Incentive Program (EQIP) administered by the Natural Resource Conservation Service (NRCS) currently can provide cost sharing on the installation and upgrading of irrigation systems for improving water quality or conservation under irrigation. Center pivots are frequently the system of choice. There is a need to assure that installed systems will provide the desired improvement in irrigation performance. A similar need exists for any user of center pivot systems to assure that an installed or modified system will perform as designed. It must be recognized that the scheduling of irrigations is most important for the beneficial use of water. Efficient scheduling of irrigation systems requires knowing the amount of water applied per irrigation. The CPED program has been streamlined and simplified for use in evaluating center pivot systems for cost sharing on new and upgraded systems. The CPEDLite program is similar to the one being used in this workshop. The primary difference is the simulations are for 1 foot intervals beginning and ending at fixed distances. This assures that any simulation will provide the same results. The uniformity is output in 5% bands.

CPED PROGRAM OPERATION

The following pages will present the various windows that are presented to the user for controlling the input and operation of the program. The program illustrated is the full version of CPED. The CPEDLite program has the same look at the window level but requires less input with some of the options being fixed so that similar results will be obtained independent of the operator.

The program is available on request but the user is cautioned that there is always the possibility of program errors when different systems present conditions that have not been experienced prior to this time. The program is therefore limited in its release to minimize the problems of users that are not familiar with center pivot operation and terminology.

MAIN PROGRAM WINDOW



The options available are to **select** or create a **new** system file, **view** output from previous simulations, and **quit** the program. Once a system file is **selected** or created, the options to **run, edit, or delete** the system file are enabled. In all cases throughout the program "click" means click the left mouse button.

A system file can be **Selected** by clicking one of the systems listed in the list box labeled *System File List.* The name of the selected system file will be displayed in the label box labeled *Name of Selected System File.*
The **New** button allows the user to create a new system file. There are two ways to create a new system. The first way is to enter a name and click the OK button. You are then transferred into the Edit window that is discussed below. The second option is to create a system from an existing file. You then select the existing file; name the new system; click the OK button and you will be in the Edit window where only changes need to be entered.

The **Delete** button will delete the selected system file from the user's hard drive. The user will be asked for confirmation before deleting a system file.

The **View** button allows examining previous simulation results. The *View previous output* button will bring up the data files that have been saved from previous simulations. Selecting one of these files will plot to the screen the simulated depth versus distance data.

The *Analyze catch can data* button allows you to enter catch can data for uniformity evaluation. A simulation output data set can be input to the catch can data file and allow the uniformity analysis for different distances along the lateral.
The procedure to save simulation data is presented latter with running the program.

The **Edit** button allows editing of the selected system file. More detail is below.

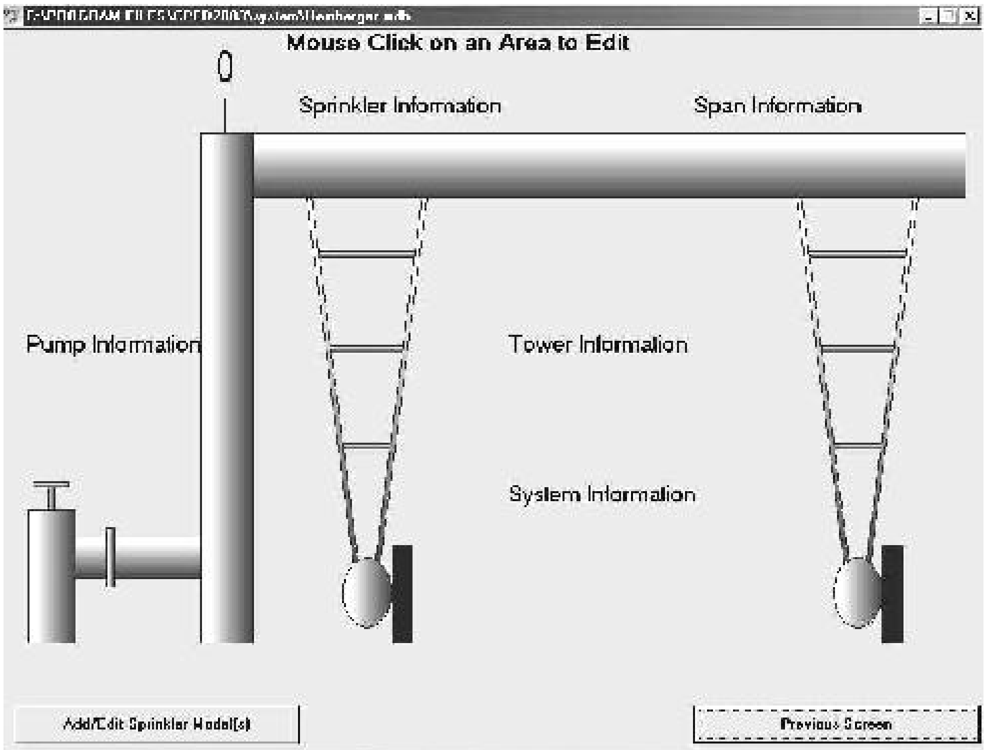
The **Run** button moves to the screen for entering the parameters to run the simulation. More detail is given below.

The **Quit** button exits the program. Pressing CTRL +Q anytime during the simulation will have the same effect.

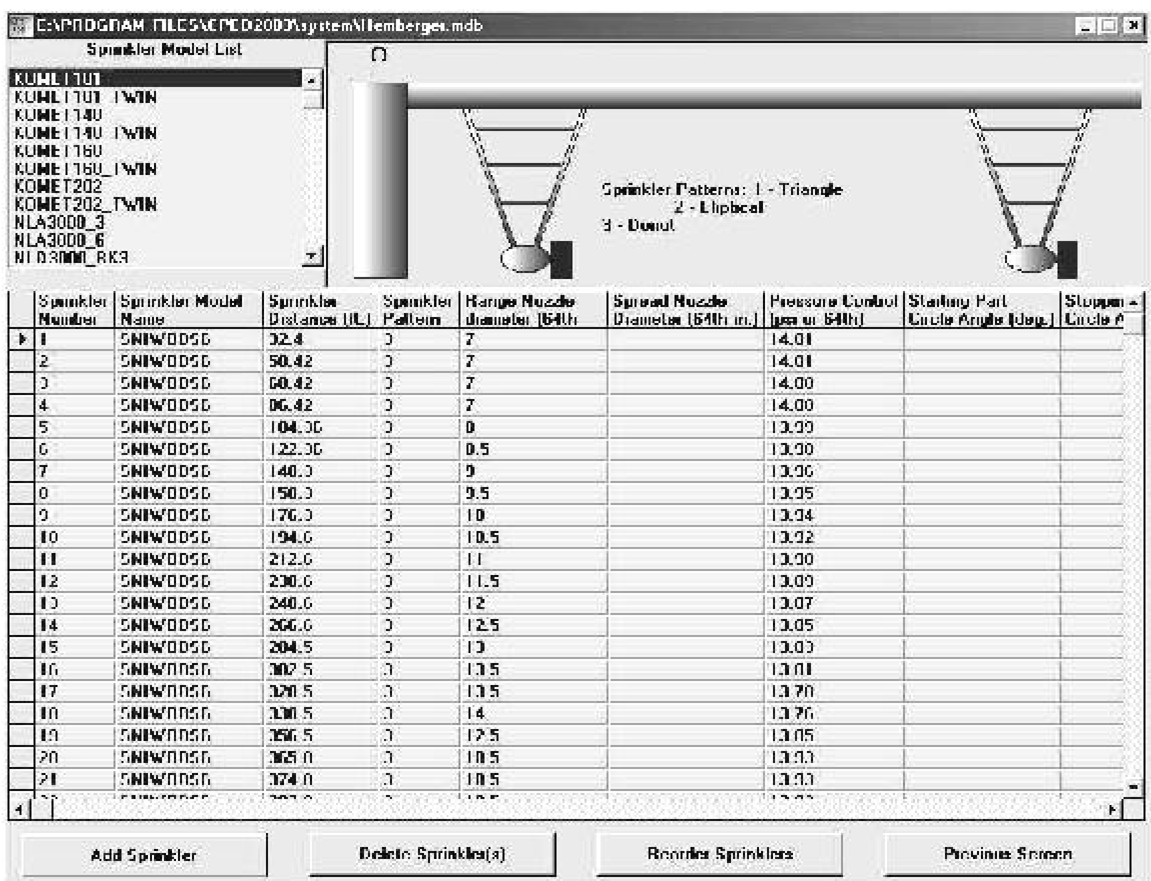
EDIT SYSTEM FILE WINDOW

The different information groups of data can be entered or edited by moving the mouse pointer over the image of the sprinkler system. The labels *Pump Information, Tower Information, Sprinkler Information, Span Information, and System Information* can be selected by clicking on the text to open its edit window.

The *Add/Edit Sprinkler Model* button opens a window for adding or editing sprinkler models. This is password protected and normally is not needed by the user. Those supporting the program will do this editing. The *Previous Window* button saves the changes and returns to the main program window.



SPRINKLER EDIT WINDOW



A new sprinkler can be added by clicking the *Add Sprinkler* button. If no sprinklers are present by pressing the *Add Sprinkler* button a sprinkler with zero distance will default and you can begin by entering the other information for the first sprinkler. The sprinkler model is selected by clicking on the model listed in the box labeled *Sprinkler Model List*. Sprinklers can be added in any order. If one sprinkler is missed you can merely add it at any time. By clicking the *Reorder Sprinklers* button the sprinklers will be ordered from the pivot to the outer end based on their individual distances from the pivot. You do not enter the sprinkler number as this is done automatically. If sprinklers are present the information from the previous record will be used and the distance will automatically be incremented. Edit the information for the newly added sprinkler. Many systems will have the same sprinkler models and these will need no editing. If the sprinkler spacing is uniform this will also require minimal editing. Even the nozzle sizes may be the same for several sprinklers minimizing the editing required.

The nozzle size is the diameter in 1/64 inches. For example a nozzle diameter of 9.5 is equal to 9.5/64 or 19/128 inch. There are columns for a range and spread nozzle which was typical for high pressure heads. Enter the diameter for single nozzle sprinklers in the range column. The pressure control column is the outlet pressure of the pressure regulator if this is selected in the *System file screen.* When the constant orifice is the selected pressure control, the orifice size in 64^{th} inch is entered. When this column is left blank, it is an indication there is no flow control on that sprinkler even if the system has pressure regulation selected.

The start and stop angles are viewed from the pivot toward a part circle sprinkler. Check if the sprinkler starts on the right or left. Then using the pipe as the zero reference point, measure the angle back toward the pivot. Use the same technique for the stop angle. All angles are positive and between 0 and 180 degrees (Figure 3).

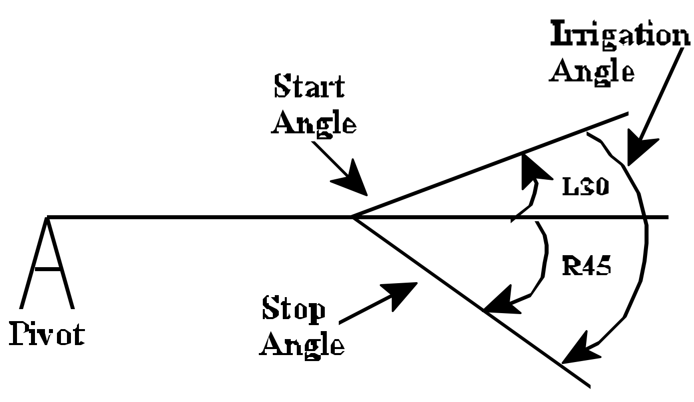


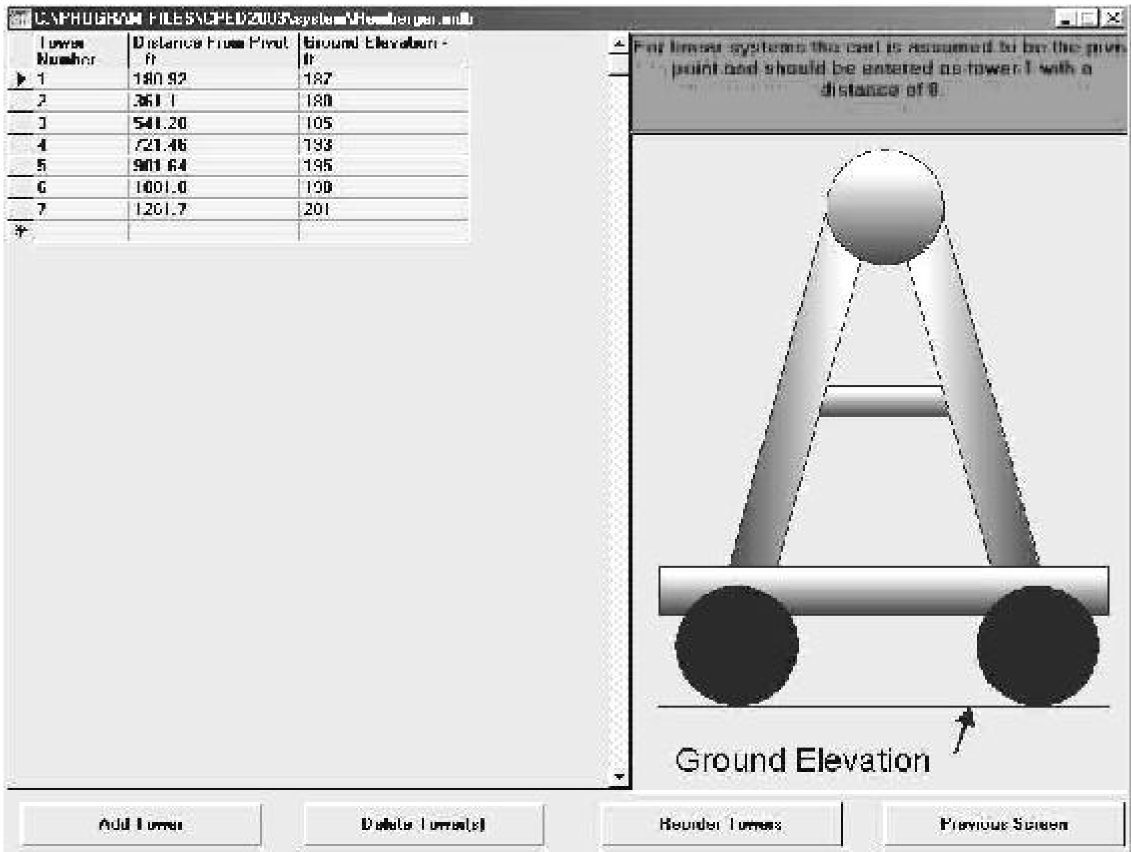
Figure 3. Part circle sprinklers angles. Angles are between 0 -180 degrees with an L or R prefix.

Alternatively you can move to the bottom row marked with an '*' and enter the new sprinkler information manually. A sprinkler can be deleted by selecting any column in the row for the sprinkler and click the *Delete* button.

The *Reorder* button will sort and number the sprinklers by sprinkler distance from the pivot.

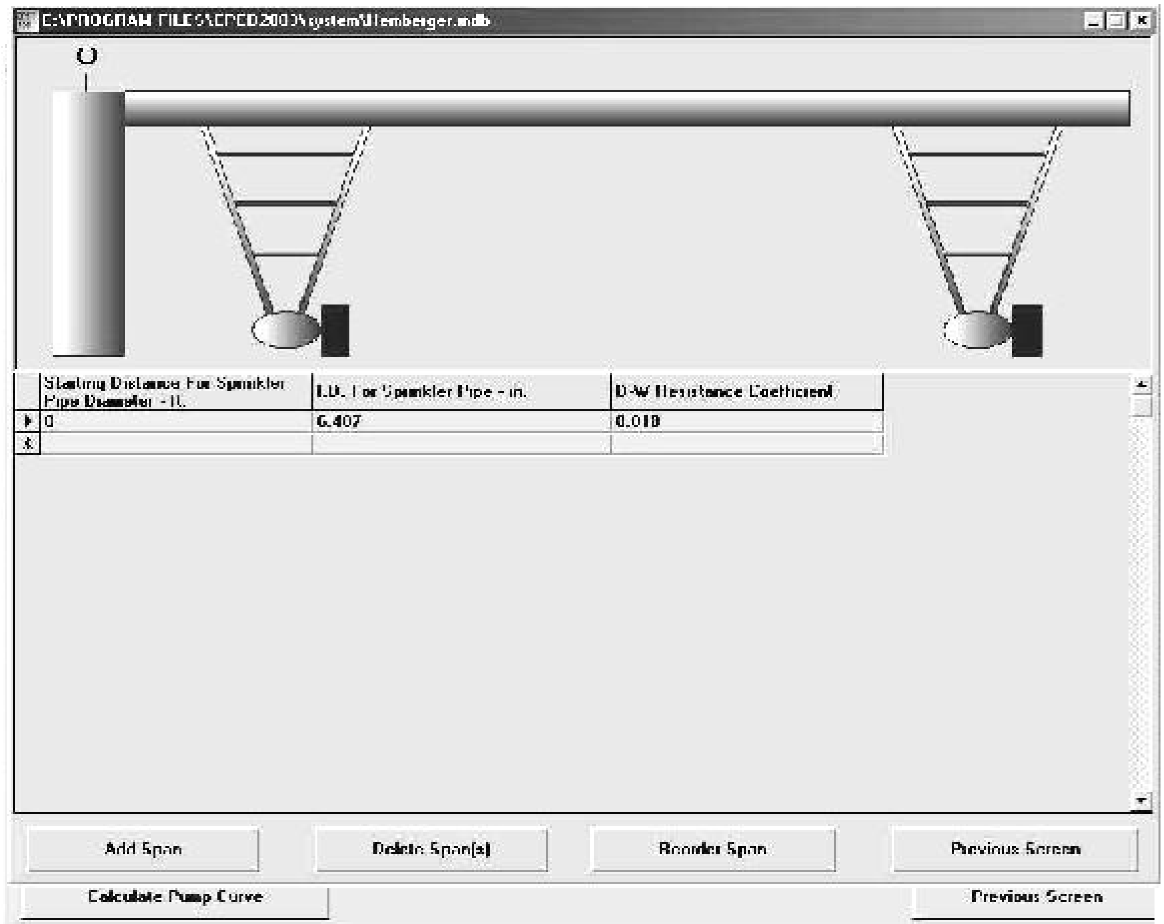
The *Previous Screen* button returns to the **Edit system file window**.

TOWER EDIT WINDOW



Towers are added by clicking on the *Add Tower* button and editing the distance from the pivot and its elevation. It is often assumed that the pivot and all towers are at an elevation of 100 feet if no field information is available. For the linear system, the first cart is assumed to be the pivot with a distance of 0. As the *Add Tower* button is clicked, the towers are added with the spacing of the previous two towers and the same elevation as the previous tower. The *Reorder Towers* will sort the towers by distance from the pivot if there happen to be entered in the wrong sequence. Select a tower and click the *Delete Tower* button if a tower needs to be deleted. The *Previous Screen* returns to the *Edit system file window.*

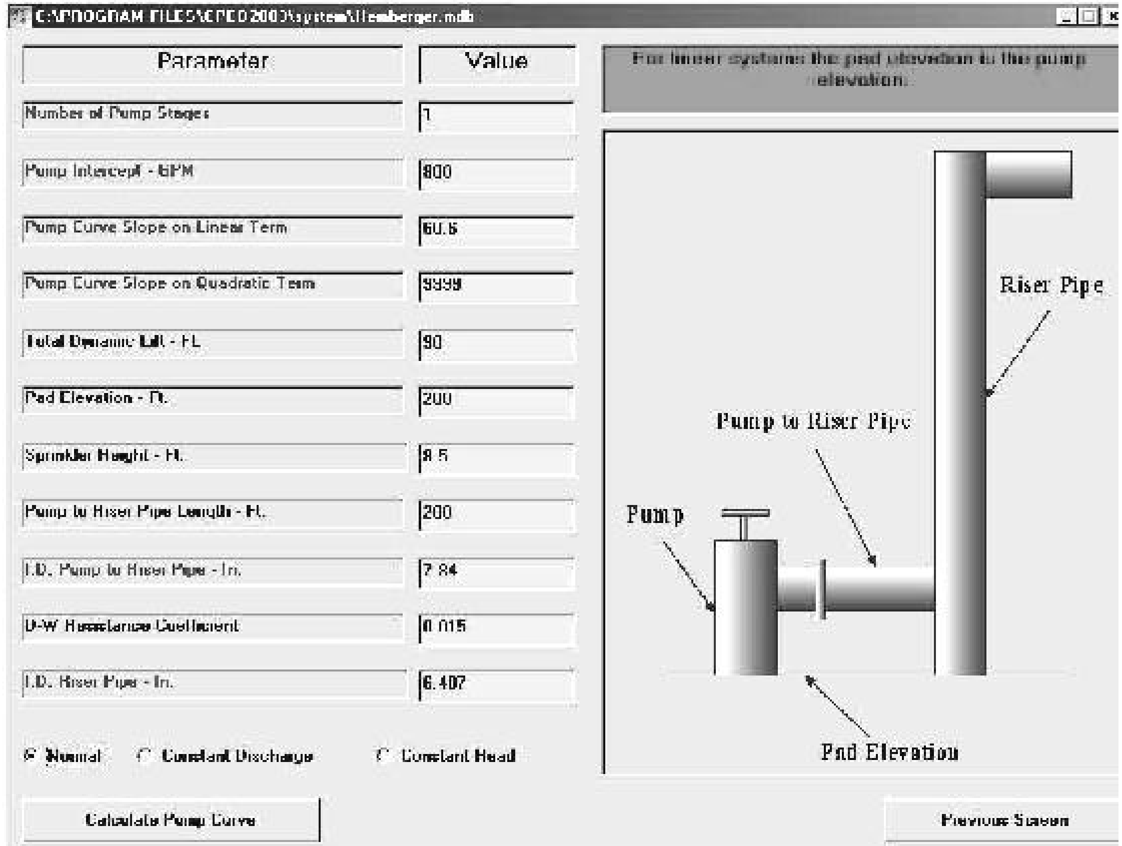
SPAN INFORMATION WINDOW



Clicking the *Add Span* button inserts a starting distance of 0 and the Pipe I.D. and the Darcy-Weisbach resistance coefficient must be entered. A typical value of the D-W coefficient is 0.xxx to 0.xxx for center pivots. Multiple pipe sizes can be added by clicking the *Add Span* button and entering the starting distance from the pivot and its resistance coefficient. The spans are assumed to go from the starting distance to the next span or end of the pivot for the last span. Spans can be deleted (*Delete Span)* and reordered (*Reorder spans)* by clicking the appropriate button. Never delete the span with starting distance of 0. The *Previous Screen* button returns to the *Edit system file window.*

PUMP INFORMATION WINDOW

The piping to the pivot, pump curve, and pivot elevation are entered in this window. If the pump curve information is not available, either a constant discharge or constant pressure can be selected.



Selecting the *Normal* option requires the quadratic equation for the pump curve. The curve of the total head vs discharge for the pump is needed to develop the regression equation that describes the pump. This relationship can be determined externally from this program or there is an option that will fit the pump curve equation with points from a pump curve or field measured data. At least 4 points that span the operating range are needed, however 8-10 will give a better fit. Problems have occurred where the operating point is beyond the pump curve data. **Use caution.** The form of the equation for the pump curve is:

$$Q = B_0 + B_1H + B_2H^2$$

where:

Q - discharge - gpm
H - head/stage - psi
B_0 - intercept
B_1 - linear slope coefficient on head
B_2 - quadratic slope coefficient on head

The number of stages for the pump must be entered when the manufacturers pump curve is for a single stage. However, if the pump curve comes from field measurements, set the number of stages equal to one. The *Calculate Pump Curve* button can be selected for calculating the coefficients when data are available from either the manufacturers pump curve or field measured data. The paired data of discharge in gpm and head in feet can be entered and the three coefficients calculated.

The total dynamic lift in feet must also be entered. It is the elevation difference (feet) between the center pivot pad elevation and the depth to the water table including the drawdown while pumping. The pad elevation is the elevation for the center pivot at from an assumed or measured datum elevation. The sprinkler height is the distance above the pad height for the sprinklers as if they were on a level field. The inside diameter (I.D.) of the pipe size and length of pipe from the pump to the pivot and the I.D. of the riser pipe must be entered. Include the Darcy-Weisbach coefficient for both pipes.

The *Constant Head* option is where the pivot pressure (psi) is specified. This is the most stable option where the pump curve is not known. Estimate the discharge in gpm and set the number of stages equal to one. The estimate discharge is only to shorten the calculation time and the actual value is not critical.

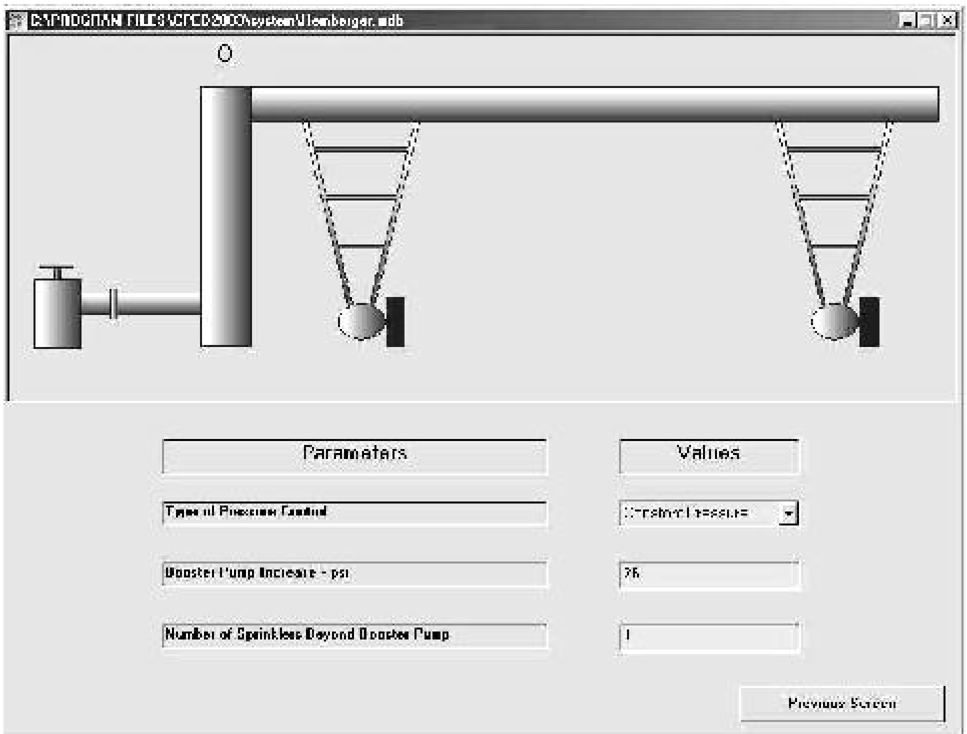
The *Constant Discharge* in gpm can also be specified. The potential problem with constant discharge is when all sprinklers are regulated. If the discharge does not match the calculated discharge with the regulated pressure an error will occur when attempting to have the calculated discharge on the system match that specified. Again set the number of stages equal to one.

The constant head and constant discharge does not require pump to riser pipe and riser pipe sizes or resistance coefficient since the pressure or discharge is assumed to be at the pivot and no head loss is calculated for these sections. The *Previous Screen* button returns to the *Edit system file window.*

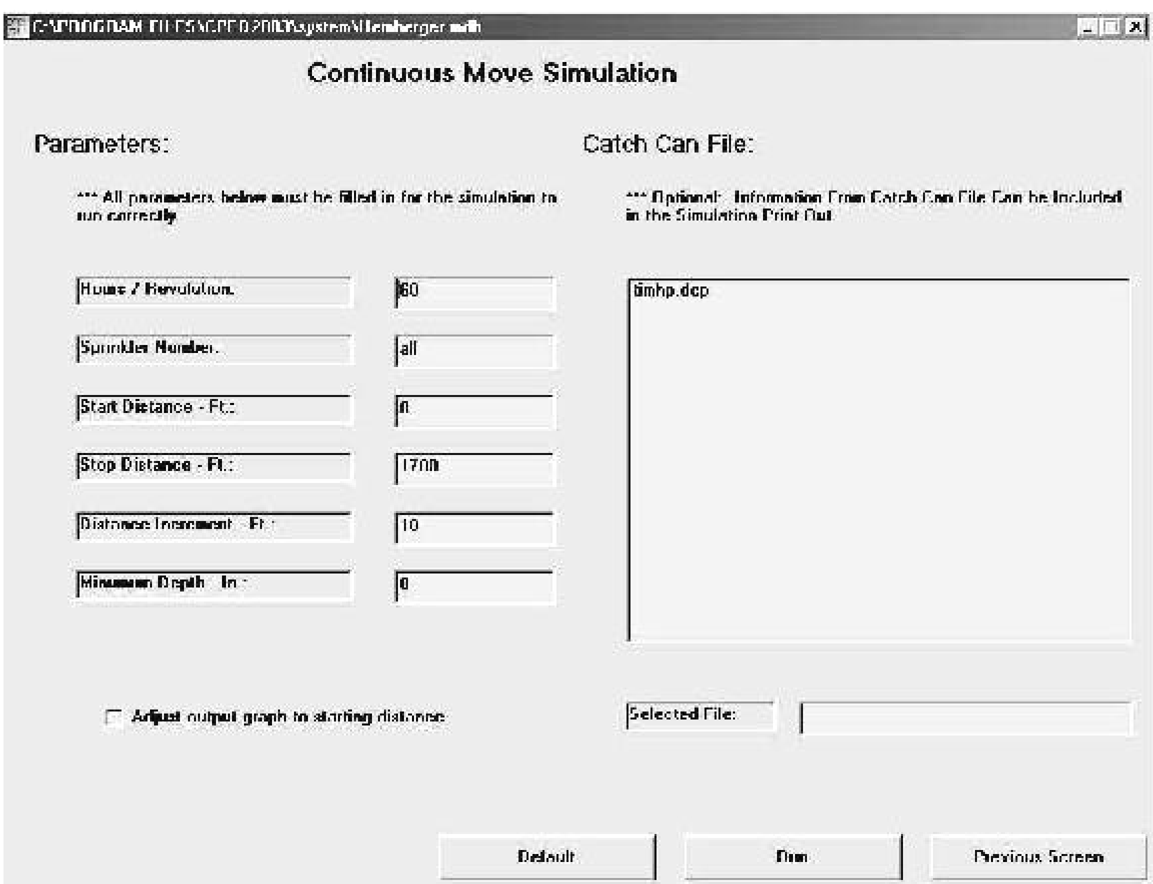
SYSTEM INFORMATION SCREEN

Three options for the *Type of Pressure Control* can be select from the drop down box. They are none, pressure regulated, or constant orifice. Systems with booster pumps for the big gun at the end of a center pivot system are simply estimated with a pressure increase in psi just prior to the big gun or guns. The number of sprinklers beyond the booster pump is specified. The actual pressure is dependent on the center pivot system and the inlet pressure, discharge or pump curve.

The *Previous Screen* button returns the *Edit system file window*.


Parameters
Values
Type of Pressure Control
Booster Pump Increase - psi
Number of Sprinklers Beyond Booster Pump
Previous Screen

RUN WINDOW


Continuous Move Simulation
Parameters:
Catch Can File:
*** All parameters below must be filled in for the simulation to run correctly.
*** Optional: Information From Catch Can File Can be Included in the Simulation Print Out.
Hours / Revolution:
60
Sprinkler Number:
all
Start Distance - Ft.:
0
Stop Distance - Ft.:
1700
Distance Increment - Ft.:
10
Minimum Depth - In.:
0
timhp.dcp
Adjust output graph to starting distance
Selected File:
Default
Run
Previous Screen

This is the screen that you will enter when you click *RUN* and all of the system files with the necessary data have been entered. Minimal input is required on this screen before the simulation is run. The *Default* button will restore the default values that were used on the previous simulation run for this system. The hours/revolution are entered to obtain the depth for this condition. Normally the sprinkler number is set to "all" for including all the sprinklers to be simulated. However, you can select one sprinkler by entering its number to see the contribution to the depths from the specified sprinkler.

The start, stop distances and distance increment specifies the location for simulation depths. For example you can start at 10 feet and go to 500 feet with 5 foot increments. The minimum depth specifies that only locations with depths greater than that will be included in the uniformity calculations. This is often desirable when not including the small depths at the outer boundary where there is not sufficient overlap with other sprinklers. The CPEDLite program fixes these four parameters and only the speed in hours/revolution can be changed.

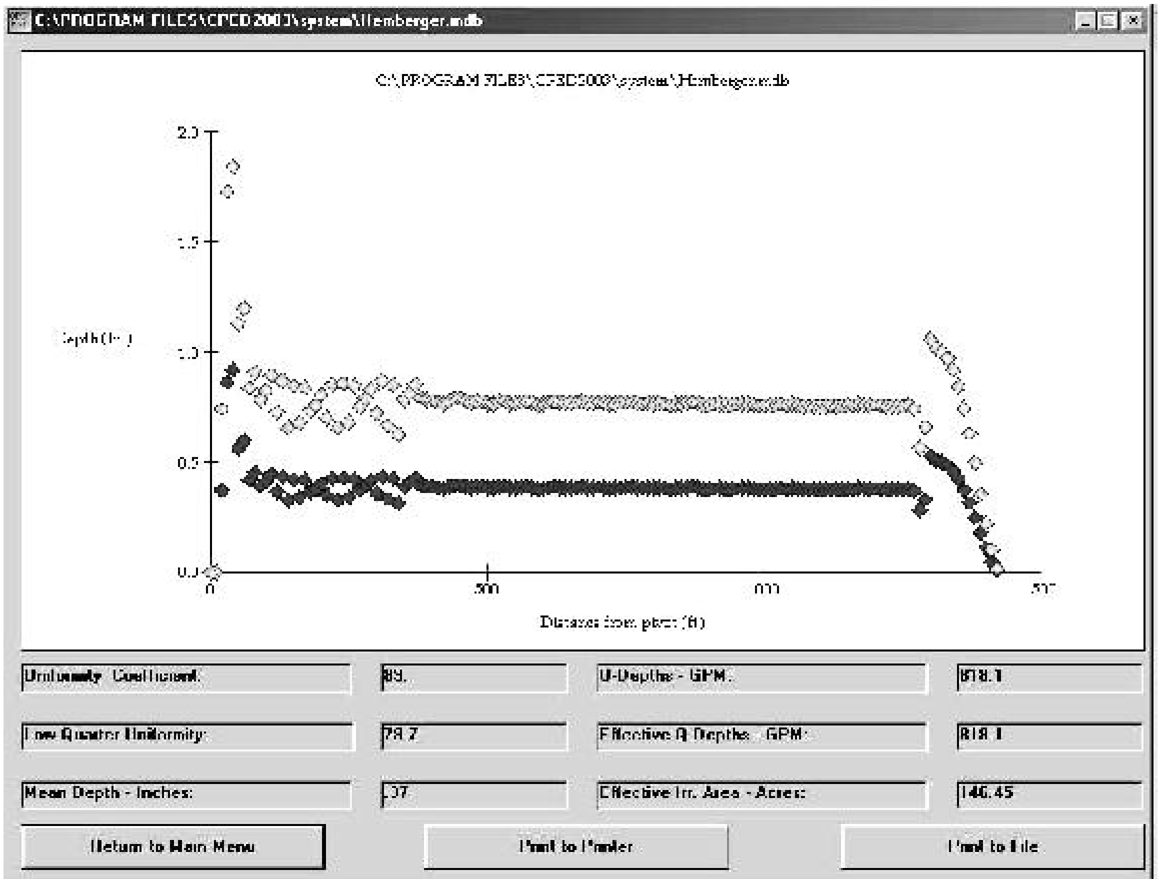
Clicking the *RUN* button will start the simulation. You will automatically be moved to another window that will plot the simulated depth versus distance data on the monitor. Prior to pressing *RUN* you can select a catch can data set or data saved from a previous run to be displayed on the monitor after the simulation is completed. This provides a visual comparison of the current simulation with other data. The data for comparison can be selected from the files listed in the Catch Can File Window. The *Previous Screen* button will return to the Main Window.

You will note a possible selection to Adjust output graph to starting distance. This is normally not needed when simulating the entire system. Clicking this selection is beneficial if you are not simulating from near the pivot and want the plot to begin at the starting distance instead of 0.

SIMULATION OUTPUT WINDOW

The output window plots the simulated depth versus distance from the pivot for the parameters set in the run window. The Coefficient of Uniformity, the Distribution Uniformity, and mean application depth are printed. The Q-Depths, gpm, is the discharge calculated from all simulated depths while the Effective Q-Depths, gpm, is calculated from the depths that are above the specified minimum depth used in the Uniformity and mean depth calculations. The effective area is the simulated area for those areas receiving more than the minimum depth between the starting and stop distances. The window below is an example of plotting catch can data from a previous simulation run.

Additional data can be printed either to the printer or to a file. The *Return to Main Menu* button will return to the main menu screen. The *Print to File* button will ask for the file name



for storing the information. You will then be prompted for saving the individual sprinkler and tower data followed for a prompt to save the simulated depth data and the name for its file. The saved simulated depth data are then available for comparison with future simulations for the same center pivot system.

The following information can be printed to the printer after the simulation run.

1. The head per stage of the pump - gpm
2. The pivot pressure - psi
3. The system discharge based on the pump curve - gpm
4. The system discharge based on all the integrated depths - gpm
5. The system discharge based on all depths above the minimum depth - gpm
6. The effective irrigated area, which is the area receiving water above the minimum depth - acres
7. The mean depth - in. (of all depths above the minimum)
8. Christiansen's uniformity coefficient (of all depths above the minimum)
9. Mean low quarter uniformity (of all depths above the minimum)
10. Plot of depth vs distance

The information that is available for each sprinkler is the line pressure - psi, the nozzle pressure - psi, the discharge - gpm, and the pattern radius - ft.

The application depths are the final piece of information provided. They are listed by distance.

The *Previous Window* button saves the changes to the system file and returns to the main program window.The *Previous Window* button saves the changes to the system file and returns to the main program window.

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USING CPNOZZLE FOR SPRINKLER PACKAGE SELECTION

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INTRODUCTION

Sprinkler irrigation systems and specifically center pivots have been adapted to operate on many different soils, to traverse extremely variable terrain, and to provide water to meet a number of different management objectives. As a buyer, you will be furnished with an array of different sprinkler types, many that are capable of performing adequately. However, you should make a selection based upon accurate field based information, and careful consideration of the interaction among several system design factors. Only then will the system installed meet your expectations.

What flow rate?

When the desire is to replace the peak water use, the flow rate required is virtually the same for all crops. The reason is that although the duration and timing of a specific crop's peak water use rate varies, peak water use rates are quite similar. The system flow rate determines how other factors impact system operation. For example, if the flow rate is greater than necessary, the peak water application rate may cause runoff toward the outer end of the pivot lateral. The system flow rate also determines the size of sprinkler head required at each position of the system and the ability to recover from system downtime.

When estimating the needed system flow rate, there are three important considerations: a) environmental factors; b) estimated system downtime; and d) the soil water holding capacity. The most important environmental considerations are the likelihood of rainfall and the peak ET rate of the crop. NebGuide G89-932 *Minimum Center Pivot Design Capacities in Nebraska* presents a procedure for determination of the minimum net system capacity of center pivots in Nebraska. Estimated crop water use rates, soil water holding capacity and rainfall data from different locations in the Nebraska were evaluated. The analysis identified areas where the system flow rate should be increased to account for lower annual precipitation and greater peak ET rates. Our best estimate is that systems located west of the 20 inch per year annual precipitation line should have greater flow rates.

Table 1 presents the estimated minimum net system capacity required to meet crop demands 90% of the time for regions in Nebraska. The last line in the table provides the system capacity necessary to meet peak water demands 100% of the time. That calculation is based on Equation 1:

$$Q_p = (18.9 \times ET_p \times A \times t_i) / (E_i \times t_f) \qquad \textbf{Equation 1}$$

where:

Q_p = irrigation system flow rate, gpm
18.9 = units conversion constant
ET_p = peak water use rate, in/day
A = irrigated area, acres
t_i = irrigation interval, days
E_i = irrigation efficiency, decimal
t_f = irrigation time per event, days

Table 1. Minimum net system capacities to meet crop water demands 90% of the time for the major soil texture classifications and regions in Nebraska[1].

Soil Texture	Available Water Capacity (in/ft)	Region 1	Region 2
Loam, silt loam or very fine sandy loam	2.5	3.85	4.62
Sandy clay loam, loam	2.0	4.13	4.89
Silty clay loam, clay loam, fine sandy loam	2.0	4.24	5.07
Silty clay	1.6	4.36	5.13
Clay, sandy loam	1.4	4.48	5.19
Loamy sand	1.1	4.83	5.42
Fine sand	1.0	4.95	5.89
Peak ET		**5.65**	**6.60**

1 Data taken from von Bernuth, et al. 1984 and NebGuide G89-932 *Minimum Center Pivot Design Capacities in Nebraska*.

The values in Table 1 need to be adjusted for system down time and the water application efficiency of the center pivot. Down time can result for regularly scheduled maintenance, load control, system failure, or labor restrictions (manager takes Sunday's off). The down time experienced due to system failure depends on the current age of the components and how frequently the system is checked. Operators with a shutdown phone alarm will have immediate knowledge when the system shuts down while others may not be aware that the system is down for 8 hours or more. For each 12 hours of down time, the system flow rate must be increased by 8%.

Once the net capacity has been adjusted for down time, the gross flow rate required is determined by dividing by the estimated water application efficiency. The system water application efficiency depends on the sprinkler package (sprinkler type and position). Some potential water application efficiencies are provided in Table 2. They are listed as potential efficiencies since they assume that runoff does not occur. Thus, the field conditions will determine what the actual efficiency will be. Selecting the package with the most efficient potential water application efficiency is a place to start, and the use of the CPNOZZLE computer program will help identify choices that should be avoided due to runoff concerns.

Table 2. Estimated water application efficiencies for different sprinkler packages.

Sprinkler/ Nozzle Type	Potential Application Efficiency
High Pressure Impact	80-85
Low Pressure Impact	82-85
Low Pressure Spray (on top of pipeline)	85-88
Low Pressure Spray (truss rod height)	87-92
Low Pressure Spray (3-7ft off the ground)	90-95
Low Pressure Spray (LEPA bubble mode)	95-98

Field data collection

The Soil Survey provides one source of estimates for average water infiltration rates, field slopes and soil water holding capacities. Figure 1 shows a copy of a quarter section located in Pierce county. A planimeter was used to determine the surface area of each mapping unit and create a table like that shown in Table 3. Look up the soil intake family, average field slope, infiltration rate and the soil water holding capacity information on each mapping unit and record them in the table. Be sure to include areas where soil moving has taken place.

Begin your analysis by looking at the mapping units with substantial areas. Look for areas with steep slopes (say greater than 7%) and with low infiltration rates (say less than the 0.5 Intake Family). Another factor to look for is soil water holding capacity. If sufficient area is involved, the system may need to be managed according to those areas. You most likely won't select a system to meet soils that comprise less than 10% of the irrigated area. However, field areas with 25 to 50 acres cannot be ignored. Tabulating soil information in this manner will make it easier to make decisions.

When selecting a sprinkler package, take the number of acres in a specific intake family and slope range into account. In Table 3, the 0.3 intake family may not be an issue for sprinkler package selection. However, despite its 0-1% field slope the high water table problems might cause wheel track problems so an attempt should be made to keep the wheel tracks dry which begins to limit the sprinkler package options. Likewise, field areas with field slopes greater than 7% cover more than 40 acres so those areas should be considered carefully. Fortunately

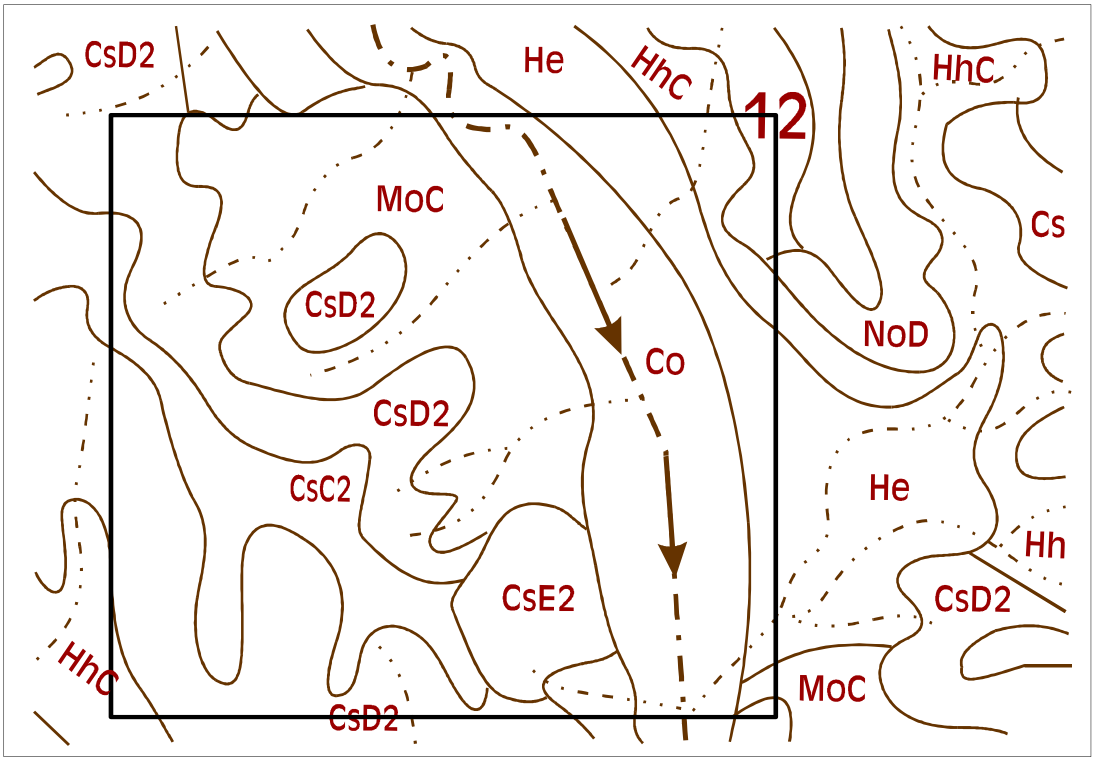

Figure 1. Copy of a soil survey map from Pierce County, NE

the areas with the greatest slope also have soils in the highest Intake Family category. One of the key areas to investigate is located in the middle of the field on the south border since slopes could be steep (CsD2& CsE2) and the steepest areas are close to the outside edge of the irrigated area where water application rates will be highest.

Many sprinkler packages are selected without a field site visit by the designer. Though soil mapping units give some indication of average field conditions, the data is seldom sufficiently accurate to allow a better decision. Therefore, a rough grid topography map (say 200' x 200') will determine if areas mapped as 7 to 11% slopes are closer to 7%.

Finally, the field visit can provide valuable information related to tillage and planting practices. A field farmed on the contour can safely use a sprinkler package that would otherwise generate runoff. Crop residues left on the soil surface absorb much of the impact energy of rainfall and irrigation, thus the soil infiltration rate would be more consistent throughout the season. Soil residues maintain surface storage to prevent runoff. Each of these factors may cause you to make a slightly different decision.

Uniform water application requires that the correct sprinklers be at each position along the pivot lateral, that the pumping plant deliver water at the appropriate pressure and flow rate and that the system is not operated under adverse atmospheric conditions. Another aspect of water application uniformity is the uniformity of infiltration. Water applied to the soil with the precision of a micrometer can be overshadowed by surface runoff problems. Thus, the goal must be to consider how the sprinkler package will match up with the field conditions.

Table 3. Summary of soil characteristics for each mapping unit in a quarter section of land in Pierce County, NE.[1]

Mapping Unit	Drainage Group	Soil Water Holding Capacity (in/ft)	Field Slope (%)	NRCS Intake Family	Land Area (Acres)
Co	Moderately Slow High Water Table	2.4	0-1	0.3	42.1
He	Well	2.4	0-1	1.0	23.9
CsC2	Well	2.4	1-7	1.0	11.0
HhC	Well	2.4	1-7	1.0	36.8
MoC	Well	2.3	1-7	0.5	5.3
CsD2	Well	2.4	7-11	1.0	28.0
NoD	Well	2.4	7-11	1.0	1.8
CsE2	Well	2.4	11-17	1.0	11.1

[1] Data taken from Pierce County Soil Survey

The zero runoff goal requires that the sprinkler package be carefully matched to the field conditions and to the operator's management scheme. Too often the desire to reduce pumping costs clouds over selecting the appropriate sprinkler package. An attempt should be made to select sprinkler packages that do not result in runoff. This requires that the water application pattern of the sprinkler be compared to the soil infiltration rate. If an accurate estimate of soil surface storage is available from field measurements, it should be included in the analysis.

Estimating Runoff

A computer program CPNOZZLE, based on research conducted across the country provides an opportunity to develop a rough estimate of how well suited the water application characteristics are to a field's soils and slopes. The program is also useful in predicting how much the design criteria should be changed to eliminate a potential runoff problem. For example, if the normal operation of applying 1.25 inches of water per revolution produces runoff, the program can be used to determine a water application depth that produces no runoff. If you are in the process of retrofitting the an old system with a new sprinkler package, the program can be used to select an appropriate system flow rate and sprinkler wetted radius.

The **CPNOZZLE** program has been converted to run in the Windows environment using the Visual Basic software. The new version incorporates the use of the Green and Ampt infiltration rate estimation procedure in addition to the NRCS Intake Family curves. The Green and Ampt procedure uses soil physical properties such as the percent sand, silt, and clay, saturated hydraulic conductivity, and porosity to estimate parameters needed to calculate infiltrated depth. Listed in Table 4 are the parameters for major soil texture categories and the estimated weighted potential runoff for a 1.3 inch application depth delivered by a 1320 foot system, with a flow rate of 1000 gpm and a sprinkler wetted diameter of 48 feet.

The program still includes the NRCS Intake Family method of estimating the weighted potential runoff. Using the same system components as used for the Green and Ampt equation, the NRCS Intake Family procedure was used to estimate the weighted potential runoff from sprinklers with wetted diameters of 30 and 48 feet. These results are presented in Table 5. Note that the 0.1 Intake Family is aligned with soils with high clay percentages, the 0.3 Intake Family with soils in the loam/silt loam categories, and the 1.0 with the sandy loam or loamy sand categories. It is clear that the use of the Green and Ampt equation allows a much broader range of soil textures to be evaluated.

Table 4. Green and Ampt parameters[1] and calculated weighted potential runoff.

Soil Type	Percent Sand	Percent Silt	Percent Clay	Saturated Hydraulic Conductivity (cm/hr)	Wetting Front Suction Head (cm)	Sat. Soil Water Content (cm^3/cm^3)	Initial Soil Water Content	Weighted Potential Runoff[2] (%)
Sa	90	3	7	11.0	3.0	0.42	0.08	O
LSa	85	6	9	8.0	7.0	0.40	0.11	3.8
SaL	66	21	13	6.0	12.0	0.41	0.15	4.6
L	43	39	18	2.7	18.0	0.43	0.20	26
SiL	20	64	16	0.8	35.0	0.49	0.24	45.8
SaCL	59	13	28	1.2	19.0	0.33	0.21	55.0
CL	32	34	34	0.9	21.0	0.39	0.30	55.9
SiCL	13	63	34	0.9	30.0	0.43	0.29	62.6
SaC	51	7	42	0.7	20.0	0.32	0.28	70.2
SiC	10	45	45	0.7	20.0	0.42	0.32	70.2
C	27	23	50	0.6	26.0	0.39	0.33	70.2

1 Values taken from the Handbook of Hydrology by Maidment, 1992.

2 Weight potential runoff for a center pivot with a system length=1320 feet; flow rate=1000 gpm; sprinkler wetted diameter=48 feet; application depth=1.3 inches.

Table 5. Weighted potential runoff estimated using the NRCS Intake Family procedure for systems with sprinkler package wetted diameters of 30 and 48 feet.

	Weighted Potential Runoff			
Intake Family Number	Wetted Diameter = 30		Wetted Diameter = 48	
	800 gpm	1000 gpm	800 gpm	1000 gpm
0.1	64	67	58	61
0.3	49	53	37	43
0.5	34	40	20	23
1.0	11	19	1	5
1.5	2	8	0	0
2.0	0	2	0	0
3.0	0	0	0	0

SUMMARY

Center pivot buyers have a vast array of sprinkler packages to choose from. Selecting the most appropriate sprinkler package for an individual field should be based upon collection of accurate field based information for soils, slopes, and cropping practices. The final selection should not be based on energy costs alone. Rather the system should first apply water uniformly without generating runoff. The "**CPNOZZLE**" computer program presents an opportunity to perform some 'what if?' sorts of analysis prior to making a sprinkler package purchase.

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CORN PRODUCTION AS RELATED TO SPRINKLER IRRIGATION CAPACITY

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INTRODUCTION

In arid regions, it has been a design philosophy that irrigation system capacity be sufficient to meet the peak evapotranspiration needs of the crop to be grown. This philosophy has been modified for areas having deep silt loam soils in the semi-arid US Central Great Plains to allow peak evapotranspiration needs to be met by a combination of irrigation, precipitation and stored soil water reserves. Corn is the major irrigated crop in the region and is very responsive to irrigation, both positively when sufficient and negatively when insufficient. This paper will discuss the nature of corn evapotranspiration rates and the effect of irrigation system capacity on corn production and economic profitability. Although the information presented here is based on information from Colby, Kansas (Thomas County in Northwest Kansas) for deep silt loam soils, the concepts have broader application to other areas in showing the importance of irrigation capacity for corn production.

CORN EVAPOTRANSPIRATION RATES

Corn evapotranspiration (ET) rates vary throughout the summer reaching peak values during the months of July and August in the Central Great Plains. Long term (1972-2003) July and August corn ET rates at the KSU Northwest Research Extension Center, Colby, Kansas have been calculated with a modified Penman equation (Lamm, et. al., 1987) to be 0.268 and 0.249 inches/day, respectively (Figure 1). However, it is not uncommon to observe short-term peak corn ET values in the 0.35 – 0.40 inches/day range. Occasionally, calculated peak corn ET rates may approach 0.5 inches/day in the Central Great Plains, but it remains a point of discussion whether the corn actually uses that much water on those extreme days or whether corn growth processes essentially shut down further water losses. Individual years are different and daily rates vary widely from the long term average corn ET rates (Figure 1). Corn ET rates for July and August of 2003 were 0.344 and 0.263 inches/day, respectively, representing an approximately 15% increase over the long-term average rates. Irrigation systems must supplement precipitation and soil water reserves to attempt matching average corn ET rates and also provide some level of design flexibility to attempt covering year-to-year variations in corn ET rates and precipitation.

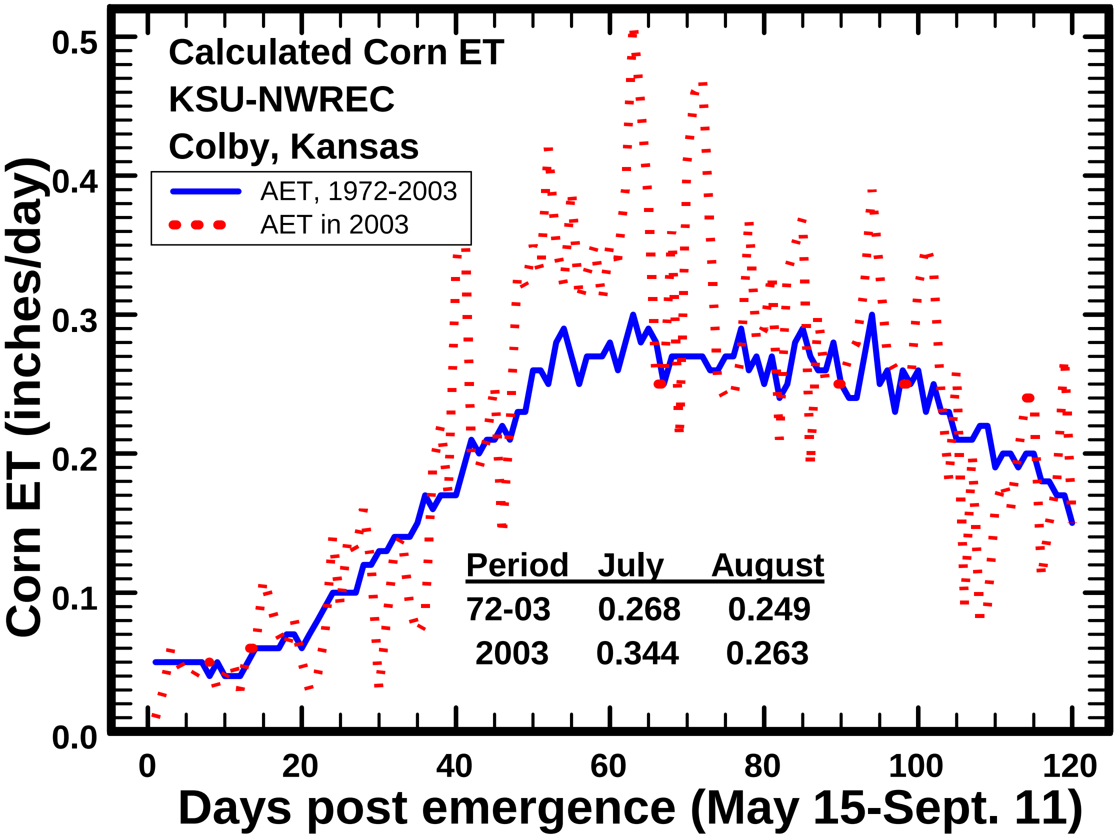

Figure 1. Long term corn evapotranspiration (ET) daily rates and ET rates for 2003 at the KSU Northwest Research-Extension Center, Colby Kansas. ET rates calculated using a modified Penman approach (Lamm et. al., 1987).

DESIGN IRRIGATION CAPACITIES

Simulation of corn irrigation schedules for Colby, Kansas

Irrigation schedules (water budgets) were simulated for the 1972-2003 period using climatic data from the KSU Northwest Research-Extension Center in Colby, Kansas. Reference evapotranspiration was calculated with a modified Penman equation (Lamm, et. al., 1987) and further modified with empirical crop coefficients for the location (Lamm, 2001) to give the actual corn ET. The irrigation season was limited to the 90 day period between June 5 and September 2 based on results from earlier simulations conducted by Lamm et.

al., (1994a). The 5-ft. soil profile was assumed to be at 85% of field capacity at corn emergence (May 15) in each year. Effective rainfall was allowed to be 88% of each event up to a maximum effective rainfall of 2.25 inches/event. The application efficiency, Ea, was initially set to 100% to calculate the simulated full net irrigation requirement, SNIR. Center pivot sprinkler irrigation events were scheduled if the calculated irrigation deficit exceeded 1 inch.

Using this procedure, the mean simulated net irrigation requirement (SNIR) for corn in the 32-year period was 14.8 inches (Table 1.). The maximum SNIR during the 31-year period was 21 inches in 1976, while the minimum was 5 inches in 1992. Monthly distributions of SNIR averaged 15.5, 38.8, 42.7, and 3% for June, July, August and September. However, it might be more appropriate to look at the SNIR in relation to probability. In this sense, SNIR values of 18 and 15 inches will not be exceeded in 80 and 50% of the years, respectively (Table 2). The minimum gross irrigation capacities (62-day July-August period) generated using the SNIR values are 0.277 and 0.225 inches/day (80% and 50% exceedance levels) for center pivot sprinklers operating at 85% Ea using the simulated monthly distributions (Table 2).

It should be noted that this simulation procedure shifts nearly all of the soil water depletion to the end of the growing season after the irrigation season has ended and that it would not allow for the total capture of major rainfall amounts (greater than 1 inch) during the 90 day season. *Thus, this procedure is markedly different from the procedure used in the USDA-NRCS-Kansas guidelines (USDA-NRCS-KS, 2000, 2002).* However, the additional inseason irrigation emphasis does follow the general philosophy expressed by Stone et. al., (1994), that concluded inseason irrigation is more efficient than offseason irrigation in corn production. It also follows the philosophy expressed by Lamm et. al., 1994b, that irrigation scheduling with the purpose of planned seasonal soil water depletion is not justified from a water conservation standpoint, because of yield reductions occurring when soil water was significantly depleted. Nevertheless, it can be a legitimate point of discussion that the procedure used in these simulations would overestimate full net irrigation requirements because of not allowing large rainfall events to be potentially stored in the soil profile. In simulations where the irrigation capacity is restricted to levels significantly less than full irrigation, any problem in irrigating at a 1-inch deficit becomes moot, since the deficit often increases well above 1 inch as the season progresses.

Table 1. Simulated net irrigation requirements for corn and monthly distributions of irrigation requirements for Colby, Kansas, 1972-2003.

Year	Simulated Net Irrigation Requirement, inches. (SNIR)	June % of SNIR	July % of SNIR	Aug. % of SNIR	Sept. % of SNIR
1972	9	11.1%	44.4%	44.4%	0.0%
1973	15	20.0%	20.0%	53.3%	6.7%
1974	16	12.5%	56.3%	31.3%	0.0%
1975	13	0.0%	46.2%	46.2%	7.7%
1976	21	19.0%	38.1%	38.1%	4.8%
1977	15	20.0%	40.0%	33.3%	6.7%
1978	18	11.1%	44.4%	44.4%	0.0%
1979	8	12.5%	12.5%	62.5%	12.5%
1980	18	16.7%	38.9%	44.4%	0.0%
1981	15	20.0%	40.0%	33.3%	6.7%
1982	16	12.5%	43.8%	43.8%	0.0%
1983	20	10.0%	40.0%	50.0%	0.0%
1984	18	11.1%	55.6%	33.3%	0.0%
1985	15	13.3%	33.3%	46.7%	6.7%
1986	16	12.5%	43.8%	43.8%	0.0%
1987	15	6.7%	40.0%	53.3%	0.0%
1988	18	22.2%	38.9%	38.9%	0.0%
1989	14	7.1%	42.9%	42.9%	7.1%
1990	16	25.0%	37.5%	37.5%	0.0%
1991	15	6.7%	40.0%	53.3%	0.0%
1992	5	20.0%	20.0%	60.0%	0.0%
1993	8	50.0%	12.5%	37.5%	0.0%
1994	16	18.8%	25.0%	50.0%	6.3%
1995	15	6.7%	33.3%	60.0%	0.0%
1996	7	0.0%	42.9%	42.9%	14.3%
1997	13	15.4%	61.5%	15.4%	7.7%
1998	11	36.4%	18.2%	45.5%	0.0%
1999	9	11.1%	55.6%	33.3%	0.0%
2000	19	21.1%	36.8%	42.1%	0.0%
2001	20	20.0%	40.0%	35.0%	5.0%
2002	19	21.1%	47.4%	31.6%	0.0%
2003	19	5.3%	52.6%	36.8%	5.3%
Mean	14.8	15.5%	38.8%	42.7%	3.0%
StDev	4.1	9.8%	12.2%	9.9%	4.1%
Min	5.0	0.0%	12.5%	15.4%	0.0%
Max	21.0	50.0%	61.5%	62.5%	14.3%

Table 2. Simulated net irrigation requirements (SNIR) of corn not exceeded in 80 and 50% of the years 1972-2003, associated monthly distributions and minimum irrigation capacities to meet July-August needs, Colby, KS.

Criteria	***SNIR***	***June SNIR***	***July SNIR***	***Aug. SNIR***	***Sept. SNIR***
SNIR value not exceeded in 80% of years	18 in.	15.8% 2.8 in.	43.3% 7.9 in.	39.5% 7.1 in.	1.5% 0.3 in
July-August capacity	0.240 inches/day				
Min. Gross capacity at 85% Ea	0.283 inches/day				
Min. Gross capacity at 90% Ea	0.267 inches/day				
Criteria	***SNIR***	***June SNIR***	***July SNIR***	***Aug. SNIR***	***Sept. SNIR***
SNIR value not exceeded in 50% of years	14.8 in.	15.1% 2.3 in.	40.3% 6.0 in.	42.5% 6.4 in.	2.2% 0.3 in
July-August capacity	0.200 inches/day				
Min. Gross capacity at 85% Ea	0.235 inches/day				
Min. Gross capacity at 90% Ea	0.222 inches/day				

Equivalent irrigation capacities are shown in Table 3.

Table 3. Some common equivalent irrigation capacities.

Irrigation capacity, inches/day	*Irrigation capacity, gpm/125 acres*	*Irrigation capacity, gpm/acre*	*Irrigation capacity, days to apply 1 in.*
0.333	786	6.29	3
0.250	589	4.71	4
0.200	471	3.77	5
0.167	393	3.14	6
0.143	337	2.69	7
0.125	295	2.36	8
0.111	262	2.10	9
0.100	236	1.89	10

SIMULATION OF CORN YIELDS AND ECONOMIC RETURNS AS AFFECTED BY IRRIGATION CAPACITY

Model description

The irrigation scheduling model was coupled with a corn yield model to calculate corn grain yields and economic returns as affected by irrigation capacity. In this case, the irrigation level is no longer full irrigation but was allowed to have various capacities (1 inch every 4, 5, 6, 8 or 10 days). Irrigation was scheduled according to climatic needs, but was limited to these capacities.

Irrigated corn yields for the various irrigation capacities were simulated for the same 32 year period (1972-2003) using the irrigation schedules and a yield production function developed by Stone et al. (1995). In its simplest form, the model results in the following equation,

Yield = -184 + (16.85 ET)

with yield expressed in bushels/acre and ET in inches. Further application of the model reflects weighting factors for specific growth periods. These additional weighting factors are incorporated into the simulation to better estimate the effects of irrigation timing for the various system capacities. The weighting factors and their application to the model are discussed in detail by Stone et al. (1995).

Factors associated with the economic model are shown in Table 4.

Yield results from simulation

Although corn grain yield is generally linearly related with corn ET from the point of the yield threshold up to the point of maximum yield, the relationship of corn grain yield to irrigation capacity is a polynomial. This difference is because ET and precipitation vary between years and sometimes not all the given irrigation capacity is required to generate the corn yield. In essence, the asymptote of maximum yield in combination with varying ET and precipitation cause the curvilinear relationship. When the simulated results are simulated over a number of years the curve becomes quite smooth (Figure 2.). Using the yield model, the 32 years of irrigation schedules and assuming a 95% application efficiency (Ea), the average maximum yield is approximately 202 bu/acre for the 0.25 inches/day (589 gpm/125 acres or 4.71 gpm/acre) irrigation capacity.

The polynomial equations for yield at 95 and 85% application efficiencies are:

$$Y95 = 86 + 34\ Icap + 0.50\ Icap^2 - 0.529\ Icap^3 \quad (1)$$

$$Y85 = 82 + 33\ Icap - 0.21\ Icap^2 - 0.347\ Icap^3 \quad (2)$$

where Y95 and Y85 are yields in bu/acre at respective Ea values of 95 and 85% and Icap is the center pivot sprinkler flowrate in gpm/acre.

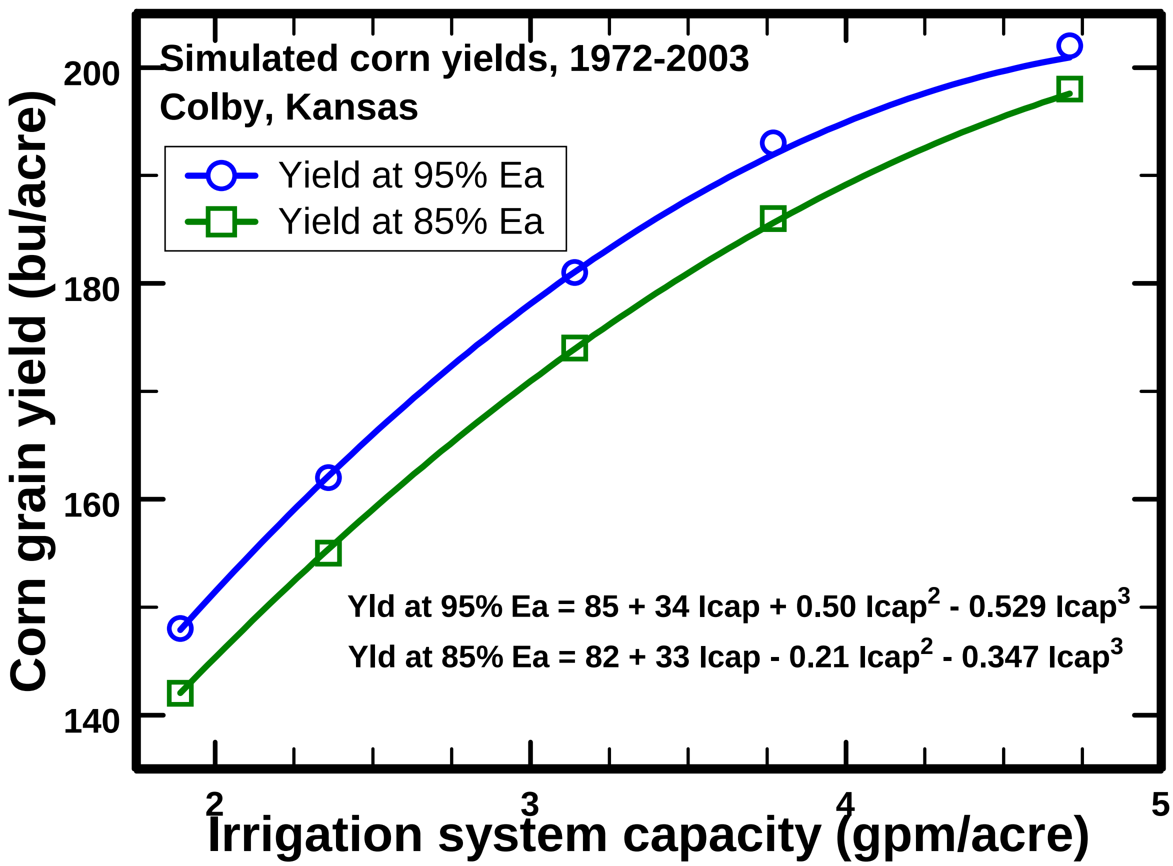

Figure 2. Simulated corn grain yields in relation to irrigation system capacity for the years 1972-2003, Colby, Kansas.

Economic results from simulation

Similarly, these yield results can be coupled with the economic model to generate the simulated net returns to land and management for the same 32 year period (Figure 3).

Table 4. Economic variables and assumptions used in the model.

Revenue streams and field characteristics	
Total field area, acres	160
Center pivot sprinkler area, acres	125
Dryland area, acres	35
Corn harvest price, $/bushel	$2.35
Government payments, $/acre spread over all acres	$27.54
Net returns from dryland area, $/acre	$32.50
Total irrigation system depreciation costs, $/irrigated acre	$93.01
Costs and factors that change with corn yield and irrigation levels	
Corn seed emergence, %	95%
Nitrogen fertilizer, lb/bushel of yield	1.10
Nitrogen fertilizer, $/lb	$0.13
Phosphorus fertilizer, lb/bushel of yield	0.43
Phosphorus fertilizer, $/lb	$0.22
Harvest base charge, $/acre	$18.10
Yield level for extra harvest charge, bu/acre	51
Rate for extra harvest charge, $/bu	$0.135
Hauling charge, $/bu	$0.115
Fuel and oil for pumping, $/inch	$3.34
Irrigation maintenance and repairs, $/inch	$0.33
Interest rate, %	8%
Other variable costs	
Corn seed, $/acre	$34.80
Herbicide, $/acre	$30.48
Insecticide, $/acre	$38.54
Crop consulting, $/acre	$6.50
Crop insurance, $/acre	$10.00
Drying cost, $/acre	$0.00
Miscellaneous costs, $/acre	$10.00
Non-harvest field operations, $/acre	$42.15
Other non-fieldwork labor, $/acre	$5.00
Irrigation labor, $/acre	$5.00
Interest rate, %	8%
1/2 yr. interest for these other variable costs, $/acre	$7.30
Total other variable costs	$189.77

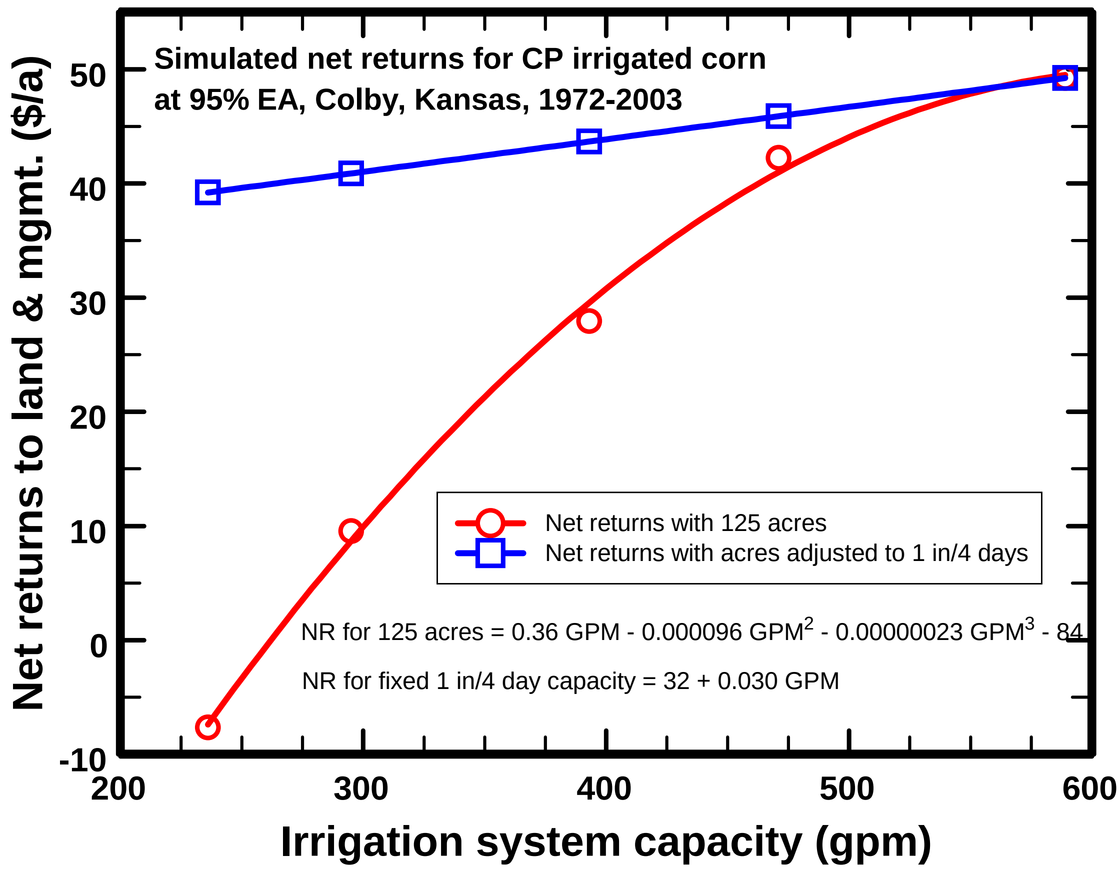

Figure 3. Simulated net returns to land and management for corn production in relation to irrigation system capacity for the years 1972-2003, Colby, Kansas.

Net returns maximized at approximately $50/acre at an irrigation capacity of 589 gpm/125 acres (0.25 inches/day or 4.71 gpm/acre) using the economic assumptions of the model. An alternative scenario where irrigation capacity is fixed at 0.25 inches/day (1 inch/4 days) and center pivot area is allowed to decrease is also shown in Figure 3. Net returns are highest when the gross irrigation capacity is held at the 0.25 inches/day level (1 in/4 days) and irrigated land area is allowed to decrease. It should be noted that fixed irrigation capacity scenarios such as this need to consider what the options are for the area coming out of corn production. In this model, the net returns for dryland production was used as estimated by dryland rent values. It would not be possible to substitute another summer irrigated crop on these acreage reductions because they would be competing for the same irrigation capacity. A winter-irrigated crop could be substituted providing there is sufficient water right available. *It also should be noted that these results are very different from simulations conducted in the mid 1990s where net returns were much higher. In those simulations (data not shown), net returns from the fixed 0.25 inch/day were less than for the full size*

125 acre center pivot sprinkler until irrigation system capacity was reduced below 330 gpm/125 acres. <u>This emphasizes how crucial economic assumptions and economic conditions are to the allocation of irrigation and land area.</u>

The equations for net returns to land and management for center pivot sprinkler irrigated corn are:

$$NR125 = 0.36\ GPM - 0.000096\ GPM^2 - 0.00000023\ GPM^3 - 84 \quad (3)$$

$$NRFixed = 32 + 0.0300\ GPM \quad (4)$$

where NR125 and NRFixed are the simulated net returns to land and management in $/acre for irrigated corn for a 125 acre center pivot sprinkler and for alternatively a fixed 0.25 inches/day irrigation capacity.

Yield and economic penalties for insufficient irrigation capacity

The penalties on yield and net returns for insufficient irrigation capacity at a 95% Ea can be calculated for various irrigation capacities (Table 5.)

Table 5. Penalties to corn grain yields and net returns to land and management for center pivot irrigated corn production at 95% Ea when irrigation capacity is below 0.25 inches/day (589 gpm/125 acres). Results are from simulations of irrigation scheduling and yield and economic modeling for the years 1972-2003, Colby, Kansas.

Various equivalent irrigation capacities				***Penalties to***	
Inches/day	GPM/acre	Days to apply 1 inch	GPM/125 acres	Yield, bu/a	Net returns to L & M, $/total 160 acre field
0.250	4.71	4	589	0	$0
0.200	3.77	5	471	9	$1,285
0.167	3.14	6	393	21	$3,194
0.143	2.69	7	337	31	$5,005
0.125	2.36	8	295	40	$6,580
0.111	2.10	9	262	48	$7,922
0.100	1.89	10	236	54	$9,064

Discussion of simulation models

The results of the simulations indicate both yields and net returns to land and management decrease when irrigation capacity was below 0.25 inches/day (589 gpm/125 acres). The argument is often heard that with today's high yielding corn hybrids it takes less water to produce corn. So, the argument continues, we can get by with less irrigation capacity. These two statements are misstatements. The actual water use (ET) of a fully irrigated corn crop really has not changed in the last 100 years. Total ET for corn is approximately 23 inches in this region. The correct statement is we can produce more corn grain for a given amount of water because yields have increased not because water demand is less. There is some evidence that modern corn hybrids can tolerate or better cope with water stress during pollination. However, once again this does not reduce total water needs. It just means more kernels are set on the ear, but they still need sufficient water to ensure grain fill. Insufficient capacities that may now with corn advancements allow adequate pollination still do not adequately supply the seasonal needs of the corn crop.

It should be noted that the yield model used in the simulations was published in 1995. It is possible that it should be further updated to reflect yield advancements. However, it is likely that yield improvements would just shift the curves upward in Figure 2. The effect on Figure 3 would be less clear. It is possible that yield advancements there might indeed shift the profitability of the fixed capacity (0.25 inches/day) line relative to the full 125 acre scenario (curve).

RECENT IRRIGATION CAPACITY STUDIES AT KSU-NWREC

A sprinkler irrigation capacity study was conducted at the KSU Northwest Research-Extension Center at Colby, Kansas during the period 1996-2001 to examine widely-spaced (10 ft) incanopy sprinklers at heights of 2, 4 and 7 ft. It should be noted that research has indicated the 10-ft. nozzle spacing is too wide for corn production (Yonts, et. al., 2003). Discussion of this study will be limited to the 2-ft. height. The weather conditions varied widely over the 6 year period. The years 1996-1999 can be characterized as wet years and the years 2000-2001 can be characterized as extremely dry years. Corn yield response to irrigation capacity varied greatly between the wet years and the dry years (Figure 4.) In wet years, there was better opportunity for good corn yields at lower irrigation capacities, but in dry years it was important to have irrigation capacities at 0.25 inches/day or greater.

Maximum corn yields in this study were indeed higher than those obtained in the modeling exercises in the previous section. This may lend more credibility to the discussion that the yield model needs to be updated to reflect recent yield advancement. However, yields are plateauing at the same general level of irrigation capacity, approximately 0.25 inches/day.

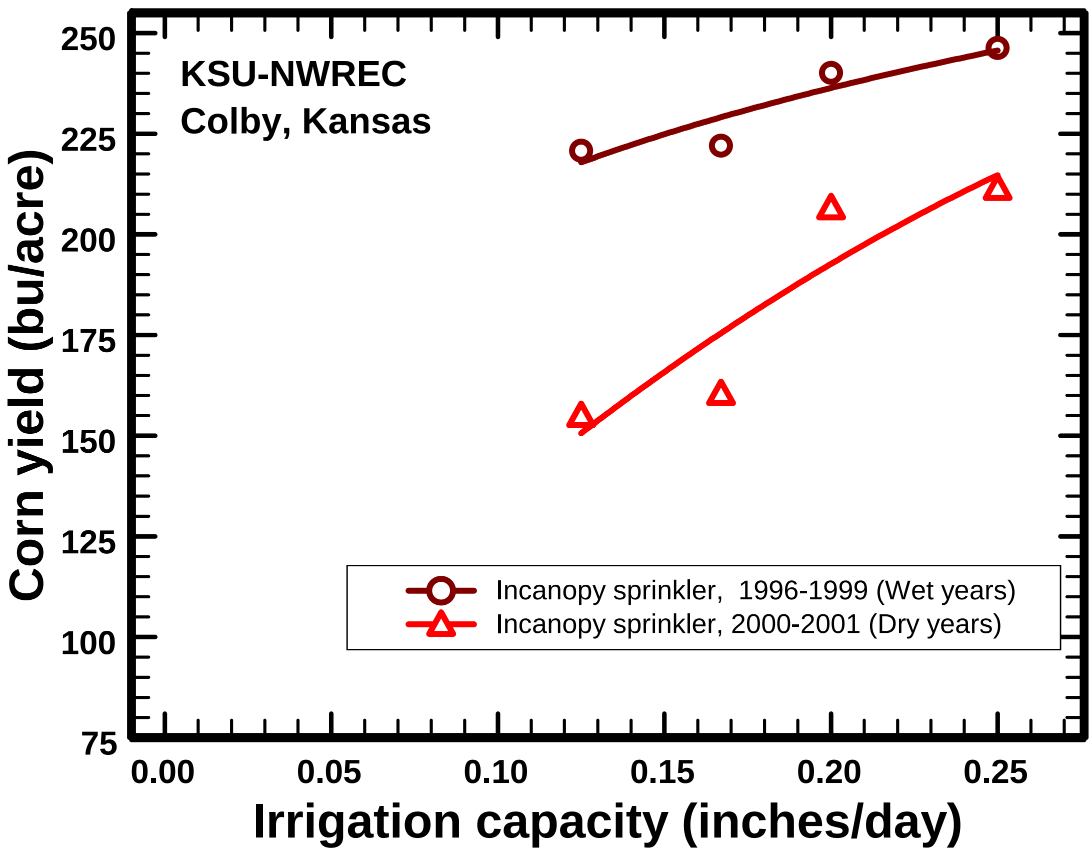

Figure 4. Corn grain yield as affected by irrigation capacity in wet years (1996-1999) and dry years (2000-2001) at the KSU Northwest Research-Extension Center, Colby, Kansas.

OPPORTUNITIES TO INCREASE DEFICIENT IRRIGATION CAPACITIES

There are many center pivot sprinkler systems in the region that this paper would suggest have deficient irrigation capacities. There are some practical ways irrigators might use to effectively increase irrigation capacities for corn production:

- Plant a portion of the field to a winter irrigated crop.
- Remove end guns or extra overhangs to reduce system irrigated area
- Clean well to see if irrigation capacity has declined due to encrustation
- Determine if pump in well is really appropriate for the center pivot design
- Replace, rework or repair worn pump

CONCLUDING STATEMENTS

The question often arises, *"What is the minimum irrigation capacity for irrigated corn?"* This is a very difficult question to answer because it greatly depends on the weather, your yield goal and the economic conditions necessary for profitability. Corn can be grown at very low irrigation capacities and there is even dryland corn in this region, but often the grain yields and economics suffer. Considerable evidence is presented in this paper that would suggest that it may be wise to design and operate center pivot sprinkler irrigation systems in the region with irrigation capacities in the range of 0.25 inches/day (589 gpm/125 acres). In wetter years, lower irrigation capacities can perform adequately, but not so in dryer years. It should be noted that the entire analysis in this paper is based on irrigation systems running 7 days a week, 24 hours a day during the typical 90 day irrigation season if the irrigation schedule (water budget) demands it. So, it should be recognized that system maintenance and unexpected repairs will reduce these irrigation capacities further.

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IRRIGATION MANAGEMENT STRATEGIES FOR CORN TO CONSERVE WATER

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INTRODUCTION

In the past, water has been plentiful and relatively inexpensive in most of Nebraska. Irrigation systems and irrigation scheduling equipment/procedures have made it challenging to put on just the right amount of water. Thus, many fields have been managed with the strategy that we will just put on a little extra water to make sure we have enough. In some fields, this has been a lot of extra water.

Today, water supplies are stretched very thin and pumping costs are much higher. In addition, more fields just simply do not have enough water to fully irrigate the crop. With this in mind, water conserving strategies are needed.

Research on conserving irrigation water in west central Nebraska has been underway since the 1920's. This research along with other work from around the world has led to the development of two water conserving strategies--Water Miser BMP and Deficit. Both conserve water by limiting irrigation water applied during the vegetative growth stage and relying upon precipitation and stored soil moisture. These two strategies can lower evapotranspiration (ET), which can potentially lower yields. In addition, the Deficit strategy lowers ET during the reproductive stages to keep water use down to the quantity available, which will defiantly lower yields. This strategy would only be used if water supplies were inadequate.

An irrigation management strategy, for purposes of this paper, is the plan or philosophy of how to decide the timing and amount of water to apply to the crop and should be developed before the crop is planted. Irrigation scheduling, on the other hand, is the in-season procedure used to carry out the management strategy.

The focus of this paper is on describing three irrigation management strategies for west central Nebraska. They are the traditional fully watered strategy and two that conserve water. Other water conserving practices that are not discussed here should be considered for irrigated corn production. Some practices to investigate include: good weed control, grow crops that need less water, and no-till or other tillage practices that minimize soil drying and leave the residue on the surface.

SOIL WATER TERMS

Before looking at the strategy in more detail, let's first review a few terms relating to soil water.

Soil holds water somewhat like a sponge. If one places the sponge in a container of water to completely fill the pore spaces with water and push out the air, the sponge would be saturated. This condition in the soil would also be called **saturation**.

The second term is **field capacity**. It describes the soil water content after the soil has been saturated and allowed to drain for about two days. This would be like lifting the sponge out of the container of water and allowing the free water to drain, but of course still leaving a lot of water in the sponge.

The third term is **permanent wilting point** and describes a soil water content that is so low that a plant growing in the soil would not be able to survive. This would be like wringing out all of the water we could get from our sponge. The soil, just like this wrung out sponge, still has some water left in it. This water is referred to as **unavailable water** and can only be completely removed by air-drying in an oven or in the sun.

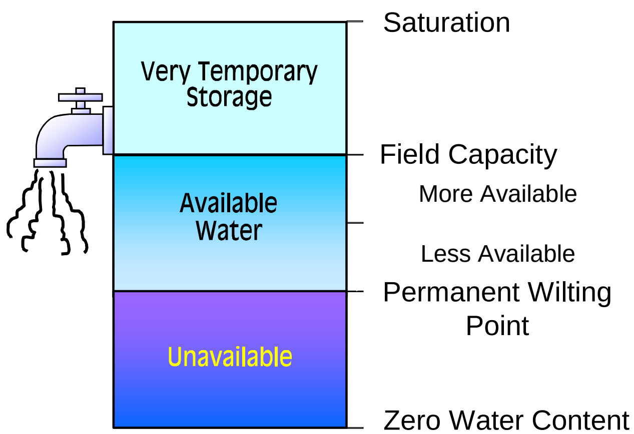

Figure 1. Relationship between different soil water terms. (Watts et al., 1998)

The water that is in the soil between field capacity and permanent wilting point is called **plant available water**. Typical soils can hold between 1(fine sands)-2.5 (loam) inches of plant available water per foot of soil. The quantity of water in the soil that is above field capacity can be used by the crop, but remember this water will drain through the soil in a couple of days. Figure 1 shows the relationship between these terms.

The crop root depth is another important concept to understand that relates to the amount of water in the soil that the crop has access to. At emergence, a corn crop can access water in about the top 6 inches of soil and the roots can grow to a depth of more than 6 feet by the beginning dent growth stage if soil and moisture conditions encourage deeper root growth. Well-watered corn may only root to a depth of three feet. For irrigation scheduling purposes, corn is assumed to have access to the water in the top 6 inches at emergence, three feet by silking and 4 feet by beginning dent. A graphic depiction of these changes over the season is shown in Figure 2. An example, also shown in Figure 2., of this would be if we had corn at the silking stage (three foot root zone) growing in a soil that is at field capacity and holds 2 inches of plant available water per foot. The plant available water in the root zone would be 6 inches.

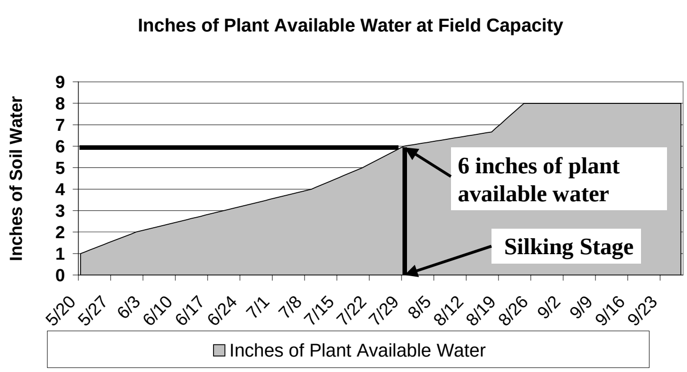

Figure 2. The gray shaded area shows the plant available soils water holding capacity in the root zone for a soil that holds 2 inches per foot of soil and how it changes during a typical growing season in Nebraska.

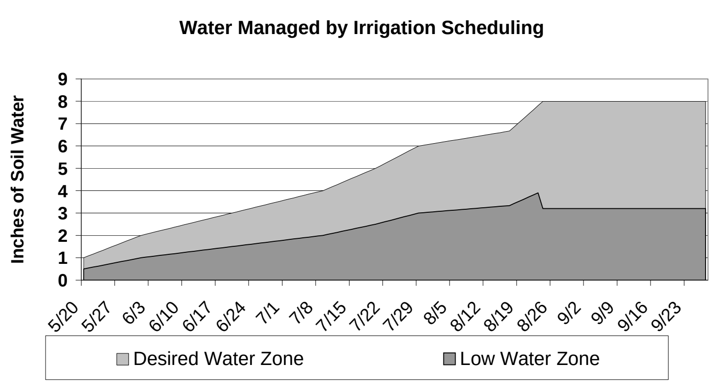

Figure 3. The gray shaded area shows the difference between the soils water holding capacity in the root zone and the maximum allowed soil moisture deficit.

FULLY WATERED

The Fully Watered management strategy is the traditional Best Management Practice (BMP) that has been around since the 1960's. It focuses on preventing moisture stress to the crop from planting to maturity by maintaining the plant available soil-water (in the active root zone) between field capacity and 50% depletion. Usually the soil in the root zone is kept one-half to one inch below field capacity to allow for rain

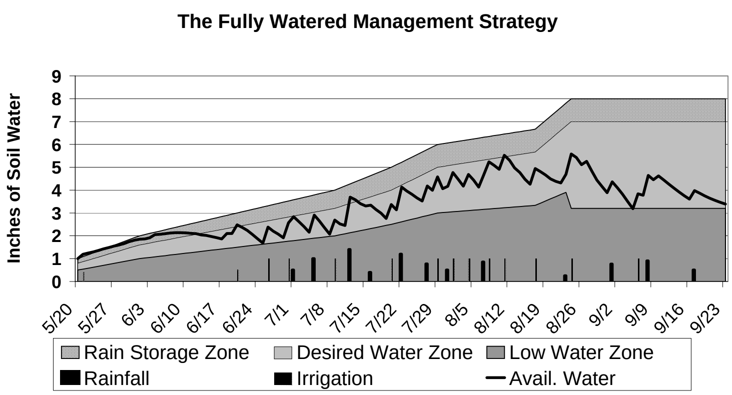

Figure 4. The gray shaded area shows desired water zone for the Fully Watered strategy. The black line showing available water should stay in the gray shaded area to indicate planned moisture level for the crop. Rain may push the line into the rain storage zone.

storage. After the dough stage, the soil is allowed to dry down to 60% depletion.

The strategy can be illustrated by taking the top 50 percent of the plant available water as shown in Figure 3. This zone can be called the desired water zone. The way to tell if the Fully Watered strategy was met is to plot the actual plant available water in the root zone each day as shown in Figure 4. If the black line stays within the desired water zone on the chart, the management objective was met. The vertical lines indicate rain and irrigation applications.

MANAGEMENT TIPS

The fully watered strategy is the easiest of the three strategies to manage. Management needs to focus on: 1. when to start irrigation for the season, 2. limiting irrigation to keeping the soil moisture below field capacity to prevent water from draining below the root zone and to provide space to store in-season rain, and 3. when to stop irrigating at the end of the season, so the crop can use enough water to dry the field down to the 60% depletion level before it matures.

WATER MISER BMP

The Water Miser BMP irrigation management strategy focuses on saving water during the less sensitive vegetative growth stages and fully watering during the critical reproductive growth stages. Irrigation is delayed until about two weeks before tassel emergence of the corn, unless soil-water depletion exceeds 70% (in the active root zone). Once the crop reaches the reproductive growth stage, the plant available soil-water is maintained in a range between field capacity and 50% depletion. Usually the soil in the root zone is kept one-half to one inch below field capacity to allow for rain storage. After the hard dough stage, the soil is allowed to dry down to 60% depletion.

The principle behind this strategy has been shown in several research studies over the years. In the 1970’s, at the former University of Nebraska’s Sandhills Lab, Gilley et al.(1980) used a line-source sprinkler irrigation system to study the effects of water-stress on corn at the vegetative, pollination and grain filling stages. They found no significant yield reduction when the crop was moderately stressed during the vegetative stage. However, significant yield reductions were found when the corn was stressed during the pollination period.

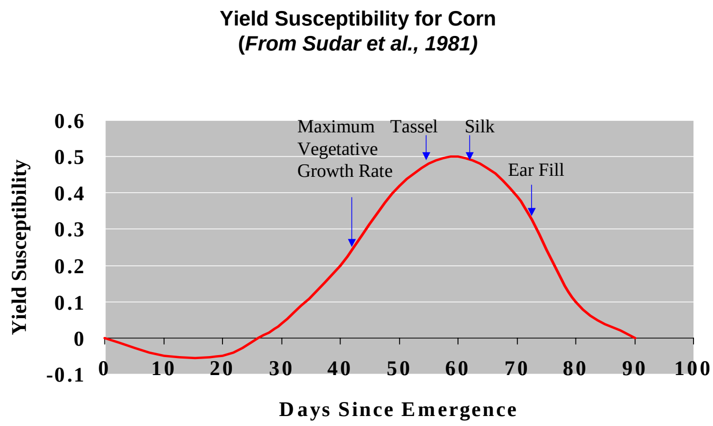

Figure 5. Yield susceptibility for corn.

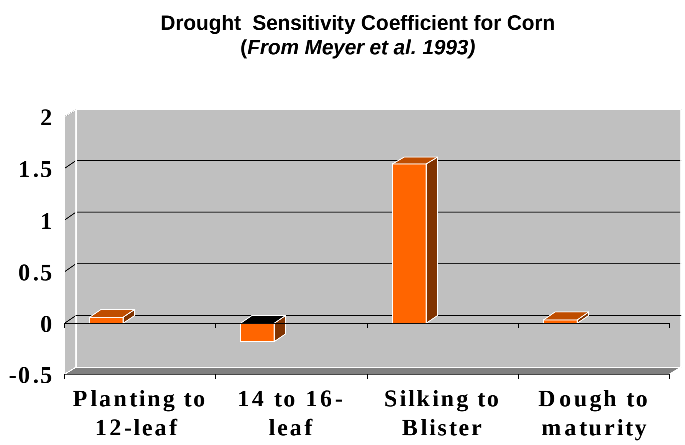

Figure 6. Drought sensitivity coefficient for corn.

The research found that a water savings of more then 4 inches or about 30 percent could be achieved without a significant yield reduction if the water was withheld only during the vegetative period and if the plots were then fully irrigated during the rest of the growing season. On-farm studies have shown that 1-3 inches of irrigation water can be saved as compared to the Fully Watered strategy. However, during springs and early summers with above normal precipitation, no water savings should be expected.

Starting in the early 1980's, this idea was confirmed by further research conducted at North Platte, both using a solid-set sprinkler irrigation system and under surface irrigation. (Schneekloth et al. 1991)

The long and short of it is that corn yields are not very sensitive to moisture stress before the tassel stage or after the dough stage, however, from the silking to the blister stages corn is extremely sensitive. All irrigation strategies should focus on minimizing moisture stress during this time. Figures 5 (From Sudar et al., 1981) and 6 (From Meyer et al. 1993) are examples of two curves that have been developed to show how moisture stress effects corn yields as the crop progress though the season.

The Water Miser BMP allows a 50 percent depletion of the plant available water during the critical growth stages. However, a strong case could be made for only allow a 40 percent depletion during this stage because corn is very susceptible to moisture stress during this time and water use is high, which would make any delay in irrigation cause a significant yield loss. Further support for the 40 percent number is based on the information presented in Figure 7 (modified from Doorenbos et al., 1979). It shows that on lower ET days (0.08-0.12 in/d) the soil can be very dry without having any moisture stress occurring. However, on high ET days (0.35-0.39 in/d) the field can only have 40 percent of the plant available water used or depleted without causing yield loss from moisture stress. Keeping the soil a little wetter during this time should not increase water use as long as the crop is allowed to use the extra water before maturing by cutting back on irrigation in the later parts of the growing season.

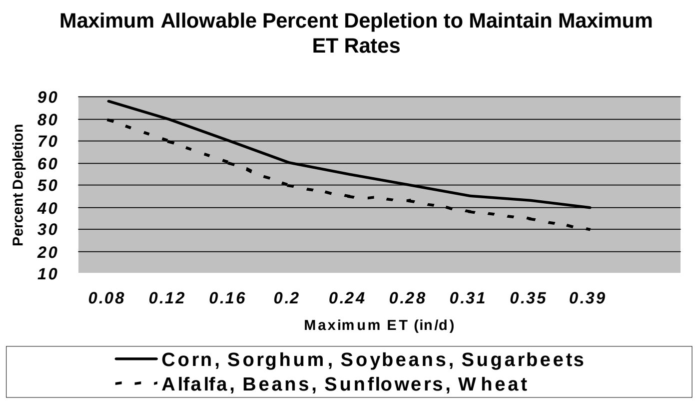

Figure 7. The maximum allowable percent depletion of the soil water that will still maintain maximum ET rates.

Another important point from Figure 7 is that in the early and late parts of the season when ET rates are lower, the soil needs to be very dry to create moisture stress.

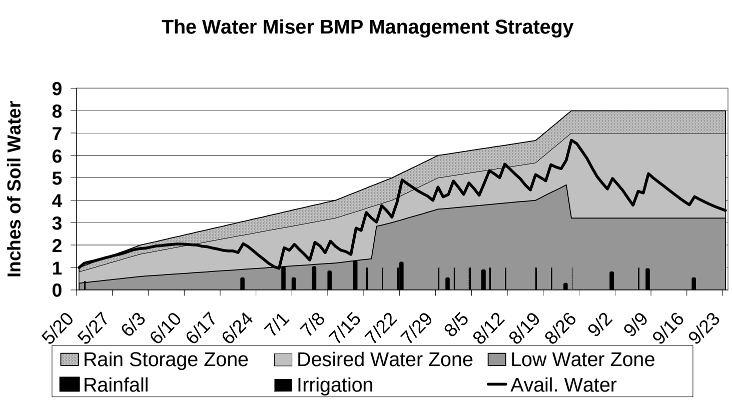

Figure 8. The gray shaded area shows desired water zone for the Water Miser BMP strategy. The black line showing available water should stay in the gray shaded area to indicate planned moisture level for the crop. Rain may push the line into the rain storage zone.

The Water Miser BMP strategy is illustrated in Figure 8. This irrigation scheduling method is sometimes called a crop growth stage irrigation strategy. Irrigation is limited during the vegetative growth stage while full irrigation management is practiced during the critical reproductive growth stages.

MANAGEMENT TIPS

Managing a field with the Water Miser BMP strategy requires good soil moisture readings and careful timing. The upper three feet of the soil profile should be at or near field capacity in the early part of the growing season so the developing roots can grow in moist soil, thus allowing the stress to come on more gradually. Most fields in west central Nebraska that were somewhat fully irrigated the previous year will meet this condition even with below normal precipitation. If the field is dry, be very careful not to over stress the corn.

The biggest hazard involved with this strategy is not getting the irrigation started soon enough to avoid excessive stress during the pollination period. If soil water reserves are depleted and something occurs to delay irrigation, severe problems could occur during the pollination period. Also, keep in mind that lower capacity systems (less then 5.5 gpm/ac) need to be started sooner, as compared to higher capacity systems (over 7 gpm/ac) which can wait to get more of this benefit, but still needs to be started soon enough to get caught up before the reproductive period starts. The above listed system capacities are net system capacities and would need to be increased by the water application efficiency of the irrigation system. (Kranz et al., 1989)

DEFICIT IRRIGATION

The deficit irrigation management strategy should only be used if the water supply is short, since it will result in reduced yields. This strategy focuses on correctly timing the application of a restricted quantity of water, both within the growing season as well as over a several year period. The intent is to stabilize yields between years by applying irrigations based on soil-water depletion. The idea is to keep the soil dry enough to significantly reduce ET, but keep it from getting so dry that it substantially lowers the yield potential. Less water will be applied during wetter years, while more will be applied through the drier years, with an average over the years equaling the available quantity of water. The management strategy is to delay the application of water until about 2-weeks before tassel emergence for corn, unless soil-water depletion exceeds 70%. Once the crop reaches the reproductive growth stage the plant available soil-water (in the active root zone) is maintained in a range between 30 and 60% depletion. It is allowed to dry down to 70% depletion after the

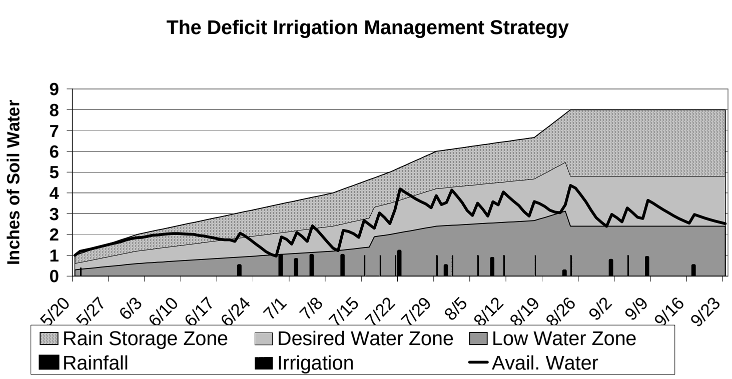

Figure 9. The gray shaded area shows desired water zone for the Deficit Irrigation strategy. The black line showing available water should stay in the gray shaded area to indicate planned moisture level for the crop. Rain may push the line into the rain storage zone.

hard dough stage. The idea is that these depletion numbers should be changed based on the amount of water the producer has to work with. More research is needed to determine guidelines for differing water use levels. Figure 9 graphically illustrates this strategy.

MANAGEMENT TIPS

The Deficit Irrigation strategy is the most challenging to manage. In fact it may be as much an art as it is science. The challenge is to keep the crop fairly dry to reduce the ET to the desired level, while preventing an extremely hot, dry few day period from significantly impacting the yield potential. Remember this strategy is intended to lower the plant water use to the amount of water available for the season, but as a consequence the yield will be lowered as well. Also, this strategy does not work with low capacity irrigation system. It only works if the restricted quantity of water can be put on the field quickly and at the right time. If the water supplies are very limited, irrigating less acres or growing a crop that requires less water may be a better option.

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Determining Crop Mixes For Limited Irrigation

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INTRODUCTION

Full irrigation is the amount needed to achieve maximum yield. However, when water supplies for irrigation are insufficient to meet the full evapotranspiration (ET) demand of a crop, limited irrigation management strategies will need to be implemented. The goal of these strategies is to manage the limited water to achieve the highest possible economic return. Restrictions on water supply are the primary reasons for using limited irrigation management. These restrictions may come in the form of mandated water allocations, from both ground water and surface water supplies, low yielding wells, and/or drought conditions which decrease available surface water supplies.

KEY MANAGEMENT STRATEGIES FOR DEALING WITH LIMITED IRRIGATION

The key management choices for dealing with insufficient irrigation supplies are as follows:

Cropping Management/Choices

- Reduce irrigated acreage and maintain the irrigation water applied
- Reduce amount of irrigation water applied to the whole field
- Rotate high water-requirement crops with those needing less water

Irrigation Management

- Delay irrigation until critical water requirement stages of the crop
- Manage the soil water reservoir to capture precipitation

Reducing irrigated acreage is one response to limited water supplies. When the irrigated area is reduced the amount of irrigation per acre more closely matches full irrigation requirements and it's corresponding per acre yield. Ideally, the land that reverts to dryland production should still produce some level of profitable returns. Another strategy may be to reduce the amount of irrigation per acre that is applied to the entire field. This would create the possibility for near normal crop yields if above normal precipitation occurred. In normal to below normal rainfall years, grain yields per acre would be less than those achieved with full irrigation. Rotating high water-requirement crops, such as corn, with crops needing less water would also be a possibility. Soybean, edible bean, winter wheat, and sunflower are the major crops with lower water requirements. Splitting fields between corn and one of these crops would reduce total water requirements for the field and distribute the water requirements across a longer portion of the growing season. For example, peak water demands for wheat are during May and June, while corn uses the most water during July and soybean water needs peak in August. Splitting the field into multiple crops allows producers with low-capacity wells to more completely meet the peak requirements of all crops.

Delaying irrigation until critical times is also a possible alternative if the volume of water is limited but well capacity is normal. Water availability during reproductive and grain filling growth stages is the most important for grain production. During vegetative growth some water stress can be tolerated without affecting grain yield and root development can be encouraged so that the crop can utilize deeper soil water. This period also typically coincides with the highest monthly rainfall amounts in the central plains. Field research from the West Central Research and Extension Center (WCREC) near North Platte has shown that corn can utilize water from deep in the soil profile when necessary. However, the irrigation system must be capable of keeping up with water demands during the reproductive growth stage of the crop if irrigation is delayed. Delayed irrigation is more feasible with center pivots than with furrow irrigation. In furrow irrigation, dry and cracked furrows do not convey water very well, especially during the first irrigation. A combination of furrow packing during the ridging operation, surge irrigation, and increased stream size may overcome some of the effects of late initiation of furrow irrigation.

An important management strategy under all limited irrigation situations is to capture and retain as much precipitation as possible. Crop residues on the soil surface intercept rainfall and snow, enhance infiltration, and reduce soil evaporation. Again, residue management is much easier with center pivot irrigation than furrow irrigation. Advancing water down a furrow may be more difficult with high residue levels. Ridge-till management along with furrow packing and surge irrigation may overcome some of these problems. Leaving room in the soil to store precipitation during the non-growing season enhances the possibility for capturing rainfall for the next growing season. Leaving room in the soil to store rainfall during the growing season may ensure more water availability during grain filling under limited water conditions.

It is very important to know the soil water status during the entire season. Limited irrigation management causes the irrigator to operate with more risk of crop water stress and grain yield reductions. Knowledge of soil water can help anticipate how severe the stress might be and help avoid disaster.

HOW CROPS RESPOND TO WATER

Yield vs Evapotranspiration

Crops respond to evapotranspiration (ET) in a linear relationship (Figure 1). For each inch of water that crop consumptively uses, a specific number of bushels is the resulting output. This relationship holds true unless excessive crop water stress occurs during the early reproductive growth stages. Where the response function intercepts the X-axis is the development and maintenance amount for each crop. The more drought tolerant crops (winter wheat) typically have lower development requirements than do high response crops (corn). Not all of the

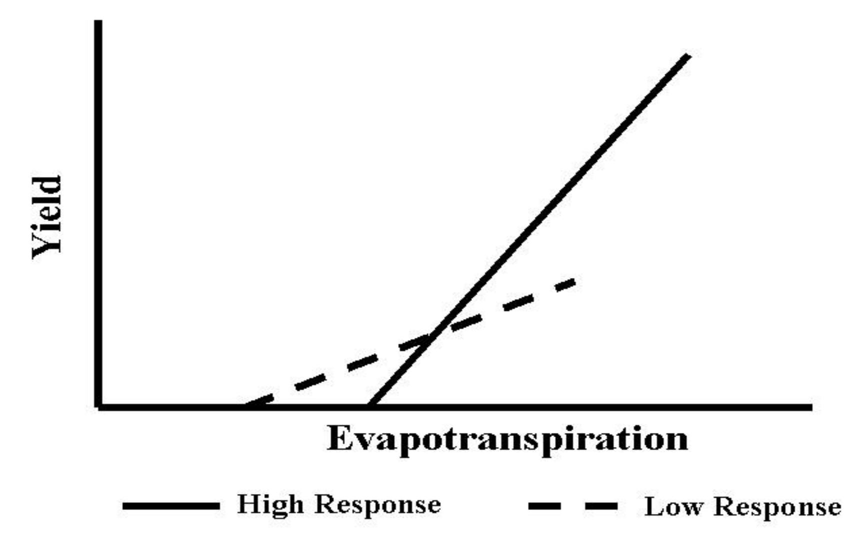

Figure 1. Generalized Yield vs Evapotranspiration response for high response crop and low response crop.

water that is applied to a crop through rainfall or irrigation is used by the crop. Losses such as runoff or leaching occur and are not useable for ET.

Yield vs Irrigation

Irrigation is applied to supplement rainfall when periods of ET are greater than available moisture. However, not all of the water applied by irrigation can be used for ET. Inefficiencies in applications by the system result in losses. As ET is maximized, more losses occur since the soil is nearer to field capacity and more prone to losses such as deep percolation (Figure 2). When producers are limited on the amount of water that they can apply by either allocations or low capacity wells, wise use of water is important for maximizing the return from water.

The yield increase of crops to water decreases as input levels approach maximum yield levels. In simple terms, as the amount of input and yield increases, the return from each unit is less than the previous unit. The yield increase from adding water from amount A to amount B is more than when increasing from amount B to C (figure 2). A producer must use this type of input to make informed decisions. The decision that must be made is irrigating at amount C with fewer acres or at amount B with more acres. The same question must be asked when comparing irrigation amount B to A. Developing a realistic yield vs irrigation production function is critical to managing limited water supplies. Producers must know what the yield increase from adding additional units of irrigation water to that crop is to determine the optimal amount of water to

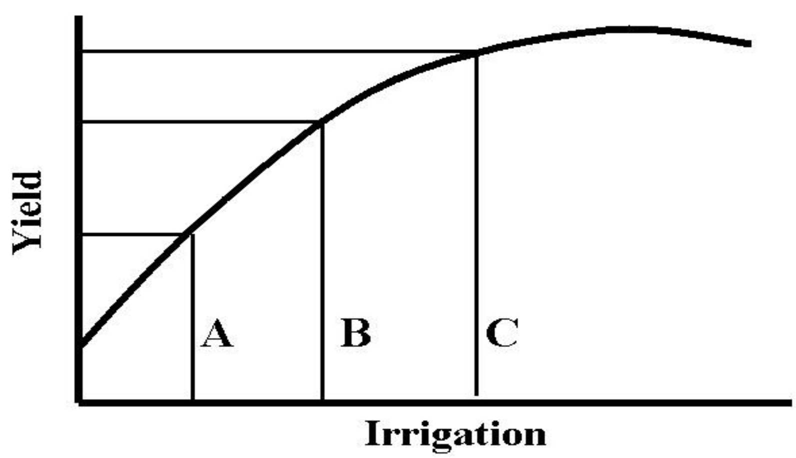

Figure 2. General Yield vs Irrigation Response.

apply to that crop. The trade off that must be evaluated is the potential return per acre with each scenario.

ALLOCATING LIMITED WATER SUPPLIES

When water is unlimited, the management strategy is to add inputs such as water until the return from that input is equal in value to the added crop production. However, when water is limited, the management strategy should look at maximum return from each unit of input of water. When producers are limited in the amount of water they can either pump or are allocated and that amount of water is less than what is needed for maximum economic production, producers must look at management options that will provide the greatest possible returns to the operation.

A Single Irrigated Crop and a Dryland Crop

The easiest production option would be to look at a single irrigated crop with the remainder of production in either a dryland crop or fallow. When the amount of water is less than adequate for maximum production, producers must ask themselves whether the yield increase from increasing the amount of irrigation to each acre will offset the reduction in irrigated acres and increased dryland production. Increasing the amount of irrigation to a crop reduces the total number of irrigated acres. An example of this would be if you have 10 inches per acre available for irrigation. One option is to irrigate all acres at 10 inches. A second option would be to irrigate 2/3 of the acres at 15 inches and have the remainder at dryland production. The question to answer is “Does the yield increase offset the reduction in irrigated acres and having 1/3 of the potential irrigated acres in dryland production?” With a 130 acre irrigation system, a change in strategy such as this would reduce the irrigated acres from 130 to 87 acres and increase the dryland acres from 0 to 43 acres. If corn is the primary irrigated crop, several crops could be used as dryland crops in this scenario including winter wheat, soybeans or sunflowers.

Two or More Irrigated Crops

The use of two or more irrigated crops in a rotation may increase the number of irrigated acres as compared to a single irrigated crop and a dryland crop. The philosophy of this strategy is to use a high water use and response crop such as corn and a low water use and response crop such as winter wheat, soybean, dry edible beans or sunflowers. This strategy uses the yield vs irrigation to its maximum advantage. The first amounts of irrigation that are applied are used efficiently resulting in a yield response similar to that of the yield vs ET response shown in Figure 2.

The strategy to find the most economical split of water and acres is similar to that of the one irrigated crop strategy. Producers must look at the yield increase of adding water to one crop and the effect upon the irrigated acres and yield of the other irrigated crop. The potential options become more numerous because now producers need to look at increasing the irrigation amount for one cropversus reducing the irrigation amount to the other crop or increasing the number of irrigated acres for the other crop to compensate for the additional water to that crop. An example of this would be if you again had a water supply of 10 inches per acre available and are irrigating two crops such as corn and winter wheat. If a producer were irrigating corn at 15 inches per acre and wheat at 5 inches per acre, the irrigated acres would be even at 65 acres per crop to match your water supply. If this producer decides to irrigate wheat at 6 inches per acre, a first option would be irrigating corn at 14 inches per acre to keep the irrigated acres of each crop similar. A second option to keep corn at the 15 inch per acre of applied water would be to reduce the irrigated acres of corn and increase the irrigated acres of wheat. Using the second option, the final acres would be irrigating 58 acres of corn and 72 acres of wheat. When using three potentially irrigated crops, the options become even more numerous.

Rotation Considerations

It is important to look at the short-term rotation aspects with multiple crops being grown. One of the more important aspects is can a crop be grown after itself. There are several crops that do not perform well when planted after the same crop. The typical problem associated with this is the build up of diseases and weeds in the system. Crops such as winter wheat, soybeans or sunflowers should not be grown immediately after itself so this must be a consideration in how many acres of each crop can be grown or whether to grow more than two irrigated crops to increase the options in the rotation.

Low Capacity Systems

When working with low capacity systems, irrigation management strategies are limited due to the systems ability to meet the ET of the crop during the critical and high ET time periods. Irrigators must start their systems before the soil moisture reaches typical management criteria with best management practices. This must be done since the system can not replace the used soil moisture and crop ET so the soil must be managed so that it is closer to field capacity in anticipation of the greater crop ET demand later in the season. The use of more than one irrigated crop decreases the amount of irrigated acres at any one point in time so the system can apply water closer to or in excess of the demand by the crop.

Another important consideration with more than one irrigated crop is to choose crops that do not have critical water timing needs. Crops such as winter wheat and corn fit together well in a system such as this since wheat uses water in May and early June while corn requires water during July and early August. Planting two crops that have similar water timing needs together is not advantageous since both crops would be irrigated at the same time.

CALCULATING CROP ENTERPRISE COST OF PRODUCTION

Calculating cost of production and enterprise net returns is accomplished with enterprise budgeting techniques. In basic terms, an enterprise budget is a listing of income generated and expenses incurred to produce that income. In this setting, the enterprise is the production of corn, winter wheat, soybean, dry edible bean or sunflower, whichever crop is used in the rotation.

Enterprise Income

The income section of the budget lists all the income generated per acre from production of the crop. This would also include any secondary income such as aftermath grazing or roughage sales. For planning purposes, it would be more efficient not to include government programs in this analysis, but recognize net income will be lower as a result. The price received for each commodity can be based on national crop loan rates as a minimum. A realistic expectation of price received will produce realistic results in the analysis.

Enterprise Expenses

The expense section of the enterprise budget lists all the expenses associated with production of the commodity. The expenses can be broken down by variable and fixed costs. Variable costs of production are those costs that change with the level of production. For instance, fertilizer cost increase as more fertilizer is applied to increase crop yield. Other variable costs include seed, chemical inputs, fuel and labor among others. In the absence of accurate machinery operating costs, custom rate estimates can be substituted in the enterprise budget. A breakdown of all expenses included in the custom rate will be required to avoid double counting of fixed or variable expenses.

Fixed costs of production are those costs that need to be covered regardless of whether production occurs or not. These include machinery replacement, land and machinery debt payments, lease payments and other overhead costs such as insurance, taxes and interest payments.

Enterprise Net Income

The net income section of the budget calculates the difference between estimated cost and returns. A positive difference (income – expenses = net income) indicates there is a positive return to the factors of production whereas a negative return would indicate the income generated is not sufficient to cover the factors of production.

Once net return per acre is calculated for each enterprise, then net return for the chosen mix of crops to be produced under a limited irrigation situation can be determined. Working through this process on paper will identify the best option for producing the greatest net returns given resource limitations.

SPREADSHEET

A spreadsheet is under development to help producers determine the optimum crop mix is under development. This tool will allow producers to input cost of production, yield vs irrigation production functions and water allotments. The spreadsheet will then give producers a starting point in helping them determine the optimum crop mix and water allocation for several management options. This spreadsheet should be available in March or April.

CONCLUSION

It is important for producers to consider management and cropping practice changes when faced with limited water availability. Management strategies for limited water generally favor introduction of low water use crops to supplement high response crops. Full irrigation management strategies favor high water use-high response crops. An economic analysis will help producers with decisions on what irrigated crops are to be grown and how much water will be applied to each crop. It is important to for producers to have accurate information relating to yield response of crops to irrigation in making these decisions.

SPRINKLER PACKAGE
WATER LOSS COMPARISONS

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INTRODUCTION

Sprinkler packages that are available and used in the Great Plains of the United States are widely varied from older impact heads to more modern spray heads or various rotator designs and have an assortment of application and/or placement modes. This paper will mainly address common sprinkler packages in use on center pivot sprinklers and linear (lateral move) machines. Sprinkler packages are designed and selected (purchased) for a variety of reasons. Often high irrigation uniformity and application efficiency are cited as priority goals in selecting a particular sprinkler package or sprinkler application method. In practice, many sprinkler packages can achieve the desired design and operational goals equally well at or near the same costs. Management, maintenance, and even installation factors can be as important as the selection of a package or application method.

This paper discusses the desired traits of various sprinkler packages and sprinkler application modes and discusses the anticipated water losses that might impact both irrigation uniformity and efficiency. In most cases "generic" descriptions are used rather than individual commercial names of sprinkler manufacturers. End-gun effects are not discussed or addressed to a significant degree.

TYPES OF SPRINKLER PACKAGES

Sprinkler Spacing

The first sprinklers used on center pivots were impact heads adopted from hand-move, portable sprinkler lines that had a large angle (~23 degrees from horizontal) of discharge to maximize the water jet trajectory. Many of these were single nozzle types, but some used double nozzles to improve the uniformity for the pattern. Early center pivot design sprinkler spacing was about 32 ft (9.8 m) with impact sprinklers while some later designs used a variable spacing (closer towards the outer end of the pivot). Two principal design modes were commonly used for these packages – 1) constant (uniform) spacing with variable nozzle diameters along the center pivot to vary the sprinkler discharge or 2) almost constant nozzle discharge and head selection with variable spacing (e.g., farther apart near the pivot point and closer together on the outer lengths of the pivot). It was common to mount larger sprinklers on the ends of the pivot (end guns) to cover more land area with a fixed pivot length. A third design mode – called the semiuniform spacing (Allen et al., 2000) is a combination of these two other design modes. The variable spacing mode is easier to apply to rotator-spinner-spray heads but complicates the center pivot pipeline design and the sprinkler package installation and maintenance. These spacing types are illustrated in Fig. 1.

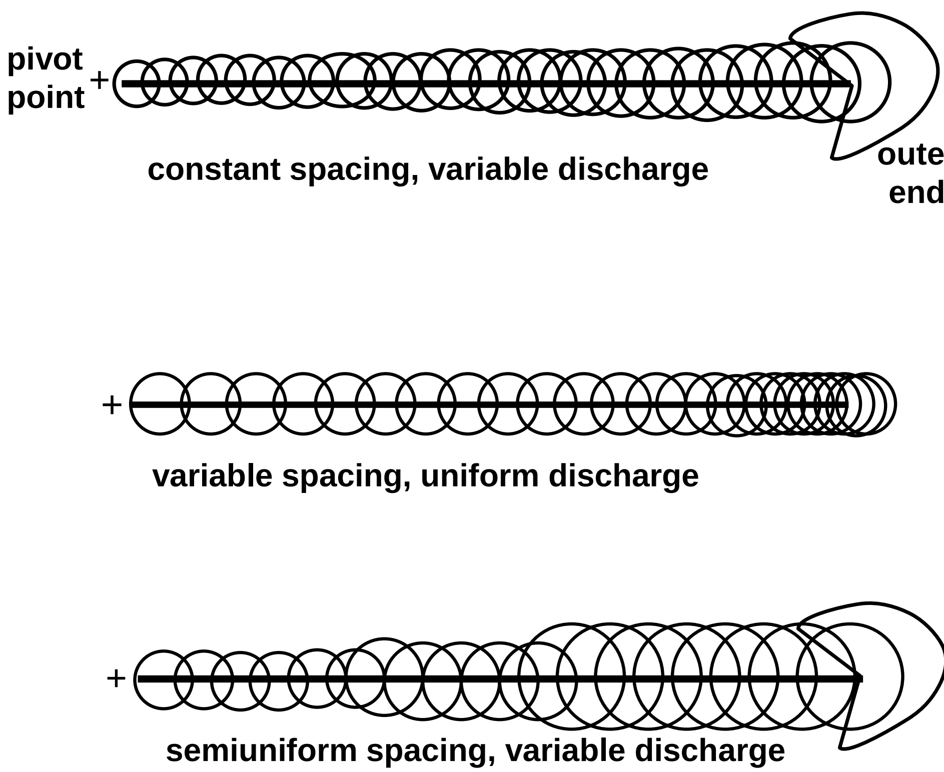

Figure 1. Diagram of typical sprinkler spacing and discharge designs. Modified and adopted from Allen et al. (2000).

The constant outlet spacing is quite common, particularly for closely spaced systems (~5 ft or 1.5 m) used with LEPA (low energy, precision application), LESA (low elevation, spray application), or LPIC (low pressure, in-canopy) methods of application. The sprinkler outlet spacing for non LEPA/LESA type systems with the constant spacing are often spaced up to 10 ft (3 m) apart. This spacing type is still used for pipeline mounted low angle impact sprinklers or spray heads on drops (typically mounted just below the truss rods). One concern with this spacing design can be the larger sprinkler discharge rate at the outer end requiring large nozzles with larger droplets. It can result in the requirement for higher operating pressures in some cases. These two factors — larger nozzles and higher operating pressures — can cause infiltration problems due to soil crusting and/or runoff difficulties from the high instantaneous application rates.

When LEPA and LESA are not used, the semiuniform spacing can rather conveniently be used with a 10 ft (3 m) outlet spacing uniformly along the pivot pipeline. Allen et al. (2000) suggested that the first third of the pivot length might use a 40 ft (12 m) sprinkler spacing, the middle third might use a 20 ft (6 m) sprinkler spacing, and the outer third might use a 10 ft (3 m) sprinkler spacing with the unused outlets plugged. This concept would also work with a 5 ft (1.5 m) outlet sprinkler spacing along the pipeline that might offer conversion options to LEPA, LESA, or LPIC application methods. This semiuniform spacing mode avoids many of the problems with larger nozzles.

The application uniformity will depend on many factors of the design and several operational factors (e.g., wind speed, pivot alignment and the wind direction, topography (tilt of the sprinkler axis in relation to the ground slope), effect on pressure at the outlet, etc., soil type, etc.) The main sprinkler factors affecting uniformity are the sprinkler spacing and the parameters associated with the sprinkler device type. These include its diameter of throw, application pattern type, operating pressure, nozzle and spray plate design, the elevation of the application device above the ground, and any crop canopy interference.

Sprinkler Types

Center pivot sprinklers can be classified generally into two broad types –impact sprinklers and spray heads. Within the impact type, nozzle angles can vary from the older type heads with higher trajectory angles (~23 degrees) to lower angle impact sprinklers (~6-15 degrees) that are typically mounted on top of the center pivot pipeline. Impact sprinklers are usually constructed using brass or plastic materials. They operate with a spring and heavy jet deflector arm with each arm return (from the spring) imparting a momentum to rotate the nozzle jet slightly. It may take up to 100 or more deflector arm returns to cause the impact sprinkler head to make a full rotation. The rotation speed depends on several design factors of the deflector arm; its mass and the bearing in which the sprinkler rotates. Nozzles can be simple “straight bore” types (that operate according to basic orifice principles where discharge depends on the nozzle diameter and the operating pressure) or can be of various design types that provide flow controls by compensating for alterations in the nozzle discharge –pressure relationship to provide a more constant discharge independent of the operating pressure. The operating pressure of most impact sprinklers is typically in the range of 25 to 40 psi (170 to 280 kPa), but the operating pressure is higher for larger sized nozzles. Impact sprinklers typically have a 3/4 in. NPT male end (18 mm), but some larger nozzles may require a 1 in. NPT (25 mm) size to reduce pressure losses across the pipeline mounting coupling.

Impact sprinklers have an advantage over lower pressure devices because they typically have a large radius of “throw”, thereby having a larger wetted area and smaller instantaneous application rate (equivalent to the “precipitation” intensity) that can more adequately match the soil infiltration rate with fewer runoff and erosion difficulties. Because they must rely on the hydrodynamics of the water jet and its breakup for the irrigation application and transport mechanism, they are affected to a greater degree by winds and subject to greater pattern distortions because of their higher application elevation above the ground or crop. Also, they typically have a higher pumping cost due to their greater operating pressure.

Spray heads are a much more diverse classification of application of devices. They can range from simple nozzles and deflector plates to more sophisticated designs involving moving plates that slowly rotate or types with spinning plates to designs that use an oscillating plate with various droplet discharge angles and trajectories. The rotator types are similar to small, low angle impacts sprinklers, except the sprinkler rotation is controlled by the nozzle jet with a hydraulic “motor.” Most spray heads have a near 360 degree coverage and can have deflector plates designed with differing groove sizes to affect the spray streams (deeper grooves with fewer jets to have larger diameter streams for windy applications, shallower grooves with more streams for smaller droplets, or flat to have a greater droplet diameter range), and they can have streams that are discharged almost horizontal (flat), upward (concave) or downward (convex) with downward orientated spray heads. They can be designed with plates that direct water streams upward at various angles for chemigation of tall or short crops. Spray heads can have partial coverage (i.e., not a complete 360 degree pattern), which are often used near towers to minimize track wetting. Spray heads can be mounted upward on the center pivot pipeline itself. On some linear (lateral move) machines, truss lateral manifolds with three to five spray heads may extend the wetting pattern to achieve a lower instantaneous application rate. Typically, spray heads are mounted on “drops” from “goose-neck” fittings that make a 180-degree bend from the top of the center pivot mainline. Wider “goose-necks” may be used to allow precise matching of LEPA or LESA drops to the furrows. These drops are basically constructed from flexible hoses. For longer drops (LEPA, LESA, or LPIC), the drop hose will typically have a weight (1-2 lb or 1/2 to 1 kg) to minimize swaying from the wind and assist in maneuvering through the plant canopy . Usually, the “goose-necks” and drops are installed on alternating sides of the center pivot pipeline. Figure 2 illustrates a typical LESA system with its drops.

Spray heads typically operate at pressures from 10 to 30 psi (70 to 200 kPa), but LEPA or LESA systems can operate at pressures as low as 6 psi (40 kPa). Lower pressure systems or ones with significant elevation changes are usually equipped with pressure regulators to achieve higher uniformities. Spray heads

Figure 2. Typical example of a LESA system with spray heads on drops spaced 5 ft (1.5 m) apart).

are often constructed from plastic, and the various parts are color-coded (varies by manufacturer). Allen et al. (2000) describes many of the common types of spray heads from several manufacturers and their characteristics. Table 1 provides a summary of some of the typical sprinkler heads used on center pivots. The list of advantages and disadvantages is intended solely as a guide, and individual situations may have unique situations not characterized here. Readers are encouraged to seek local advice from technical advisors (e.g., irrigation dealers, irrigation extension specialists, consultants, county extension agents, USDA-NRCS specialists, etc.) before making any sprinkler design selection or changes. Figure 3 illustrates the relative application rates under various sprinkler types after (King and Kincaid (1997). The values in Fig. 3 are conceptual. The peak application rate linearly increases along the center pivot radius and is maximum at the outer end. The X-axis presented as a distance scale in Fig. 3 can be converted to a time scale based on the speed of the center pivot at that

Table 1. Characteristics of common center pivot sprinkle types.

Sprinkler Type	Pressure Range psi (kPa)	Typical Height ft (m)	Advantages	Disadvantages
Impact, high angle	25-50 (170-300)	6-15 (1.8-4.5)	Low application rate.	High energy requirement. Exposure to wind effects.
Impact, low angle	25-35 (170-250)	6-15 (1.8-4.5)	Low application rate.	High energy requirement. Still impacted by winds.
360°Spray head, Rotator, Spinner; high location	10-30 (70-200)	6-15 (1.8-4.5)	Lower energy requirement. Closer spacing.	High application rate. Only over canopy chemigation.
360°Spray head, low location LESA or LPIC	10-30 (70-200)	1-6 (0.3-1.8)	Lower energy requirement. Less wind effect. Close spacing. Some have LEPA drag hose adapters. Under canopy chemigation.	High application rate.
Low Drift and Multiplate Spray Heads	10-30 (70-200)	Varied Pipeline Truss Level. LPIC	Lower energy requirement. Lower drift and wind effects. Many configurations. Some have LEPA drag hose adapters and chemigation plates.	High application rate.
Rotator	15-50 (100-300)	Varied. Pipeline. Truss Level. LPIC	Larger wetted diameter, lower application rate. Good resistance to wind effects.	Can have higher energy requirement. Limited in-canopy chemigation applications.

Table 1 (Continued). Characteristics of common center pivot sprinkle types.

Sprinkler Type	Pressure Range psi (kPa)	Typical Height ft (m)	Advantages	Disadvantages
Spinners	10-20 (70-150)	Varied. See Rotators	Low energy requirement. Gentler droplet applications.	Limited in-canopy chemigation applications.
Oscillating/Rotating Spray Plates	10-20 (70-150)	3-6 (0.9-1.8)	Low energy requirement. Low misting from small droplets. Low application rate and gentler applications.	Limited in-canopy chemigation applications.
LEPA Bubble	6-10 (40-70)	1-3 (0.3-0.9)	Low energy requirement. Usually, alternate furrow applications and less evaporation. Multi purpose (convertible from spray to bubble to drag sock). Excellent in-canopy chemigation options.	Extremely high application rate. Requires furrow dikes or surface storage (~1-2 in., 15-50 mm of water volume).
LEPA Drag Sock	6-10 (40-70)	0 (0)	See LEPA Bubble. Less erosion of furrow dikes.	See LEPA Bubble.

point (e.g., divide the distance wetted by the speed (ft/hr) to achieve the time course of the application as the pivot passes a particular point). The area under each of the transformed curves will be a constant along the center pivot's length representing the application amount (in. or mm).

Sprinkler Application Modes

The application modes for center pivot "sprinkler packages" can be described as either 1) overhead or over-canopy methods or 2) near-canopy or in-canopy methods. The sprinkler type selected is influenced by the mode of the desired application method. The mode and sprinkler type may influence the required spacing. Thus, these are not independent alternatives. Hence, they have been called "sprinkler packages" because all aspects of design, installation, maintenance, and management affect the "package" performance.

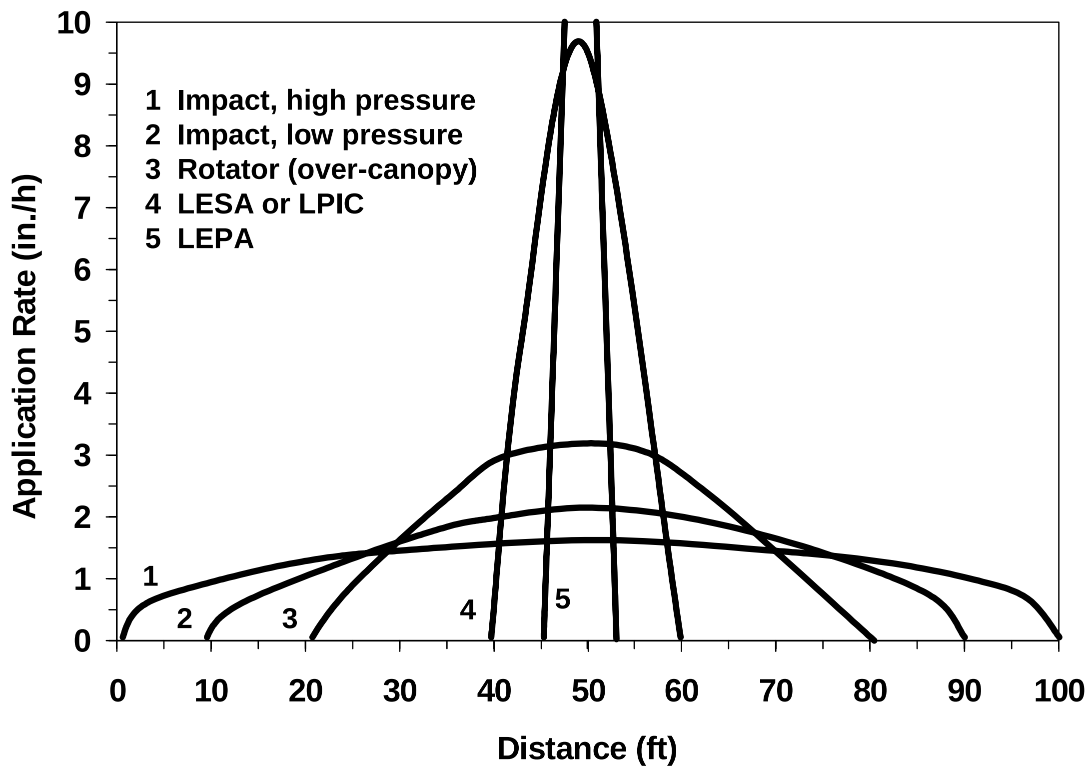

Figure 3. Illustration of the relative application rates for various sprinkler types under a center pivot. Modified and adopted from King and Kincaid (1997). The LEPA application rate is difficult to show because it is essentially a "point" discharge, and its peak was illustrated to exceed the rate range of this graph.

The overhead or over-canopy methods are those application types mounted on the center pivot pipeline itself or those mounted on drops that are typically just below the truss rod elevation above ground. Of course these descriptions are still arbitrary depending on the system height and the crop height. One of the main decision factors for this mode is whether only overhead or over-canopy chemigation is desired or if no chemigation option is desired. Impact sprinklers, spray heads, and rotators are typically considered for this application mode. This mode and application method is well suited to rolling topography, low intake soil types, and crops tolerant of overhead wetting.

The near- canopy or in-canopy application methods are always mounted on drop tubes from the center pivot mainline. The main difference is whether the sprinkler devices are mounted near the ground (LEPA or LESA), within the crop canopy or the mature crop canopy (LPIC), or just above the maximum height of the crop. Of course, a LPIC system designed for a tall crop may not be a LPIC system in a shorter crop (e.g., a corn LPIC system will not be a LPIC system in cotton, peanut, or soybean crops; Fig. 4). For that reason, we (USDA-ARS Bushland) have preferred to use the name — LESA for a system with the spray heads

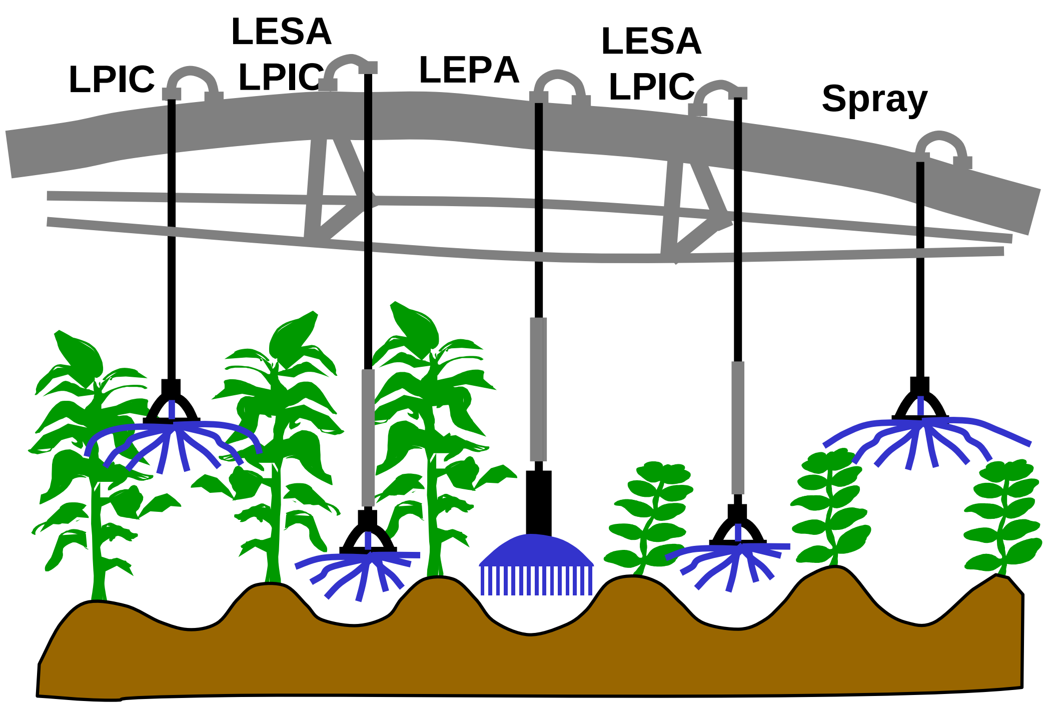

Figure 4. Illustration of the LEPA, LESA, LPIC, and spray application concepts in tall and short crops. The illustration has drops in each furrow to conserve space while actual systems typically use drops in alternate furrows either 60-in. or 80-in. (1.5-m or 2-m) apart depending on the crop row spacing.

mounted 1-2 ft (0.3-0.6 m) above the ground or MESA (mid elevation spray application) for a system with spray heads mounted 5-8 ft (1.5-2.4 m) above the ground. The name LEPA should only be used for a system with bubblers (e.g., an adjustable multi-purpose head) or drag socks mounted on a flexible hose. LEPA hoses can be attached with commercial adapters to many types of spray heads whether the spray heads are mounted low near the ground like LESA or at a higher elevation like a LPIC or MESA system. Although Lyle and Bordovsky (1981) originally used LEPA in every furrow, subsequent research (Lyle and Bordovsky, 1983) demonstrated the superiority for alternate furrow LEPA. The reasons aren't always evident, but they may result from the deeper irrigation penetration (twice the volume of water per unit wetted area compared with every furrow LEPA), possible improved crop rooting and deeper nutrient uptake, and less surface water evaporation (~30-40% of the soil is wetted). LEPA and LESA work best with either LEPA heads or 360° spray heads. These systems (LEPA or LESA) also have flexibility to chemigate either a tall crop (e.g., corn) or shorter crops (e.g., sorghum, soybean, wheat, cotton, or peanut). LPIC and MESA systems have the conversion potential to LEPA, but they don't have the under canopy chemigation potential of LEPA or LESA systems. LEPA and LESA systems are typically located in or above alternate furrows or between alternate rows if furrows are not used. LEPA requires a furrow with furrow dikes according to the concepts described by Lyle and Bordovsky (1981) while LESA can be effective without furrows in no-till or conservation till systems. This doesn't imply LEPA heads cannot be used without furrow dikes, but it shouldn't be described as "LEPA". LPIC or MESA systems are typically spaced for a desired uniformity and may not be bound by the row spacing. LPIC systems may require a narrower spacing to compensate for crop interference (Spurgeon et al., 1995).

Lyle and Bordovsky (1981) developed the LEPA concept as a "system" comprising irrigation combined with furrow diking (basin tillage). In fact, all advanced center pivot sprinkler application packages need to be incorporated into a complete agronomic package involving tillage, controlled traffic, residue management, fertility, harvesting, etc. (Fig. 5). Table 2 summarizes several of the typical center pivot "sprinkler packages" and their "system" components.

WATER LOSS COMPARISONS

The efficiency of an irrigation application depends on many factors. The water losses depend on the application technology and operation and include other agronomic cultural aspects. The interpretation and characterization of water loss estimates or measurements involves the conservation of mass applied to sprinkler irrigation as outlined by Kraus (1966). He presented the components as

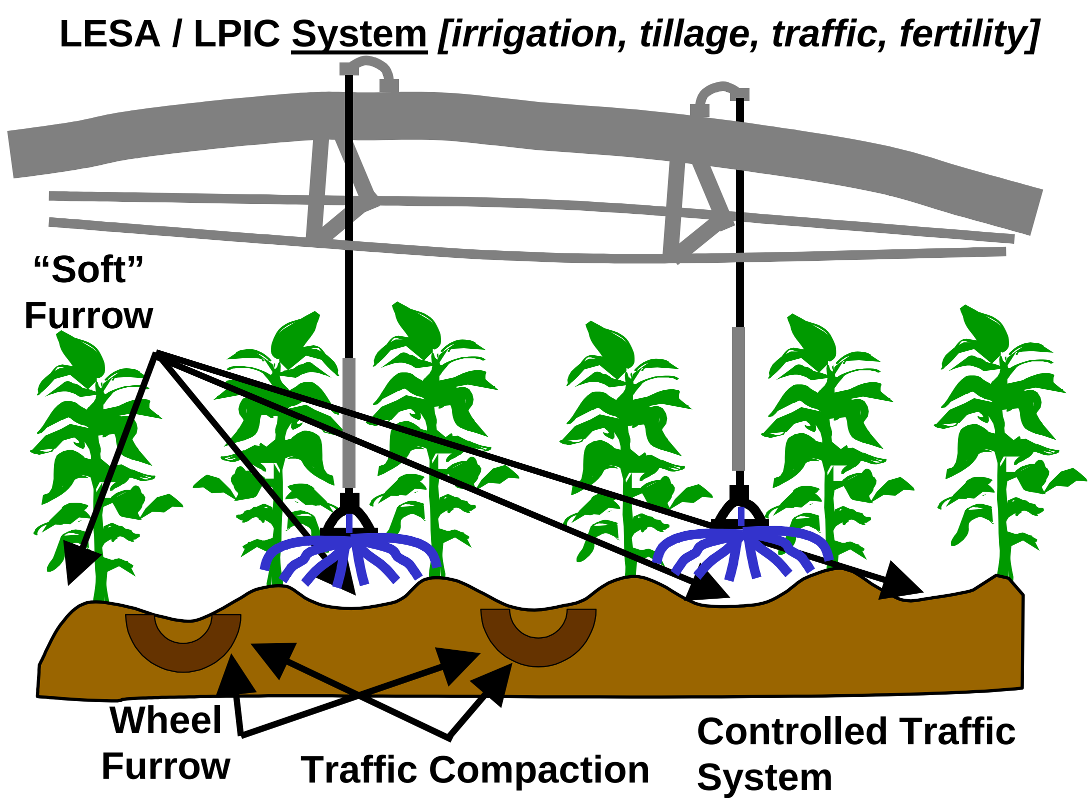

Figure 5. Illustration of the "agronomic system" concept involving irrigation, controlled tillage, fertility, etc.

$$Q_s = Q_{ae} + Q_{ad} + Q_{fi} + Q_{gi} \qquad \text{...[1]}$$

where Q_s is the sprinkler discharge, Q_{ae} is the droplet evaporation during travel from the nozzle to the target surface, Q_{ad} is the water drift outside the target area, Q_{fi} is the intercepted water on the foliage, and Q_{gi} is the water reaching or intercepting the ground. The units for these components can be expressed on a rate, mass, or volume basis. Q_{fi} represents the sum of water evaporated from foliage at the end of then irrigation (Q_{fs}). The water reaching the ground (a defined unit area) can be partitioned into its components characterized as

$$Q_{gi} = Q_{si} + Q_{ge} + Q_{gs} + Q_{gwe} + Q_{gri} + Q_{gro} \qquad \text{...[2]}$$

where Q_{si} is the infiltrated water, Q_{ge} is the water evaporated from the ground during the irrigation, Q_{gs} is the water stored on the ground during the irrigation, Q_{gwe} is the water evaporated from the water stored on the ground prior to infiltration during irrigation, Q_{gri} is the water that runs onto the unit area, and Q_{gro} is the water that runs off the unit area. In its simplest case, irrigation application efficiency is the ratio Q_{si}/Q_s because percolation beneath the root zone can

Table 2. Example sprinkler packages with desired tillage and agronomic systems.

Sprinkler Package	Tillage System	Agronomic System
Overhead		
Impact Sprinklers Rotators, Spinners	Any	Any
MESA or Spray	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any
Within canopy		
LPIC 360° Spray head Low drift head Spinner Oscillating plate	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any
LESA 360° Spray head Low drift head Spinner	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any, circular rows desired
LEPA (bubble)	Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with beds.	Circular rows
LEPA (drag socks)	Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with beds. (basin tillage is more effective)	Circular rows

usually be ignored. Percolation beneath the root zone depends on irrigation scheduling and other water management issues. Percolation can be significant in low lying areas in the field that accumulate runoff from upland areas.

Generally for a center pivot, drift outside the area is small and is often ignored; however, it could be more significant with systems equipped with end guns or in extremely high wind situations. Typically, irrigation application efficiency can only be measured after the water application has been completed and perhaps several hours after the irrigation (perhaps a day later). Dynamic measurement of these various components is practically impossible, and their "static" measurement remains complex in most cases unless major simplifications are used. Sprinkler applications usually involve water transport through the air and the integral vapor transfer of water vapor into the atmosphere through the evaporative process affect the Q_{ae}, Q_{fe}, and Q_{ge} components. For methods that wet the foliage, transpiration will decline, and generally the "net" evaporation (evaporative loss offset by the reduced transpiration) is the component of interest. Also, the movement of the water vapor downwind humidifies the drier air reducing the crop evapotranspiration rates, even before the area is wetted by the irrigation. In addition evaporation continues after the completion of the irrigation event from the foliage intercepted water (Q_{fi}) and surface storage water (Q_{gs}) and the evaporation from the ground during the irrigation (Q_{ge}) and

Table 3. Water loss components associated with various sprinkler packages.

	Sprinkler Package			
Water Loss Component	**Overhead**	**MESA or Spray**	**LESA LPIC**	**LEPA**
Droplet evaporation	Yes	Yes	Yes	No
Droplet drift	Yes	Yes	No	No
Canopy evaporation	Yes	Yes	Yes, (not major)	No, (chemigation mode only)
Impounded water evaporation	No	Yes	Yes	Yes, (major)
Wetted soil evaporation	Yes	Yes	Yes	Yes, (limited)
Surface water movement	No, (but possible)	Yes, (not major)	Yes	Yes, (not major)
Runoff	No, (but possible)	Yes	Yes	Yes, (not major unless surface storage is not used)
Percolation	No	No	No	No

following the event (Q_e, total evaporation of water from the ground surface). At the typical observation time, the intercepted water on the foliage and the ground will already have evaporated and these amounts are largely unknown, except by some inference methods (qualitative comparisons; e.g., estimating Q_{ge} from evaporation from an "open" water body near the site). Table 3 outlines the possible water loss components common for various sprinkler packages. Howell et al. (1991) reviewed many of the studies that had measured evaporative losses from sprinkler systems, especially those using lysimeters. They noted the great difficulty in making measurements of evaporative losses, but they found major differences in the application losses for differing sprinkler methods – low angle impacts, LEPA, and over canopy spray (MESA or LPIC) due to their different wetted times, differing wetted surfaces (e.g., LEPA only wetted a small portion of the soil surface with minimal or no canopy wetting). Tolk et al. (1995), using measured corn transpiration, found net canopy evaporation of intercepted water was 5.1 to 7.9% of applied water for a one-inch (25-mm) application volume. McLean et al. (2000) reviewed several past evaporation studies and evaluated above canopy evaporation losses from center pivots using the change in electrical conductivity of sprinkler catch water as an indicator of evaporation. They reported impact and spray losses from –1 to 3%. The negative losses were attributed to atmospheric condensation on the droplets due to the cool groundwater temperatures that were less than the atmospheric dew point temperature. Schneider (2000) reviewed the evaporation losses from LEPA and spray systems (LESA, LPIC, and MESA types). He summarized the limited studies reporting "net" canopy evaporation that had values ranging from 2 to 10% (some of these were simulated and/or based on a theoretical model). Evaporation from LEPA systems ranged from 1 to 7% of the applied amounts with application efficiencies ranging from 93 to 100%. His review of evaporation losses from spray irrigation studies had values that ranged from 1 to 10%, while their mean application efficiencies ranged from 85 to 100%.

Surface water redistribution (runoff from one area to a lower area but not perhaps leading to runoff leaving the field) and field runoff should not occur in most cases. Yet, they regularly happen and affect the infiltration uniformity, deep percolation, and ultimately the efficiency of the application. Spray systems (LESA, LPIC, or MESA) or LEPA systems (despite the use of surface tillage designed to enhance surface water storage volume) are most prone to runoff problems. Soil type and slope play a central role in the surface water redistribution and runoff potential of a particular site in addition to the sprinkler package and system capacity (system flow rate per unit area) (Fig. 6). Either surface storage (basin or reservoir tillage) or crop residues from no-till or profile modification tillage (chiseling, para-till, etc.) may be needed to reduce or eliminate surface water redistribution and runoff. Increasing the system speed (decrease the application depth) generally reduces the potential runoff volume but may affect the "effective percolation" of the applied water. Both water redistribution and field runoff that occur from rainfall can further impact irrigation water requirements. Few studies are published on rainfall runoff from sprinkler-irrigated fields or that have measured the total season water balance components.

Schneider (2000) reviewed many of the previous studies on irrigation runoff and surface storage as influenced by tillage systems for LEPA and spray application methods. Runoff or water redistribution without basin or reservoir tillage ranged from 3 to over 50% in several studies with the greatest runoff losses occurring from LEPA modes without basin tillage (most in the bubble mode). LEPA applications in alternate furrows will require twice the storage volume needed for equivalent LESA or LPIC systems (representing full wetting like rain or MESA). Runoff from LESA or LPIC systems may be critical on steeper slopes (>1-2%), low intake soils (heavier textures like clay loams), and higher capacity systems (>6 gpm/ac or 0.32 in./d or 8.1 mm/d).

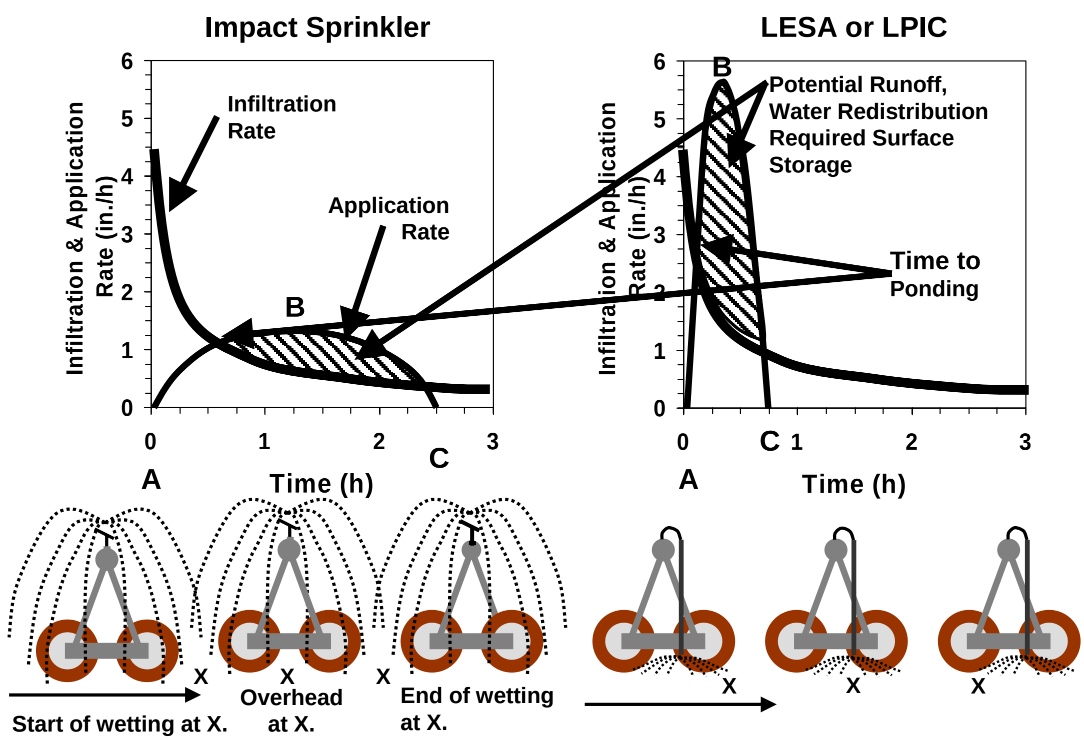

Figure. 6. Illustration of runoff or surface water redistribution potential for impact sprinkler and spray (LESA or LPIC) center application packages for an example soil. (A) represents the start of the irrigation, (B) is the peak application rate (usually when the system is directly overhead), and (C) is the completion of the irrigation**.** The first intersection point of the infiltration curve and the application rate curve represents the first ponding on the soil surface.

CONCLUSIONS

The sprinkler package is a combination of the sprinkler applicator, the application mode, and the applicator spacing. The system capacity determines the peak application rate of the particular sprinkler application package. The sprinkler package should be designed together with the tillage and agronomic system of the operator. The particular soil and slope conditions will define the infiltration rate. The intersection area between the infiltration curve and the application rate curve illustrates the "potential" runoff or surface water redistribution that may require surface storage from basin or reservoir tillage needed to reduce or eliminate runoff from LESA, LESA, or LPIC systems.

The type of sprinkler applicator and the mode of application determine the particular components of water losses. "Net" canopy evaporation may be in the 5-10% range. Overall evaporation losses in several cases ranged between 10-20%. Irrigation efficiency of LEPA systems without runoff were in the 93 -99% range, but without basin tillage, LEPA systems in several cases had large runoff (or surface water redistribution) amounts. LESA or LPIC systems can be efficient with evaporative losses less than 10% in most cases, particularly with basin, reservoir tillage or with a no-till system.

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IMPACT OF WIDE DROP SPACING AND SPRINKLER HEIGHT FOR CORN PRODUCTION

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Introduction

Using center pivot sprinkler nozzles below the top of the corn crop canopy presents unique design and management considerations. Distortion of the sprinkler pattern can be large and the resultant corn yield can be reduced. In many areas, water available for irrigation is being limited due to reduced supply of both ground and surface water. During periods of drought, uniformity problems associated with center pivot irrigation become quite visible. Many times water stress on the crop is not evident until late in the season when the crop has nearly matured. In many cases aerial observations of fields have revealed concentric rings that corresponded to sprinkler spacing(Figures 1a - b).

Figure 1a. Height reduction in corn caused by drops spaced too wide.

F

igure 1b Concentric rings in corn field caused by having drops spaced too wide.

The impact of sprinkler spacing on water distribution and corn yield was the focus of University of Nebraska and Kansas State research studies. Researchers conducted field experiments along with on-farm evaluations to gain a better understanding of operating sprinkler devices within the corn canopy. The results from these experiments will be discussed.

Field Evaluation of Changes in Soil Water Content

In a Nebraska study soil water content was measured as a method to evaluate the uniformity of water distribution. Soil water content was measured in the top 12 in. of soil before and after irrigation. Spinners[1] were spaced 12.5 ft apart and located at a height of 42 inches in a mature corn crop. Sprinklers were moving parallel to the corn rows but not necessarily between the corn rows. Figure 2 shows the location of the sprinklers in the corn rows and the change in soil water content measured before and after irrigation. Soil water content increased nearly 12% in the rows nearest the sprinkler device. Soil water content averaged less than a 2% increase at locations directly between the sprinkler devices. The small change in soil water content indicates the rows between the sprinkler devices received little or no water during the irrigation event.

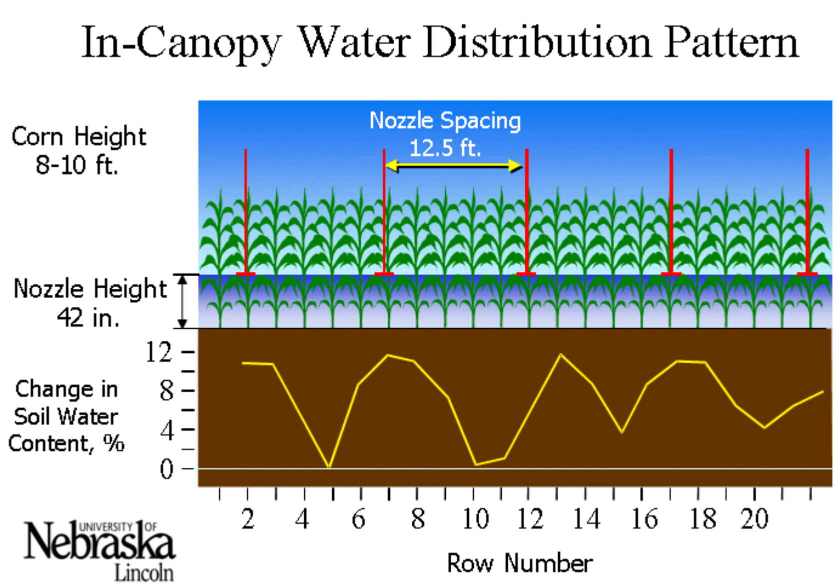

Figure 2. Changes in water content following irrigation with sprinkler nozzles located in a corn canopy.

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[1]Mention of trade name is for information only and does not imply endorsement

Variation in Corn Yield as Affected by Sprinkler Height

When the sprinkler pattern is distorted and the nozzle spacing is wide enough to prevent some corn rows from getting equal opportunity to water, yields can be reduced. A study was conducted at the KSU Northwest Research-Extension Center from 1996-2001 to examine the effect of irrigation capacity and sprinkler height on corn production when the spray nozzle spacing was too wide for adequate in-canopy operation (10 ft instead of more appropriate 5 ft spacing). Performance of the various combinations was examined by measuring row-to-row yields differences (i.e. Row yields 15 inches from the nozzle and 45 inches for the 10 ft nozzle spacing.) Corn rows were planted circularly allowing the nozzle to remain parallel to the corn rows as the nozzle traveled through the field. As might be expected, yield differences were greatest in dry years and nearly masked out in wet years. For the purpose of brevity in this report, only the 6 year average results will be reported. Even though the average yield for both corn rows was high, there is a 16 bu/acre yield difference between the row 15 inches from the nozzle and the corn row 45 inches from the nozzle for the 2 ft nozzle height and 10 ft nozzle spacing (Figure 3). At a four ft nozzle height the row-to-row yield difference was 9 bu/acre and at the 7ft height the yield difference disappeared. This would be as expected since pattern distortion was for a shorter period of time for the higher nozzle heights. It should be noted that the circular row pattern probably represents the least amount of yield reduction, since all corn rows are within 3.75 ft of the nearest nozzle. For straight corn rows, the distance for some corn plants to the nearest nozzle is 5 ft.

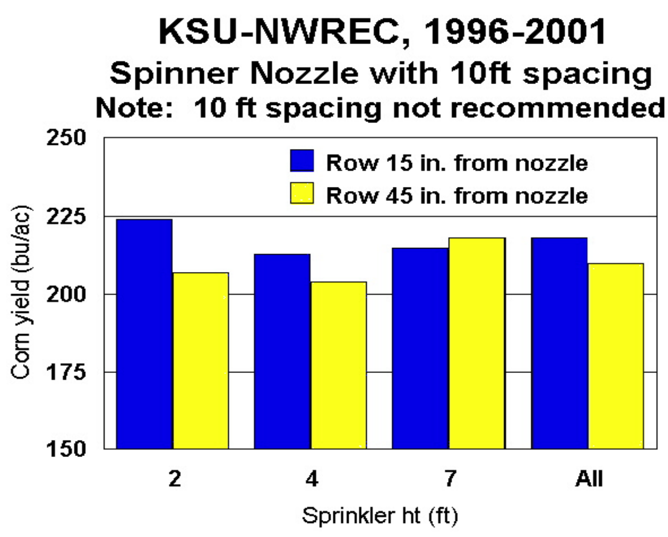

Figure 3. Row-to-row variation in corn yields as affected by sprinkler height in a study with a nozzle spacing too wide (10 ft) for in-canopy irrigation, Colby, Kansas. Data averaged across 4 different irrigation levels. Note: The average yield for a particular height treatment would be obtained by averaging the two row yields.

On-Farm Evaluation of Sprinkler Spacing

Many center pivot sprinkler systems are designed with wide sprinkler spacing as a method to reduce equipment cost. For outer spans closer sprinkler spacing is needed in order to meet the water application requirements. Although concentric rings were showing up in Nebraska fields, the outer portions of the fields showed no such pattern. To evaluate the rings, a series of samples were collected to determine crop yield and soil water content. Samples were collected from both sprinkler spacings where the spacing transition occurred to insure similar soil type and cultural conditions.

The location of sprinklers were first identified in relation to the wheel tracks. Then the location of sprinklers were superimposed in that area of the field where the center pivot sprinkler devices run nearly parallel with the planted rows of corn. All corn rows between two sprinkler devices were sampled to determine soil water content and grain yield. Yield was determined by harvesting 10 feet of row. Soil water content was measured to a depth of 4 feet at one location in each row. The results given are the average of two yield and soil water content samples.

Field measurements were collected for two different center pivot fields represented in figures 4 and 5. Sprinklers were located at a height of 7 ft. and at either a 9 or 18 ft. spacing. Corn rows were planted 30 in. apart. Figures 4a and 5a shows the results for the narrow spacing of the two fields while figures 4b and 5b show results for the wide sprinkler spacing.

Generally, there were no reasonable patterns for either yield or soil moisture content for the 9 ft. sprinkler spacing in figures 4a and 4b. However, corn yield did decline when the sprinkler spacing increased to 18 ft. in figures 5a and 5b. Because soil water data was collected at the end of the season when the crop was mature, some of the difference, or lack of difference, in soil water content may have been eliminated with late season precipitation or added irrigation. It should also be noted that soil water content is extremely low and most likely approaching wilting point.

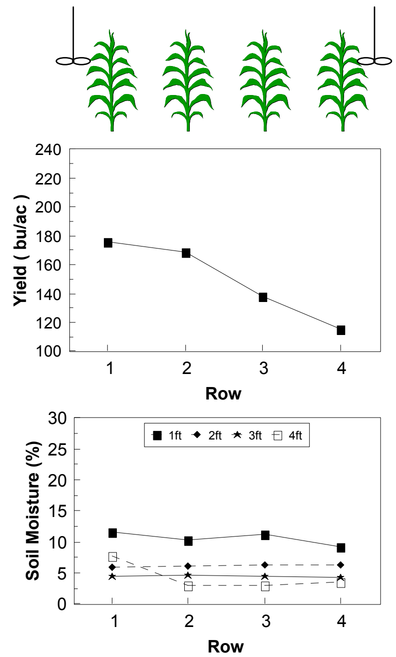

Figure 4a. Corn yield and soil water content for sprinkler devices spaced 9 ft apart at 7 ft height.

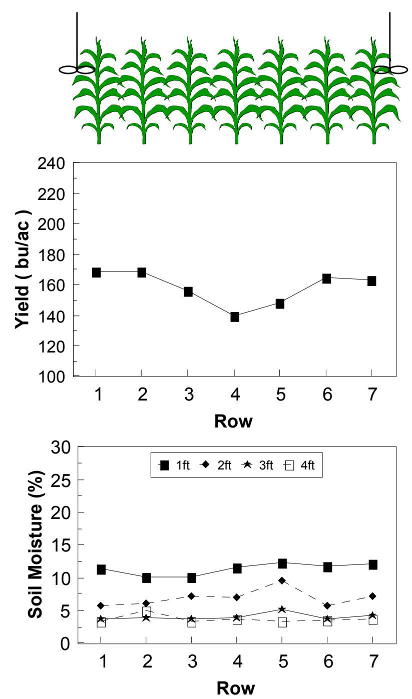

Figure 4b. Corn yield and soil water content for sprinkler devices spaced 18 ft apart at 7 ft height.

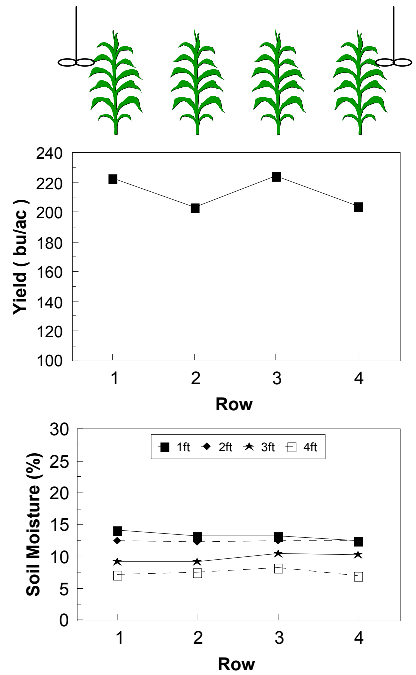

Figure 5a. Corn yield and soil water content for sprinkler devices spaced 9 ft. apart at 7 ft height.

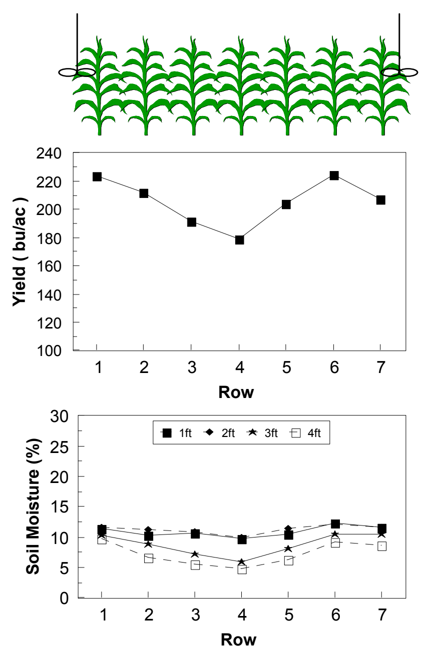

Figure 5b. Corn yield and soil water content for sprinkler devices spaced 18 ft. apart at 7 ft height.

Effect of sprinkler height and type on corn production

Another study conducted from 1994-95 at the KSU Northwest Research-Extension Center examined corn production as affected by sprinkler height and type and irrigation capacity. Spray nozzles on the span (14 ft), spray nozzles below the truss rods (7 ft) and low energy precision application (LEPA) nozzles (2 ft) were compared under irrigation capacities limited to 1 inch every 4, 6, 8 or 10 days.

Corn yields averaged 201, 180, 164, and 140 bu/a for irrigation capacities of 1 inch every 4, 6, 8, or 10 days, respectively. No statistically significant differences in corn yields, or water use efficiency were related to the sprinkler package used for irrigation. There was a trend for the (LEPA) package to perform better than spray nozzles at limited irrigation capacities and worse than the spray nozzles at the higher irrigation capacities (Figure 6).

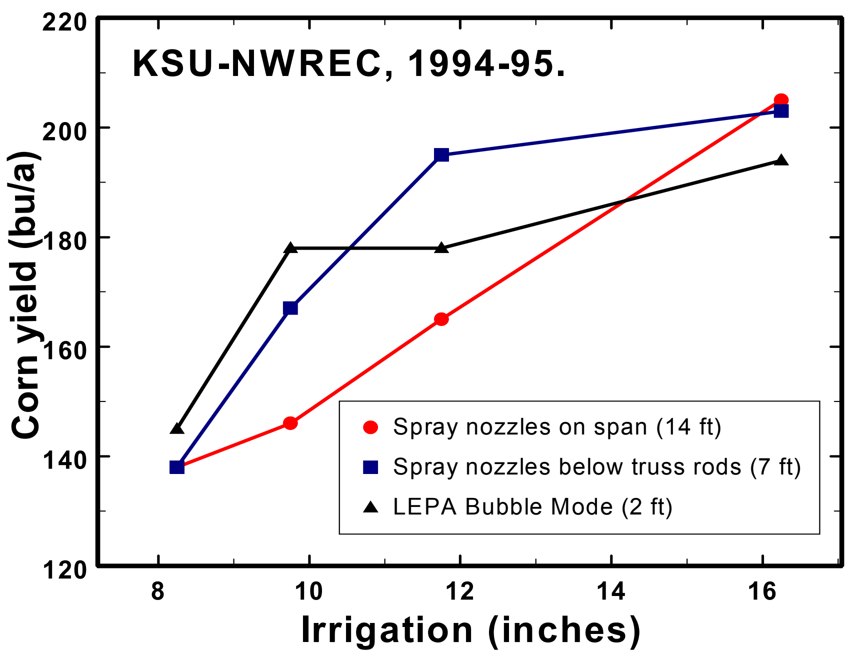

Figure 6. Corn grain yields as affected by sprinkler height and type at four different irrigation levels, KSU Northwest Research-Extension Center, Colby, Kansas, 1994-1995.

The first observation is supported by research from other locations, which shows that LEPA can help decrease evaporative water losses and thus increase irrigation efficiency. The second observation indicates that LEPA may not be suited for higher capacity systems on northwest Kansas soils, even if runoff is controlled as it was in this study. It should be noted that this study followed the true definition of LEPA with water applied in bubble mode to every other row.

The term LEPA is often misused to describe in-canopy spray nozzle application.

The reason that LEPA is not performing well at the higher irrigation capacities may be puddling of the surface soils, leading to poor aeration conditions. However, this has not been verified. In 1995 with a very dry late summer, LEPA performed better than the other nozzle orientations at the lower capacities and performed equal to the other orientations at the higher capacities. Averaged over the two years, the trend continued of LEPA performing better at the lower irrigation capacities. Overall, spray nozzles just below the truss rods performed best at the highest two capacities, but LEPA performed best when irrigation was extremely limited.

Conclusions

As the cost of pumping increases and water supplies become more restricted, irrigation schedules that more closely match water application to water use will exaggerate the nonuniform application of water due to sprinkler spacing and in-canopy operation of sprinkler devices with similar results to what we have shown here.

It has been a common practice for several years to operate drop spray nozzles just below the center pivot truss rods. This results in the sprinkler pattern being distorted after corn tasseling. This generally has had relatively little negative effects on crop yields. The reasons are that there is a fair amount of pattern penetration around the tassels and because the distortion only occurs during the last 30-40 days of growth. In essence, the irrigation season ends before severe deficits occur. Compare this situation with sprinklers operated within the corn canopy that may experience pattern distortion for more than 60 days of the irrigation season. Assuming a 50% distortion for sprinklers beginning 30 days earlier, it would result in irrigation for some rows being approximately 40% less than the needed amount. These experiments have shown that significant yield reductions do occur because of the extended duration and severity of water stress.

IMPROVING CENTER PIVOT PERFORMANCE TO INCREASE SURFACE WATER SYSTEM EFFICIENCY

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INTRODUCTION

Tests to determine water distribution uniformity under center pivot irrigation in order to improve performance are a single component of The Central Nebraska Public Power & Irrigation District's (CNPPID) multi-faceted effort to advance whole system efficiency. Continuing efforts to improve system components are critical at this time as reduced inflows at Lake McConaughy threaten a continuous water supply. For the reader unfamiliar with the CNPPID surface water system, an overview is included here. Efforts to increase whole system, conveyance lateral and on-farm systems efficiency will be discussed and examples of on-farm center pivot test results are presented.

System Overview

Kingsley Dam closed in 1941, forming the twenty-two mile long Lake McConaughy on its west side. Lake McConaughy is located just to the north of Ogallala in western Nebraska (storage capacity is 1,743,000 acre-feet (AF) at 3265.0 feet above mean sea level) and is the District's primary storage facility on the main-stem of the North Platte River (Figure 1). Storage volume at Lake McConaughy not only serves CNPPID producers but also holds water for other interests. Nebraska Public Power District (NPPD) uses McConaughy water to cool the coal-fired, electric generators at the Gerald Gentleman Station, turn hydroelectric turbines at North Platte and serve its irrigation customers with the water. Storage water from the Glendo Reservoir in Wyoming becomes a part of Lake McConaughy in the fall to serve the five Nebraska canals with Glendo water accounts in the spring and summer months. The US Fish and Wildlife Service (USFWS) maintains and manages a parcel of Lake McConaughy inflows for downstream endangered and threatened species. CNPPID diversions currently provide hydroelectric generation, irrigation water to 113,170.67 acres in Lincoln, Dawson, Gosper, Phelps and Kearney counties and maintain river flows according to the Federal Energy Regulatory Commission (FERC) license requirements.

In addition to Lake McConaughy, the CNPPID system includes four hydroelectric power plants (104 megawatt capacity), a diversion dam directly below the confluence of the North and South Platte Rivers, 26 smaller reservoirs and canyon lakes, a supply canal and three primary irrigation canals that total 587 mi. of conveyance laterals and 1,989 field turnouts.

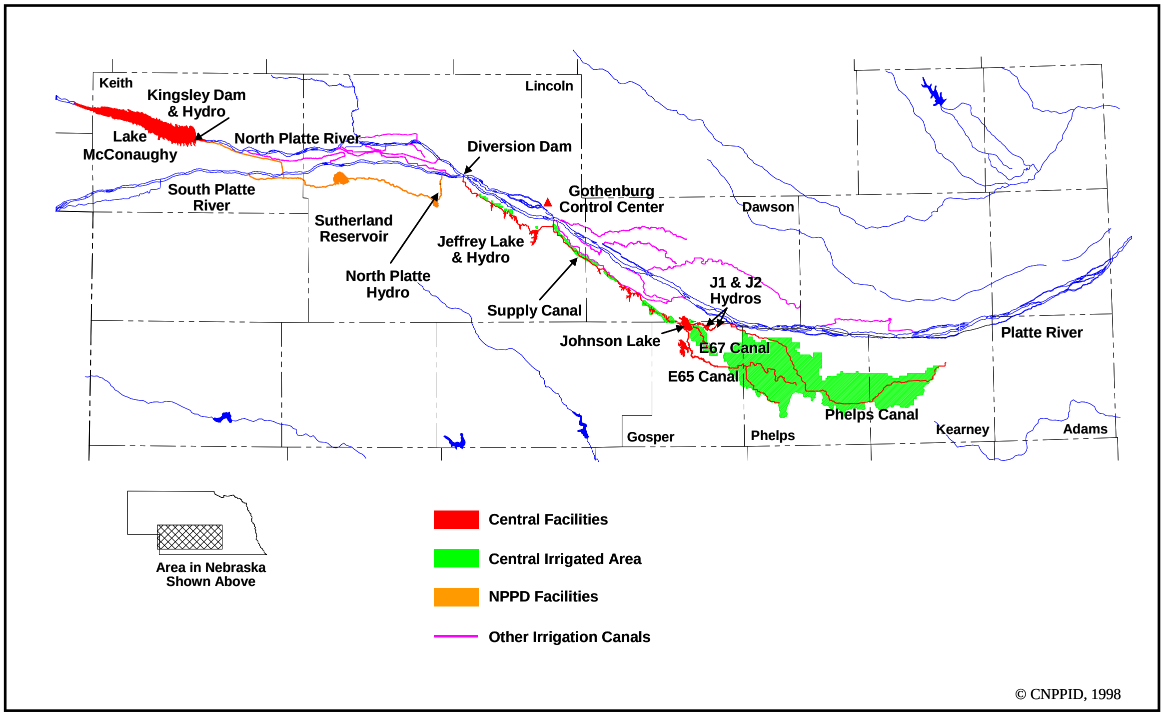

Figure 1. The CNPPID system.

INCREASING WHOLE SYSTEM EFFICIENCY

The goal of whole system efficiency is to provide a continuous, reliable storage water supply where the ratio of irrigation use to water diverted at the headgates is high. Basin parameters are key inputs to the annual Operations Plan, developed by CNPPID engineers in cooperation with other users and approved by the fifteen member Board of Directors. Water supply and releases to and from Lake McConaughy are projected and mass balance calculations applied to keep the system sustainable and provide water for all downstream beneficial uses. Releases are necessarily higher in wet conditions and held to minimum flows when water in the basin is in short supply.

Due to the current historic low inflows to Lake McConaughy, surface elevation is 51 foot below full pool with 585,800 AF of stored water or roughly a third of total capacity. This level is up 9.6 feet from the September low following the 2003 irrigation season (Figure 2). An emergency conservation mode of operations has limited all but essential use within the District since 2002, however, the current low inflows are not meeting minimum demand and a system water balance has not been achieved (Figure 3).

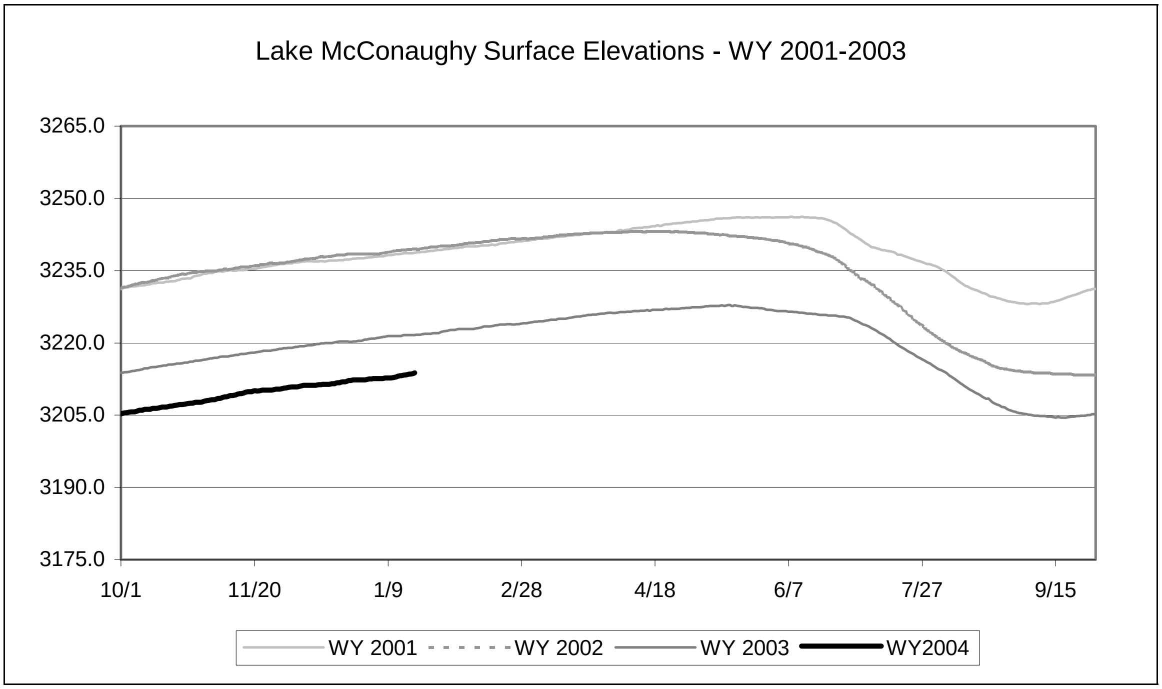

Figure 2. Lake McConaughy Surface Elevations Water Years (WY) 2001-2004.

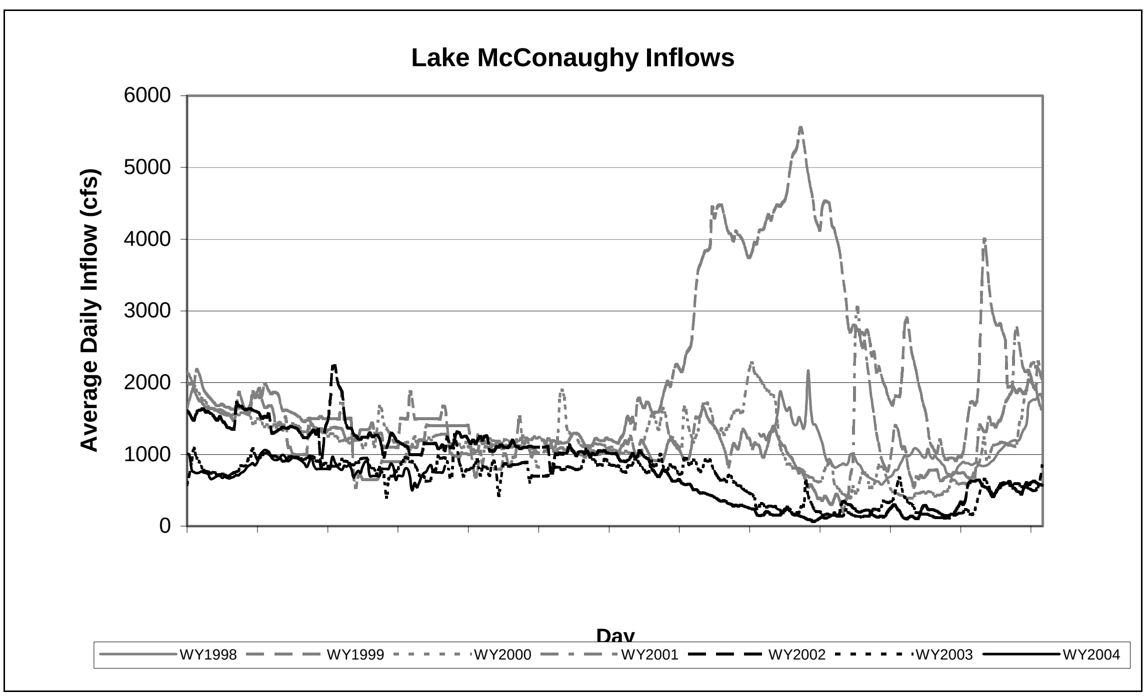

Figure 3. Lake McConaughy inflows, Water Years 1998 – 2004.

New measures have been taken in recent years to increase whole system efficiency and although they may seem small, storage water savings appears to be substantial. A series of automated rain gauges installed along the supply and irrigation canals allows operators at the Gothenburg Control Center to track location and intensity of summer storm events in real time and reduce the response time needed to shut down releases from McConaughy to compensate. Also the smaller, downstream lakes are being drawn down further in August to meet the irrigation demand, saving system water by reducing the additional conveyance losses from Lake McConaughy.

INCREASING CONVEYANCE LATERAL EFFICIENCY

Seepage and evaporation are an inherent part of running water through earthen canals. The evaporation portion is somewhat significant in the reservoirs (near 3 ft. annually at full pool in Lake McConaughy) and of little significance in the canals as the canal banks help attenuate the wind speed across the water surface and stream width is small.

Canal seepage losses recharge groundwater supply, which can be pumped to the surface again, or they become part of return flow to both the Platte and Republican Rivers. However, seepage losses require CNPPID to divert additional water at the headgates to meet that demand. Hydraulic conductivity of the canal beds varies by soil type. Within a same soil type, cut sections tend to have a better retention rate than fill sections.

Efficiency efforts to reduce seepage demand or improve the ratio of AF delivered/diverted include pipeline installations and membrane, concrete and polymer linings. One hundred and thirty-one miles of pipeline and another 13 linear miles of membrane or concrete liners have replaced earthen laterals since the District was formed (Figure 4). Membrane linings include full linings where losses are limited to evaporation and partial linings installed below the canal bed. An estimated 60% reduction in losses occurs with partial linings.

In 2003 an anionic polyacrylamide (PAM) solution was sprayed along 233 miles of earthen or open laterals to slow seepage with only limited success. More study will be done with this product to determine its use in the system.

Additional reduction of losses have been achieved by: automation of check gates that keep canal head steady, and use of the Target Operations Curve (TOC) at Elwood Reservoir. The fill and release schedule at Elwood Reservoir in Gosper County closely follows the TOC developed by an engineering group for CNPPID. By incorporating the TOC into the Operations Plan, surface elevation of the reservoir is lower for part of the year, water needs are adequately met and losses to seepage have been reduced by an average of 5000 AF annually.

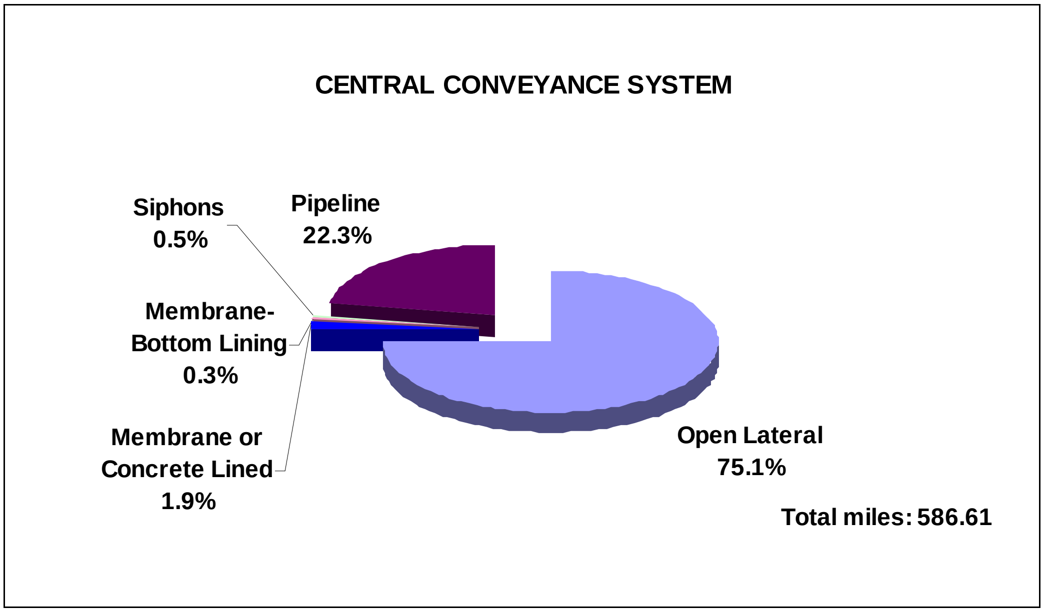

Figure 4. CNPPID system conveyance.

INCREASING ON-FARM EFFICIENCY

The 2003 on-farm systems, shown with associated acres in Figure 5, include flood (USFWS wetland areas), siphon tubes, gated pipe; with and without associated reuse pits and/or surge valves, three sub-surface drip (SDI) demonstration sites and center pivots.

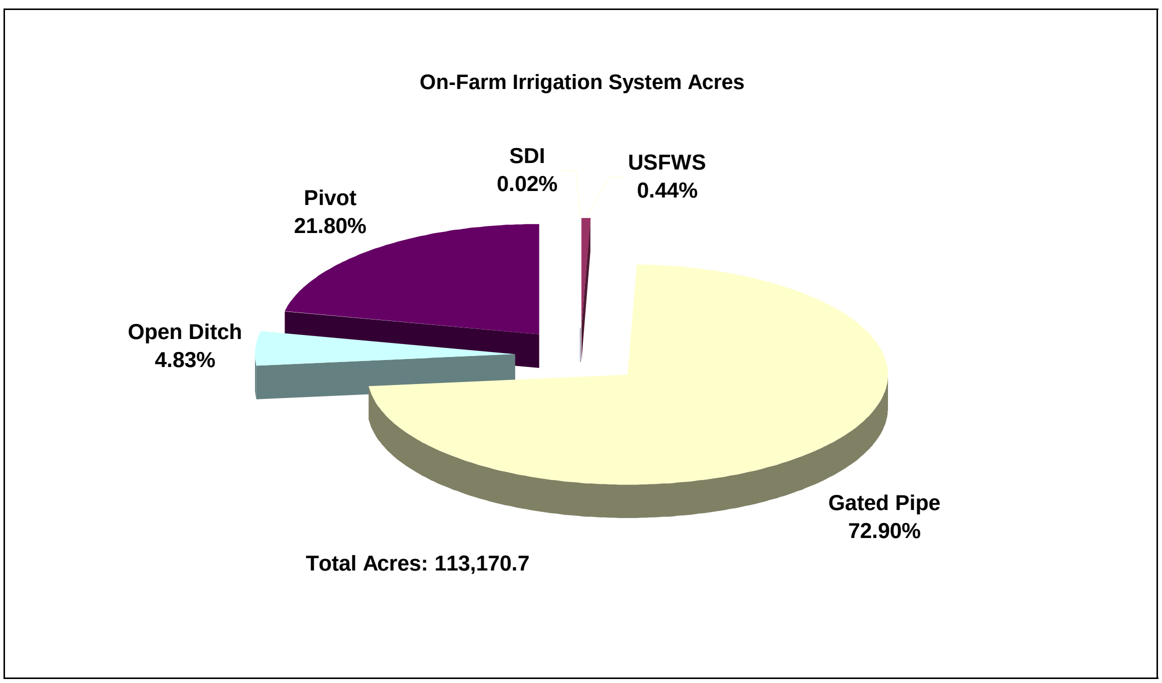

Figure 5. On-farm irrigation system acres served by CNPPID in 2003.

CNPPID has encouraged on-farm conservation efforts for many years through cost-share assistance. Up to $1,500 in material and labor costs is available at each turnout to accommodate an upgrade to a new water conservation practice. An additional conservation policy was implemented in 2001 with the introduction of the Pivot Incentive Policy.

This policy provides a cash incentive to producers to install a center pivot and is designed to offset some of the start-up costs associated with the change. The Pivot Incentive Policy represents a significant financial commitment to water conservation; incentive payments for the 68 new pivots added since 2002 total $194,046.31. Two hundred-six pivots served District acres in 2003 (Figure 6) and 26-29 installations, most replacing gated pipe, are slated for the 2004 season.

CNPPID has experienced a significant upswing in the number of center pivots replacing open ditch or siphon tube systems at the field level. Labor availability and labor cost are most probably the driving force of the increase, however, the potential benefit to water supply without yield reductions are of interest to both CNPPID and its producers.

Pivots coming on-line are normally designed and installed by local dealership staff using manufacturer's software packages and the CNPPID flow rate options to the field. Necessarily, the District's interest is not design but function of these systems following installation.

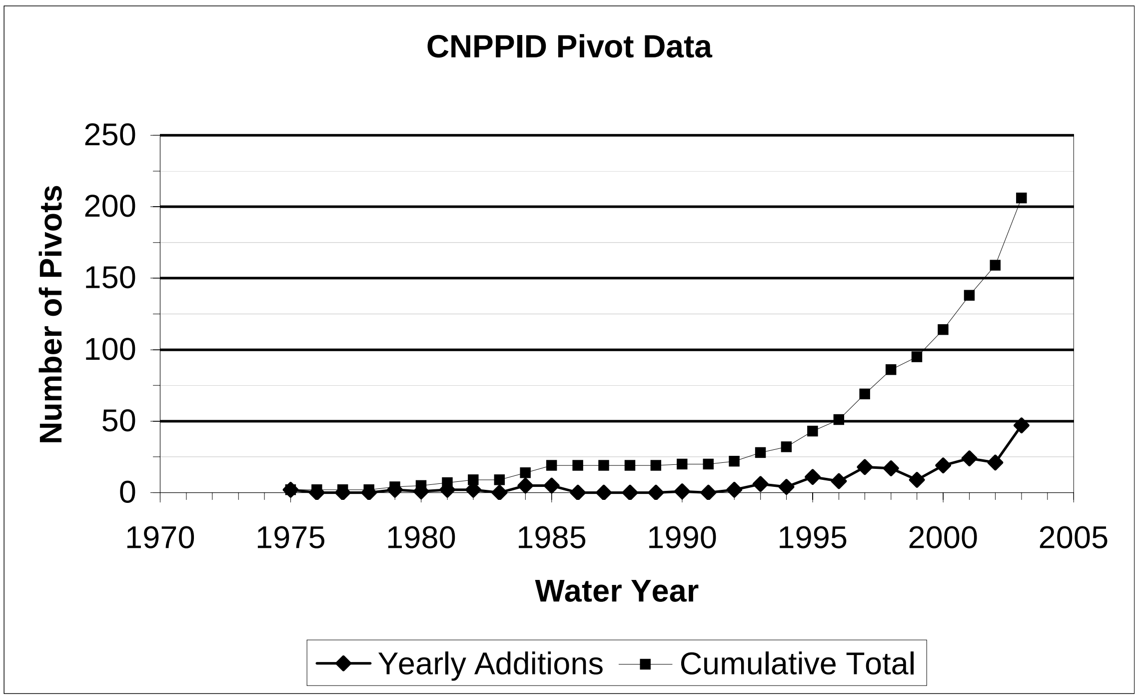

Figure 6. The number of annual additions and cumulative total of center pivot irrigation systems served by the CNPPID District.

On-Farm Center Pivot Testing

A survey of the CNPPID system prior to the 2001 irrigation season revealed that none of the center pivot installations had been field-tested for water distribution uniformity. And so began the effort to assess center pivot installations against the following assumptions:

- Modified Heermann and Hein coefficient of uniformity (CU) is 90 ± 5% after the second tower to the outside edge of the wetted perimeter,
- Sediment load in the water has no effect on CU,
- Number of years pivot has been in service has no effect on CU
- Calibrated table provided by the manufacturer matches actual field application rate.

Surface water use through a pivot presents challenges related to filtering debris, sediment and algae loads. Filtering of surface debris and small fish or benthic organisms is accomplished with 5/32" perforated galvanized steel pipe, 18" or 24" in diameter and in lengths indirectly proportional to canal depth. Any sediment or algae load carried by the water pass through pipe perforations and sprinkler heads and are delivered to the field.

The agricultural engineering standard; ANSI/ASAE S436.1 OCT97: *Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles* was used for these tests with one exception. A single line of Irrigage rain collectors (Rogers, et al, 2001) replaces the multiple lines of the catch cans in the standard to improve data collection. Rogers et al., have done extensive testing to verify this substitution. The main outcome of this test, the modified Heermann and Hein coefficient of uniformity (CU), describes variation of the sample data from the mean (average) depth applied at all locations. A value of 100% is an unlikely scenario, however, coefficients near 90% are attainable. Application depths ± 10% of the mean depth applied were accepted as normal, as in the standard.

Test 1ER

Results of this test are shown in Figure 7. Most notably, this producer believed he was applying 0.75 inches of water to his field in a single rotation while actual mean depth of application is 0.41 inches; CU is 78%. The unit is an older model with spray nozzles above the lateral and in this case, sediment appeared to be the problem. No pressure regulators are in place, however, differential elevations at the base of each collector are not correlated with changes in the uniformity pattern. According to field elevations, this test should represent maximum application uniformity in this field.

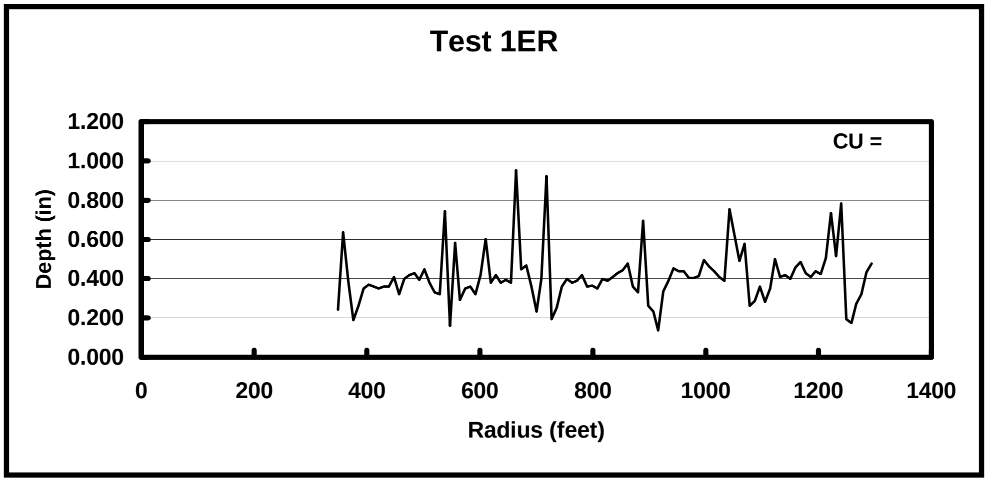

Figure 7. Test results at ER site.

Tests 2OL

The 1983 impact sprinkler unit has 8, 155 ft. spans, an 86 ft. overhang and a cornering unit. The unit was tested twice, first with the cornering unit fully extended and then folded to the "off" position. In the first test, CU was 80.5% and average application depth was 0.67 inches (Figure 8).

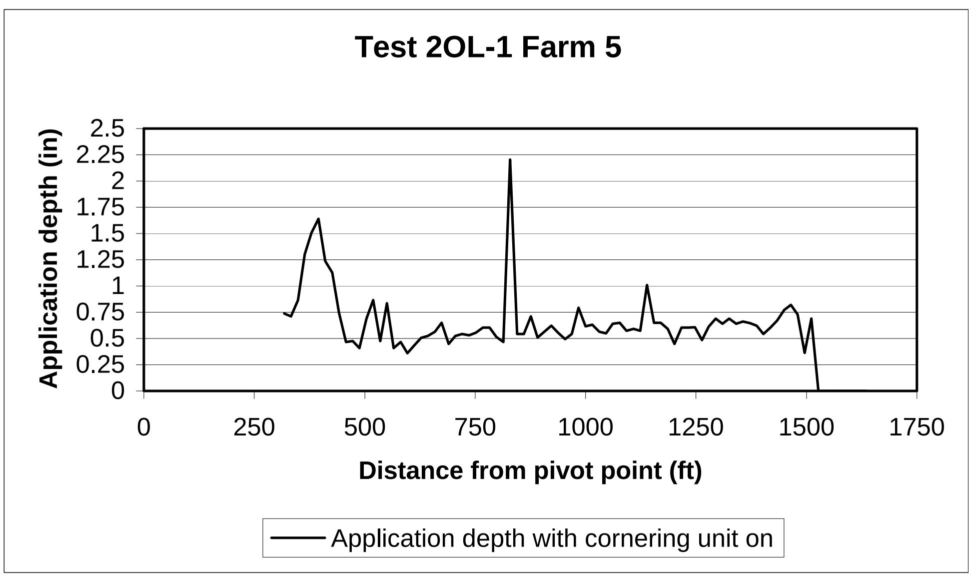

Figure 8. Test 2OL-1.

With the cornering unit folded, CU was 78.9% and average depth applied was 0.90 inches (Figure 9). As shown, a nozzle problem was apparent in the third span and in the folded position, the cornering unit did not shut off completely and depth of application spiked to 2.37 inches. Worn sprinkler heads and a malfunctioning solenoid were the problem here. Also, mean depth of application changed between tests; the producer intended a 0.75-inch application and so the cornering unit needed to be slowed down when fully extended. All problems were easily corrected. Elevations at the base of the collectors were determined again at this site and were not correlated to the uniformity patterns.

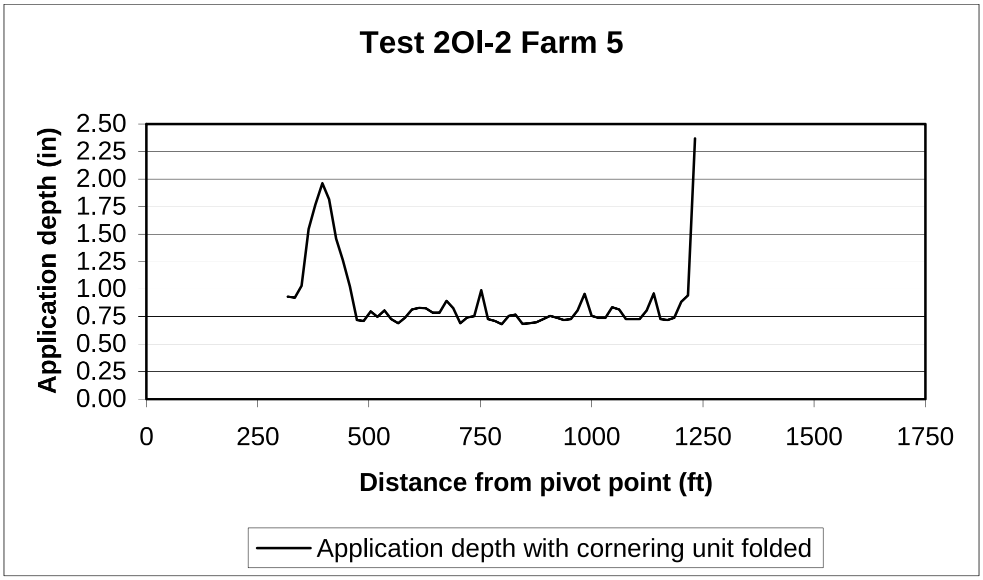

Figure 9. Test 2OI-2.

Test 3EK

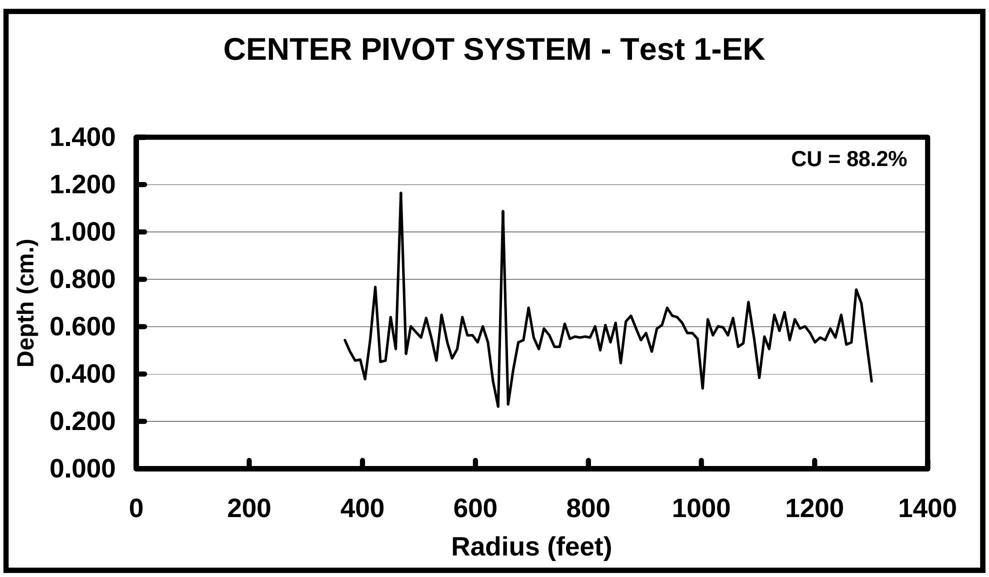

Figure 10. Test 3EK

The pivot in Test 3EK was in its second year of service, a low-pressure system with drops and spray heads. CU is high and the mean application depth of 0.56 inches is just short of the expected 0.60 inches, however, there is room for improvement. The graph clearly shows what happens when sprinkler heads use too much water; neighboring heads are shorted. If the deficit irrigation is not mitigated by rainfall a yield loss would be expected here. Irrigage spacing was 9 feet.

None of the pivots tested to date are without a problem area and each problem found has been easily addressed. Additional field observations not shown here have shown drought conditions can exist under a pivot that is not operating properly and yield losses occur.

The studies completed to date suggest that continuing pivot testing in the system would be useful. CU's near 90% are attainable and although we have formed no opinion on age being a factor in CU we do believe that sediment load in the water can affect CU if it accumulates in sprinkler heads.

Timing of these tests is troublesome in south-central Nebraska as wind speeds higher than the standard allows (11 mph) prevails when corn height does not interfere with data collection. Test conditions in the District are best in July and August, on the soybean side of the corn/soybean crop rotation.

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KEY CONSIDERATIONS FOR A SUCCESSFUL SUBSURFACE DRIP IRRIGATION (SDI) SYSTEM

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INTRODUCTION

Subsurface drip irrigation (SDI) systems are currently being used on about 15,000 acres in Kansas. Research studies at the NW Kansas Research and Extension Center of Kansas State University begin in 1989 and have indicated that these systems can be efficient, long-lived, and adaptable for irrigated corn production in western Kansas. This adaptability is likely extended to any of the deep-rooted irrigated crops grown in the region. Many producers have had successful experiences with SDI systems; however most have had to experience at least some minor technical difficulties during the adoption process. However, a few systems have been abandoned or failed after a short use period due to problems associated with either inadequate design, inadequate management or combination of both.

Both research studies and on-farm producers experience indicate SDI systems can result in high yielding crop and water-conserving production practices, but only if the systems are properly designed, installed, operated and maintained. SDI systems in the High Plains must also have long life to be economically viable when used to produce the relative low value field crops common to the region. Design and management are closely linked in a successful SDI system. A system that is not properly designed and installed, will be difficult to operate and maintain and most likely will not achieve high irrigation water application uniformity and efficiency goals. However, a correctly designed and installed SDI system will not perform well, if not properly operated and is destined for early failure without proper maintenance. This paper will review important considerations for a successful SDI system.

IMPORTANT SDI SYSTEM CONSIDERATIONS

Design considerations must account for field and soil characteristics, water quality, well capabilities, desired crops, production systems, and producer goals. It is difficult to separate design and management considerations into distinct issues as the system design should consider management restraints and goals. However, there are certain basic features that should be a part of all SDI systems, as shown in Figure 1. Omission of any of these minimum components by a designer should raise a red flag to the producer and will likely seriously undermine the ability of the producer to operate and maintain the system in an efficient manner for a long period of time. Minimum SDI system components should not be sacrificed as a design and installation cost-cutting measure. If minimum SDI components cannot be included as part of the system, serious consideration should be given to an alternative type of irrigation system or remaining as a dryland production system.

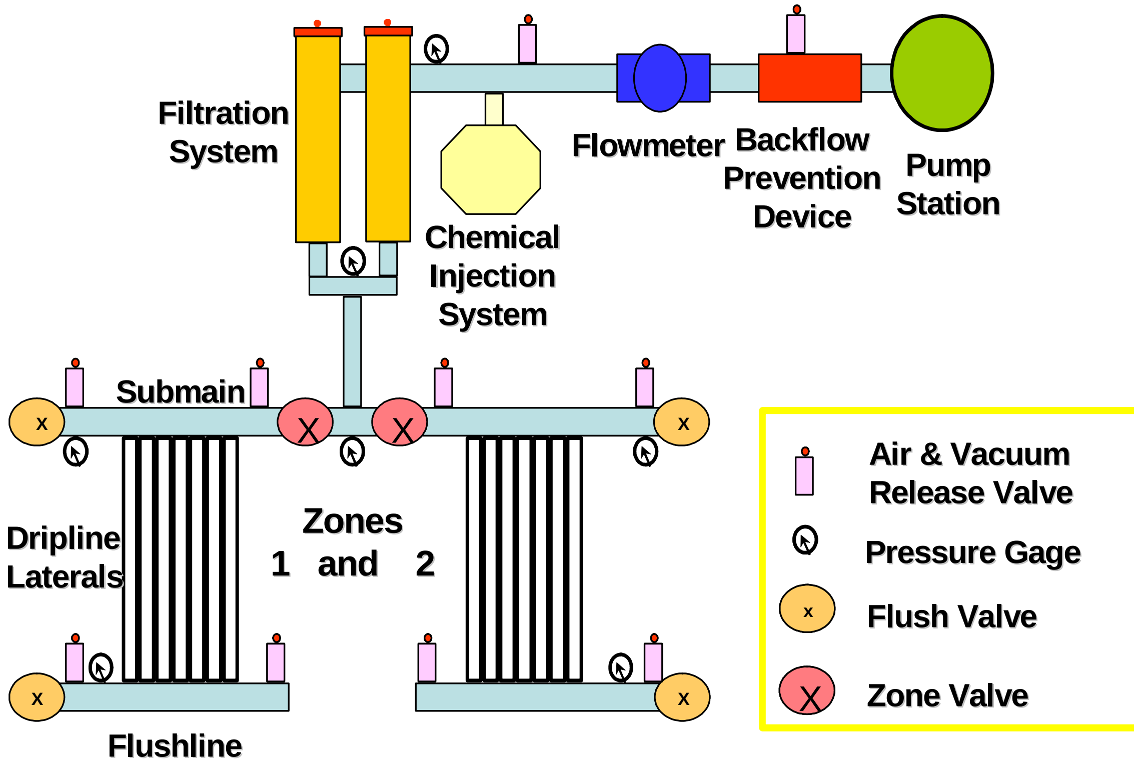

Figure 1. Schematic of Subsurface Drip Irrigation (SDI) System. (Components are not to scale) K-State Research and Extension Bulletin MF-2576, Subsurface Drip Irrigation (SDI) Component: Minimum Requirements

DISTRIBUTION COMPONENTS

The water distribution components of an SDI system are the pumping station, the main, submains and dripline laterals. The size requirements for the mains and submains would be similar to the needs for underground service pipe to center pivots or main pipelines for surface flood systems. Size is determined by the flow rate and acceptable friction loss within the pipe. In general, the flow rate and acceptable friction loss determines the size (diameter) for a given dripline lateral length. Another factor is the land slope. Theoretically, but totally unwise, a drip system could be only a combination of pumping plant, distribution pipelines and dripline laterals. However, as an underground system, there would be no method to monitor system performance and the system would not have any protection from clogging. Clogging of dripline emitters is the primary reason for SDI system failure.

MANAGEMENT COMPONENTS

The remaining components outlined in Figure 1, are primarily components that allow the producers to protect the SDI system, monitor its performance, and if desired, provide additional nutrients or chemicals for crop production. The backflow preventive device is a requirement to protect the source water from accidental contamination should a backflow occur.

The flow meter and pressure gauges are essentially the operational feedback cues to the manager. In SDI systems, all water application is underground. In most properly installed and operated systems, no surface wetting occurs during irrigation, so no visual cues are available to the manager concerning the system operating characteristics. The pressure gauges at the control valve at each zone, allows the proper entry pressure to dripline laterals to be set. Decreasing flow and/or increasing pressure can indicate clogging is occurring. Increasing flow with decreasing pressure can indicate a major line leak. The pressure gauges at the distal ends of the dripline laterals are especially important in establishing the baseline performance characteristics of the SDI system.

The heart of the protection system for the driplines is the filtration system. The type of filtration system needed will depend on the quality characteristics of the irrigation water. In general, clogging hazards are classified as physical, biological or chemical. The Figure 1 illustration of the filtration system depicts a pair of screen filters. In some cases, the filtration system may be a combination of components. For example, a well that produces a lot of sand may have a sand separator in advance of the main filter. Sand particles in the water would represent a physical clogging hazard. Other types of filters used are sand media and disc filters.

Biological hazards are living organisms or life by-products that can clog emitters. Surface water supplies may require several layers of screen barriers at the intake site to remove large debris and organic matter. Another type of filter is a sand media filter, which is a large tank of specially-graded sand and is well-suited for surface water sources. Wells that produce high iron content water, can also be vulnerable to biological clogging hazards, such as when iron bacteria have infested a well. Control of bacterial growths generally requires water treatment, in addition to filtration.

Chemical clogging hazards are associated with the chemical composition or quality of the irrigation water. As water is pulled from a well and introduced to the distribution system, chemical reactions can occur due to changes in temperature, pressure, air exposure, or the introduction of other materials into the water stream. If precipitants form, they can clog the emitters.

The chemical injection system can either be a part of the filtration system or could be used as part of the crop production management plan to allow the injection of nutrients or chemicals to enhance plant growth or yield.

The injection system in Figure 1 is depicted as a single injection point, located upstream of the main filter. In many cases, there might be two injection systems. In other cases, there may be a need for an injection point downstream from the filter location.

The injection system, when it is a part of the protection system for the SDI system, can be used to inject a variety of materials to accomplish various goals. The most commonly injected material is chlorine, which helps to disinfect the system and minimizes the risk of clogging associated with biological organisms. Acid injection can also be injected to affect the chemical characteristic of the irrigation water. For example, high pH water may have a high clogging hazard due to a mineral dropping out of solution in the dripline after the filter. The addition of a small amount of acid to lower the pH to slightly acid might prevent this hazard from occurring.

PRODUCER RESPONSIBILITIES

As with most investments, the decision as to whether the investment would be sound lies with the investor. Good judgments generally require a good understanding of the fundamentals of the particular opportunity and/or the recommendations from a trusted and proven expert. While the microirrigation (drip) industry dates back over 40 years now and its application in Kansas as SDI has been researched since 1989, a network of industry support is still in the early development phase in the High Plains region. Individuals considering SDI should spend time to determine if SDI is a viable systems option for their situation. They might ask themselves:

What things should I consider before I purchase a SDI system?

1. Educate yourself before contacting a service provider or salesperson by
   a. Seeking out university and other educational resources. Good places to start are the K-State SDI website at www.oznet.ksu.edu/sdi and the Microirrigation forum at www.microirrigationforum.com. Read the literature or websites of companies as well.
   b. Review minimum recommended design components as recommended by K-State. http://www.oznet.ksu.edu/sdi/Reports/2003/mf2576.pdf
   c. Visit other producer sites that have installed and used SDI. Most current producers are willing to show them to others.

2. Interview at least two companies.
   a. Ask them for references, credentials (training and experience) and sites (including the names of contacts or references) of other completed systems.
   b. Ask questions about design and operation details. Pay particular attention if the minimum SDI system components are not met. If not, ask why? System longevity is a critical factor for economical use of SDI.
   c. Ask companies to clearly define their role and responsibility in designing, installing and servicing the system. Determine what guarantees are provided.

3. Obtain an independent review of the design by an individual that is not associated with sales. This adds cost but should be minor compared to the total cost of a large SDI system.

CONCLUSIONS

SDI can be a viable irrigation system option, but should be carefully considered by producers before any financial investment is made.

OTHER AVAILABLE INFORMATION

The above discussion is a very brief summary from materials available through K-State. The SDI related bulletins and irrigation related websites are listed below.

MF-2361 *Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems*
http://www.oznet.ksu.edu/sdi/Reports/2003/mf2361.pdf

MF-2576 *Subsurface Drip Irrigation (SDI) Components: Minimum Requirements* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2576.pdf*

MF-2578 *Design Considerations for Subsurface Drip Irrigation* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2578.pdf*

MF-2590 *Management Consideration for Operating a Subsurface Drip Irrigation System* *http://www.oznet.ksu.edu/sdi/Reports/2003/MF2590.pdf*

MF-2575 *Water Quality Assessment Guidelines for Subsurface Drip Irrigation* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2575.pdf*

MF 2589 *Shock Chlorination Treatment for Irrigation Wells* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2589.pdf*

Related K-State Research and Extension Irrigation Websites:

Subsurface Drip Irrigation
www.oznet.ksu.edu/sdi

General Irrigation
www.oznet.ksu.edu/irrigate

Mobile Irrigation Lab
www.oznet.ksu.edu/mil

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SUBSURFACE DRIP IRRIGATION IN NEBRASKA

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INTRODUCTION

Interest on subsurface drip irrigation (SDI) to irrigate row crops has been increasing in Nebraska in recent years. This increased interest has been due in part by limited irrigation water supplies in parts of the state. In places where water supplies are limited, some farmers have been experimenting with SDI as an alternative to surface irrigation, to produce crops with less water and to reduce labor. This is specially the case in small, odd-shaped field where installing a center pivot system in not practical. Another common use of SDI in Nebraska is to irrigate center pivot corners, which are commonly non-irrigated.

To put SDI in Nebraska in the right prospective, it should be stated that, even thought irrigated acreage in Nebraska is only second to California, only 33% of its cropland is irrigated (fig.1). At the same time, center pivots irrigate most of the irrigated land in Nebraska. Although reliable information on acreage irrigated by SDI in Nebraska are not currently available, it is safe to say that the number a acres currently irrigated by SDI is insignificant as compared with those irrigated by center pivot and surface systems.

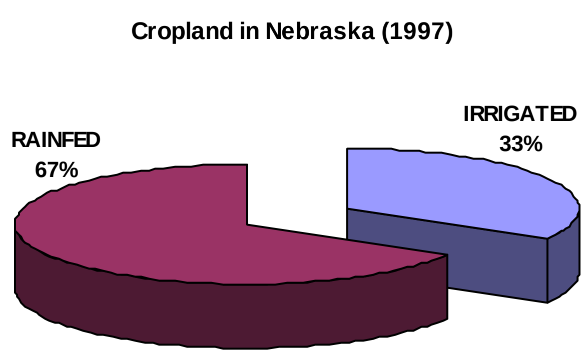

Figure 1. Partitioning of irrigated and rainfed land in Nebraska (Adapted from Bruce Johnson, Cornhusker Economics, June 20, 2001).

At the time of this writing, the Nebraska Department of Agricultural Statistics did not have any information on acres irrigated by SDI in the state, and the Nebraska Department of Environmental Quality (NDEQ) is just starting to keep records on SDI systems installed in the state. In 2001, however, the Irrigation Journal published the result of an irrigation survey, which included irrigated acreages by different irrigation systems by state and nationwide. Results for Nebraska shown in fig. 2 indicate that low-flow systems, which include systems like SDI, surface drip systems and micro-sprinklers, only represent approximately 0.04% of all irrigated acreage. By comparison, the same source indicates that in the entire United States low-flow systems represent approximately 4.9% of irrigated acreages (fig.3).

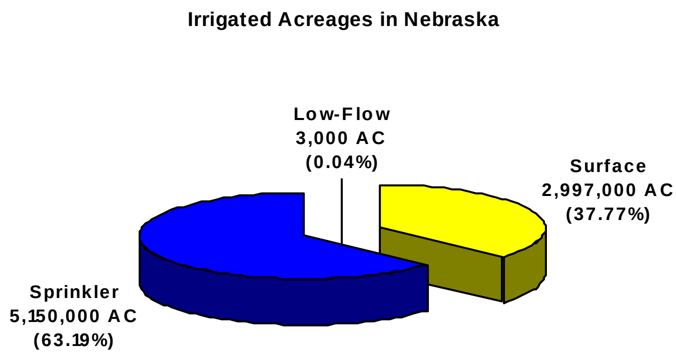

Figure 2. Irrigated acreages by irrigation method in Nebraska (Adapted from Irrigation Journal, Jan/Feb 2001).

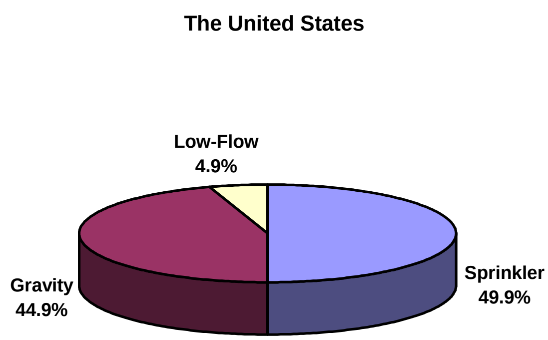

Figure 3. Percent irrigated land by irrigation method in The United States (Irrigation Journal, Jan/Feb 2001).

As suggested above, Nebraska has been slower in the adoption of low-flow system, including SDI, as compared with the national average. This may be due to a variety of factors. First, the high cost of SDI is difficult to recuperate by growing low-value crops like those commonly grown in Nebraska (such as corn, soybean and wheat). This contrasts with places like California, where SDI is used to grow high-value crops, like fruits and vegetables. Although the cost per acre of an irrigation system can vary widely depending on field size and desired level of automation, researchers in Texas have published the cost comparison for different irrigation systems shown in Table 1. It shows that an SDI system cost approximately twice as much as a center pivot. For a crop like corn, the advantages of SDI as compared with center pivots, in terms of labor and water savings, are not as significant as to justify paying approximately twice as much for an SDI system. For surface irrigators, on the other hand, even though the water and labor savings that can be realized by switching to SDI can be significant, the logical step would, however, be to switch to a center pivot if field size and shape allow. Researchers in Kansas, however, have done economic comparison between SDI and Center pivots for row crops (O'Brien et al. 1997). They have shown that as the field gets smaller, the economic feasibility of SDI becomes more attractive. The farm size at which a break-even point is reached, however, depends on a variety of factors, some of which are not well documented, such as:

- Live expectancy of the SDI system,
- Expected yield increase with SDI over center pivot,
- Expected water savings with SDI,
- Value of the water saved using SDI.

Table 1. Irrigation investment cost for different irrigation systems (adapted from or Amosson et al., 2002).

Irrigation System	Cost ($/Ac)		
	Gross	Net[1]	Net[2]
Conventional furrow	165	153	142
Center pivot	367	268	252
SDI	832	615	570

1. Assuming tax rate of 15% and discount rate of 6%.
2. Assuming tax rate of 28% and discount rate of 6%.

A second factor that drives the adoption of more efficient irrigation systems like SDI is water scarcity, which until recent years, have not been much of a problem in Nebraska. Nebraska is sitting on top of a large portion of the High Plains Aquifer and has far more ground water than any other High Plains state. The volume of groundwater stored in the Nebraska portion of the aquifer has been estimated at 2,000 million acre-feet (McGuire et al., 2003). Despite the large quantity of groundwater available in Nebraska, decreases in water table due to over-pumping are now a big problem in South West Nebraska and in Box Butte County. At the same time, due to several years of drought, surface water resources stored in reservoirs and in the soil profile in the area are at all-time lows. This situation has motivated many surface irrigators to install center pivots, and others to consider SDI. The groundwater depletion problem, however, is not yet as widespread and severe in Nebraska as it is, for instance, in Texas, Kansas, Oklahoma, Colorado, and New Mexico (McGuire et al. 2003).

Another factor limiting SDI in Nebraska has been the fact that information for farmers wanting to install SDI systems has been very limited. For instance, even though research with SDI has been carry out for decades in California, and for over 12 years in Kansas, no similar programs have been established in Nebraska. Only now is Nebraska establishing SDI research and extension programs as a reaction to farmer's demands for information. Innovative farmers have mainly been leading the introduction of SDI to the state. Without the benefit of independent information sources, other than that provided by the industry and irrigation dealers, a share of SDI system failures have occurred. Initially, farmers started experimenting with “leaky hose” type of systems, with disappointing results, and now thin-wall drip tapes are commonly used. Also, other than cost, the main problem limiting the adoption of SDI in Nebraska is the lack of a viable solution to potential rodent problems.

What follows is a description of demonstrations, extension, and research efforts that have been made or are currently underway to either generate and/or provide information related to SDI in Nebraska.

UNL SDI RESEARCH FACILITIES

In recent years, the University of Nebraska-Lincoln (UNL) has been in the process of establishing SDI research and extension programs. So far, SDI research facilities have been installed at North Platte, Scottsbluff, Lincoln, and there are plans to install another facility at Clay Center. A Brief description of these facilities follows.

SDI Research Facility at North Platte

In 2003, installation of a SDI research and demonstration facility was completed at the UNL West Central Research and Extension Center located in North Platte, NE. Funding for this facility was obtained through grants from the Nebraska Foundation and from the US Bureau of Reclamation. The facility covers 12 acres, divided into 72 individual plots. This number of plots can accommodate 18 treatments, replicated four times. Each plot is 30 ft x 237 ft, which can accommodate 12 rows of crop planted at a 30-inch spacing. A drip tape was installed every other row (every 60 inches) at a depth of approximately 16 inches. The drip tape installed was a T-Tape TSX 515-12-340, with a wall thickness of 15 mil, an inside diameter of 0.625 inch and a nominal flowrate of 0.34 gpm/100 ft at 8 PSI of pressure.

The tapes in each plot are connected to an individual supply line at the head of the plot, and to an individual flushing line at the downstream end of the plot. The supply line of each plot is connected to a manifold. The manifold has an air vent, electric valve, flowmeter, and pressure regulator for each plot. The electric valves are then connected to a SDM-CD16AC relay controller (Campbell Scientific, Inc, Logan UT) system that is controlled by a CR10X datalogger (Campbell Scientific, Inc, Logan UT). Eight of the plots are instrumented with $ECH_20^{®}$ Dielectric Aquameters (Decagon Devices, Inc, Pulman, WA) to continuously monitor soil moisture at five depths in the soil profile, to a depth of five feet. The system can be automated by programming the datalogger to respond to environmental inputs, such as soil moisture or weather information. The water supply for the system is a 720 GPM well. A Cycle Stop Valve® (Cycle Stop Valves, Inc., Lubbock, TX), pressure switch, and pressure thank combination was installed at the pump to allow irrigating a reduced number of plots at one time. A chemigation system to allow injecting fertilizer, chlorine, and acid with the irrigation water was also installed. The chemigation system was designed and installed with all the safety devices to meet NDEQ regulations (Vitzthum, 2002).

During the 2003 growing season, the system was used to irrigate a silage corn crop. The system operated as expected, with very few problems. Before installation, Rozol® pocket gopher bait (Liphatech, Inc. Milwaukee, WI) was applied all around the field, with the purpose of preventing rodent damage. No rodent problems were detected during 2003. During the next three years, the facility will be used to conduct an experiment in which several irrigation amounts, nitrogen rates, and methods of nitrogen application for corn will be evaluated. Funding has already being secured to install an additional 72 plots in an adjacent field.

SDI Research Facility at Scottsbluff

The installation of the SDI Research and demonstration facility in Scottsbluff, NE, was completed in 2003. Funding for this facility was obtained from the US Bureau of Reclamation. The facility covers approximately 8 acres and is divided into 34 plots. Each plot is 400 ft x 22 ft, which accommodates 12 rows of crop spaced 22 inches. The system has Netafim Typhoon 630-12.5 mil tapes with drippers spaced every 24 inches and a nominal dripper flowrate of 0.25 gallons per hour at 10 PSI of pressure. The tapes were installed every other row (every 44 inches) at a depth of 10-12 inches. Irrigation to each plot can be controlled using a control manifold installed in each plot. Each control manifold is instrumented with a flowmeter, pressure regulator, electric valve, manual valve, and air vent. The electric valves are connected to a programmable control panel. A flushing manifold was also installed at the downstream end of each plot. The water source for the system is canal water. Water is filtered using a Netafim Disc-Kleen disc filter. The system is also set up to be able to apply chemicals with the irrigation water.

The system was designed to grow corn and dry beans. Sugar beet, which is another important crop in the area, may also be grown with the SDI system in the future. The system will be used for demonstration and, in the next 3 years, an irrigation frequency trial will be conducted. Even though irrigation research could not be started with the system in 2003, the system was used to irrigate a corn crop. Leaks were the main problem detected during the 2003 growing season. Approximately 50 to 60 leaks in the tapes were found, which seemed to be caused by field mice. Digging out the tapes to repair those leaks was a very time-consuming and difficult task.

SDI Research Facility at Lincoln

The objective of installing this SDI research facility was to conduct an experiment to evaluate corn yield potential under intensive management. In 1999 and 2000, the experiment was irrigated to replenish daily crop evapotranspiration via a surface drip system, with the tape placed next to the plants in each row. In 2001, a permanent SDI system was installed with drip tapes in alternate rows at a depth of about 12 to15 inches.

SDI Research Facility at Clay Center

Funding to install a SDI research facility at the UNL South Central Research and Extension Center (SCREC) has been secured since about two years ago. Delays in installing this facility, however, have occurred because of two reasons. First, the Irrigation Engineer leading the effort took a different job and move to another state. Second, because of budget cuts to UNL by the state, the SCREC was closed down and the tenured faculty was moved to Lincoln. The research farm at SCREC, however, will remain in operation and under the control of UNL faculty and some on-site support staff. Therefore, the plans to install the SDI research facility at Clay Center are still underway. Currently, a 40-acre farm is available for this purpose, and a new Irrigation Engineer has recently been hired, who is expected to lead this effort. Current plans are to start the installation during spring of 2004 and initiate a research project in 2005. Initially, a three-year experiment will compare nitrate leaching under SDI and surface irrigation. The experiment will also evaluate different irrigation levels and nitrogen fertigations scheduled using weekly chlorophyll meter readings.

SDI EXTENSION PROGRAMS IN NEBRASKA

In the last few years, a series of extension programs dealing with SDI have been taken place in Nebraska. The University of Nebraska Cooperative Extension, in collaboration with other partners, has been the main institution organizing these programs. Partners have included the Natural Resource Districts (NRD’s), the Natural Resource Conservation Service (NRCS), the Nebraska Department of Environmental Quality (NDEQ), and the irrigation industry, among others. Several of the SDI extension programs that have been conducted in Nebraska include, among others:

- In 2001, the NRCS organized a one-day SDI meeting directed to provide information for NRCS personnel. This included speakers from the SDI industry, including NETAFIM, T-Tape, and Agricultural Products, Inc.

- In 2001, a coalition of groups organized an SDI meeting. Groups represented included the NRCS, the Tri-Basin Natural Resources District, the Lower Republican NRD, and the Harlan County UNL Cooperative Extension. The meeting was held in Alma, Nebraska to discuss SDI and the impact it can have to agriculture. Speakers were invited to share their knowledge and a farmer panel was presented to discuss real life experiences with the 65 people who attended.

- In 2001, UNL Cooperative Extension and NRCS organized a Farmer's Panel on SDI, as part of the Central Plains Irrigation Conference, which was conducted at Kearney, NE. The purpose of the panel was to discuss local farmer's experiences with SDI. Approximately 40 people attended the farmer's panel. Displays from the SDI industry were also presented at this conference.

- In 2001, the Nebraska Fertilizer and Agricultural Chemical Institute conducted and educational program for crop consultants, in Omaha, NE. This program included a presentation on SDI as an emerging technology by a UNL faculty.

- In 2002, a half-a-day SDI meeting was conducted at North Platte, NE. Speakers came from Kansas State University, NRCS, and NDEQ. Also, industry displays were presented. This was an informational meeting covering design, management, advantages and disadvantages of SDI, and legal requirements for SDI. The information was directed to farmers and crop consultants. Approximately 30 people attended this meeting, which included farmers, crop consultants, and agency personnel.

- In 2002, a two-day SDI informational meeting was conducted at Hastings, NE. This meeting presented speakers from the SDI industry (NETAFIM) and from the NRCS. It was mainly directed to educate UNL extension educators, UNL faculty, and personnel from the NRD, NRCS, and other local agencies. Approximately 25 people attended this program.

- In 2002, a field day was conducted at the South Central Research and Extension Center at Clay Center. A presentation on SDI by UNL faculty was included as part of this field day. Approximately 200 people attended this presentation.

- In 2003, UNL Cooperative Extension faculty conducted a series of educational programs focusing on irrigation related issues important to farmers in the state. One of the topics of this program was a discussion of advantages and disadvantages of SDI. It also included the presentation of displays by the SDI industry. The program was offered at five different locations across Nebraska. Approximately a total of 200 people participated in this educational program.

- In addition to educational meetings on SDI, written material and TV spots have produced to educate Nebraskans about SDI (Benham and Payero, 2001; Payero, 2002; Payero, 2003).

NRCS SITES

NRCS has helped SDI in Nebraska by providing cost share funds through the EQIP program and by providing technical assistance for farmers. Following is a description of some examples of SDI demonstrations that NRCS has been involved with.

<u>Leaky Pipe System in Phelps County, NE.</u>

An evaluation of a 67-acre leaky pipe system installed in Phelps County, Nebraska, was conducted by a group of institutions during 1995 and 1996. Funding for the evaluation was provided by a NDEQ 319 non-point Source Water Pollution grant. Institutions involved in the evaluation included the NRCS, UNL Cooperative Extension, Central Nebraska Public Power & Irrigation District (CNPP&ID) and the Tri-basin Natural Resource District. The purpose of the evaluation was to help state and federal agencies determine if the practice was eligible for cost sharing through the Farm Service Agency (FSA) and the Great Plains Conservation Program.

In this farm, a 3/8-inch diameter leaky pipe was installed at 18-inch depth, a 6-ft spacing, and run length of 960 ft. The soil was a Holdredge silt loam with a 0-1% slope. The water source was surface water, which was filtered using a sand-and-gravel medium filter. The system was also instrumented with a venturi fertilizer injection system.
Access points were installed to measure flow and pressure changes at 5 points along three randomly selected laterals. Access tubes were also installed for weekly monitoring of soil moisture at 6-inch increments to a depth of 6 feet. Nitrogen fertigations were scheduled based on chlorophyll meter readings.

During the 1995 evaluation, it was found that the individual line Distribution Uniformity (DU) was poor. The three line tested emitted water a different rates. Section of the line with the higher pressure did not emit the most water. The average seasonal DU for the three lines was only 54%. It was determined that by the end of the growing season the smaller holes on the leaky pipe had become plugged. The average daily application for 1995 had dropped to 0.11 in/day from

0.17 in/day measured in 1994. Chemical treatment applied in 1995 did not improve flows. In August 1995, the water source was changed to well water. Chemical treatment applied in spring of 1996 was able to improve flowrates from 0.11 in/day, measured in 1995, to 0.20 in/day. On July 2, 1996, a pressure switch installed at the filter was causing the filter to continuously flush. On this date the subsurface system was abandoned and a gated pipe system was used for the remainder of the season.

<u>SDI System in Gosper County</u>

In 2002, an SDI system was installed in a 22.8-acre field located in Gosper County, Nebraska, which was previously irrigated by conventional gravity without reuse. In this farm, a 1 3/8 inch diameter T-Tape with a 24-inch emitter spacing was installed every other row (60-inch spacing). The field was 2000 ft in length in the West site and 2500 ft in the East site. The soil was a Holdrege Silt Loam with 0-1% slope. The system was designed to irrigate corn and soybean using a groundwater well. Filtration is accomplished with a Fresno filter with 200-mesh screen. From the producer's prospective, the goals for installing the system were:

- To reduce labor
- To save irrigation water

After two seasons operating the system, the producer feels that 2100 feet of length is the maximum length that can be irrigated with a 1 3/8-inch tape on 0-1% slopes. He feels that half-mile length is too long. In 2003, soil moisture was monitored. It was found that soil moisture stayed pretty consistent in the first 2000 feet of row length and decreased in the 2000-2500 feet section.

The producer has had very little problems with gophers. To prevent gopher problems, after harvesting in 2002 he irrigated to get the area around the tape wet for the winter. He also ran a gopher machine around the borders of the field. So far, he has only had to repair 2 holes. After the 2003 season, he just watered and is still waiting to see the results.

Regarding the quality of the well water, an iron bacteria problem was detected. Because of this, in the second season he chlorinated the well using 100 gallons of chlorine bleach in the spring and chlorinated again with 25 gallons just prior to irrigating. There were no problems during the 2003 growing season. The producer doesn't know if chlorination helped with the iron bacteria or if it was just one of those years where the iron bacteria wasn't around much. At the end of the season, the producer chlorinated the system, not the well. This will be flushed out in spring 2004.

Based on his experience, the producer advice is:

- Know your installer to make sure he knows what he is doing.
- Test your water so you know what water problems you may have to address, if any.

Regarding the original goals, he has found that labor has been reduced and he is pretty sure that there have been water savings in this field, as compared to the previous system, even though water use has not been rigorously measured. He has found, however, that with SDI the problems/headaches are not really decreased or increased, they are just different. From the NRCS prospective, the purpose in 2004 is to use this field as a demonstration site and to compare irrigation water savings between the SDI and conventional gravity irrigation with reuse system.

SDI in the Aurora, NE, Area

In this area there have been quite a bit of interest in SDI, but few have actually installed SDI systems. In 2002 a farmer converted a 15-acre field, located southwest of Aurora, to SDI. According to NRCS personnel in the area, the producer seems to be getting along well with the system. It was a system cost shared by the EQIP program, so NRCS was involved in making sure he had the proper design and installation to meet NRCS specifications. Another farmer, North of Aurora, has also been converting to SDI without NRCS assistance. He has so far installed approximately 50 acres. There have been several others who started the process of applying for help through the EQIP program but then backed out. One of them backed out because he couldn't get anyone to install the system. The others probably just were unsure or became fearful of the unknowns about this fairly new system. There have also been some installations in nearby counties.

CNPP&ID DEMONSTRATION SITES

The Central Nebraska Public Power & Irrigation District (CNPP&ID), in cooperation with The Nebraska Environmental Trust established three SDI demonstration sites in the spring of 2002. The sites are 7-9 acre pivot corners, installed in a single corner of three different pivots across the Irrigation District. CNPP&ID has the following two primary questions to resolve with SDI research:

- Can surface water be used successfully in these systems? and,
- How does water use efficiency (WUE) of SDI compare to the other types of irrigation systems used in the District?

The SDI systems performed well in the 2002 and 2003 seasons; yields on the center pivot corners have met or surpassed yields under the pivot at each of the sites. In particular, higher yields on all SDI corners were noted in 2002 when extended periods of high winds and temperatures, coupled with record low relative humidity and precipitation levels, stressed plants under the pivots for several hours of each pivot rotation. In 2003, adjusted yields for one of the Phelps County fields were 205, 220, and 29 bu/Ac for the pivot, SDI, and dryland, respectively. In-depth study of the WUE question will start in 2004 since cooperators have become familiar with system operation, and soil disturbance around the tape laterals is not as pronounced as in 2002 when the tapes were laid down behind a deep shank chisel. Plans for the future include looking into nutrient applications, relative differences in root development, and further automation of the SDI systems.

Legal requirements for SDI in Nebraska

In Nebraska, according to NDEQ, SDI systems are considered as a Class V injection well, and therefore have to comply with all regulations of Title 122, despite the fact that Title 122 makes no mention of SDI. The full text detailing the requirements of Title 122 can be found at www.deq.state.ne.us. For this reason, before an SDI system can be installed in Nebraska, a permit needs to be obtained from NDEQ. For this, the interested party needs to fill up a NDEQ "*Application for underground injection of fluids using a sub-surface irrigation system.*" This requires information, which includes:

- An aerial photograph of the section in which the SDI system is to be installed, indicating where all wells are located.
- Average flow rate of the SDI system
- Depth to groundwater where the SDI system is to be located.
- Construction details of the water wells.
- Design details of the SDI system.

Also, before chemigating, producers need to be certified by NDEQ. This is done by attending an applicator's certification training and passing a written test. In addition to this, NDEQ requires the SDI system to comply with a series of safety regulations. This is done by obtaining a Chemigation Permit from the local NRD. The NRD has to make sure that all chemigation safety measures have been included in the irrigation system before it can issue a permit, which requires a field inspection. The chemigation permit is valid for one year, which means that the NRD has to re-inspect the system every year. System safety requirements have been described by Vitzthum (2002).

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AVAILABILITY OF CLIMATE DATA FOR WATER MANAGEMENT

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ABSTRACT. Evapotranspiration from crops causes depletion of soil water reserves and without rainfall or irrigation to replenish the soil moisture serious crop stress can occur. The Nebraska Automated Weather Data Network (AWDN) was initiated in 1981 in order to provide information on weather variables that effect crop water use: air temperature, humidity, solar radiation, wind speed/direction, soil temperature, and precipitation. By 2003 the public access to AWDN and related products reached 12M per year. This paper describes the Automated Weather Data Network (AWDN) and the interfaces that provide near real time climate services with emphasis on evapotranspiration (ET) or crop water use. Currently, automated weather stations are monitored daily at 54 locations in Nebraska and 10 new stations have been purchased with federal drought funds. There are over 150 stations available in a nine state region.

1.0 INTRODUCTION

Several major hurdles must be cleared in order to adequately monitor climate resources. First, an adequate data collection system is needed to monitor critical variables at an acceptable sampling and delivery frequency. Second, quality control (QC) and assurance (QA) are necessary. The QC and QA, when linked to a quick response maintenance and repair capability ensures complete and accurate data for use in summaries and products. Third, regular client feedback (surveys, advisory committees, etc.) is needed in order to meet the needs of decision makers and resource managers in the targeted sectors of the economy. It is essential that the interfaces serve the general consulting communities, so that the private sector can develop and deliver value-added products . In some cases, applied research is needed to develop models and other technological tools for the purpose of relating the current climate situation to the area of interest (agriculture, water resources, energy, transportation, recreation, etc.). Another requirement is adequate technology to deliver the summaries and products in a timely manner.

The use of electronic equipment to automate the collection of measurements from weather-related sensors at remote sites has ushered in a change in the ability to collect weather data and Nebraska was the clear leader in this revolution (Hubbard et al., 1983).

Communication and computer technology have greatly increased the ability of scientists to monitor and disseminate the important climate signals. The High Plains Regional Climate Center (HPRCC) in the School of Natural Resources engages in applied research necessary to improve climate products including crop water use estimates.

2.0 DATA COLLECTION

Automated weather stations are maintained at 54 locations in the state. These stations collect hourly data for variables known to be of importance to agricultural crop and livestock production, including air temperature and humidity, soil temperature, precipitation, wind speed and direction, and solar radiation. A computer calls each station beginning at 1 A.M. The data for the previous 24 hours is downloaded, quality controlled, and archived for use by the HPRCC system. A telephone line or a cell phone is installed at each site. A flow diagram is shown in Fig. 1. Software and system components were developed for this system (Hubbard et al., 1990).

Weather stations at remote sites monitor sensors every 10 sec and calculate the hourly averages and where appropriate totals. The minimum set of sensors is shown in Table 1. The installation heights shown are standard for AWDN stations.

The AWDN in Nebraska has grown from 5 stations in 1981 to 54 stations in 2003. Much of the initial growth was due to the interest of researchers who were operating digital weather stations without the benefit of telecommunication or a data management system. Beginning in 1983, the AWDN began to include sites from surrounding states (currently 100 additional stations are collected from 9 nearby states). As time passed the interest in additional stations came from the private sector, resource management agencies, and communities.

Maintenance is an important and costly activity. Replacement of sensor components includes bearings in the cup anemometer and potentiometers in the wind vanes. Relative humidity sensors are calibrated on an annual cycle. The tipping bucket is checked for level and calibrated each year by using the volume to mass relationship for a known amount of water. Leveling screws are adjusted if needed in order to obtain the correct number of tips. Certain sensors are removed from service for calibration. The silicon cell pyranometers are calibrated as a group against an Eppley Precision Spectral Pyranometer (Aceves-Navarro et al., 1989). In a similar manner anemometers can be calibrated against a "secondary standard." Thermistors and humidity sensors can be calibrated directly under controlled conditions. The AWDN facility maintains dry block calibrators and dew point generators for use in calibrating temperature and humidity sensors. Complete troubleshooting guidelines have been developed. AWDN repair and calibration facilities are maintained.

3.0 DATA MANAGEMENT AND APPLICATIONS PROGRAMS

A tremendous amount of data can be generated with an hourly weather network. About 1 Mb of data is produced annually for any three stations. If this data is to be used effectively it must be easy to access. Thus, data management is a real concern. In the case of the AWDN, the approach has been to develop a data management system written entirely in FORTRAN (Hubbard et al., 1992). This system is indicated as the data base component in Fig. 1.

A suite of utility programs includes tools for data management, quality control, data retrieval, and station selection. Applications software includes programs (see Fig. 1) to analyze data and produce summaries for any variable over any desired time period. Summaries include temperature, precipitation, heating and cooling degree days, growing degree-days, evapotranspiration, leaf wetness, soil water, and crop yield.

On the HPRCC Internet site for on-line subscribers a crop water use report may be generated by selecting inputs from the screen depicted in Fig. 3. The user is able to choose any combination of crops, maturity groups, and emergence dates.

An example of the ET product is shown in Fig. 4 as it would appear on the computer screen.

4.0 RESEARCH NETWORK

The High Plains Automated Weather Data Network has served as a source of data for both research and service efforts. Some of the research aspects will be covered in this section and the service aspects will be covered in the following section.

Evaporation (ET) at the earth's surface is a major component of the hydrological cycle and is critical to irrigation scheduling from a water balance approach. Research in the area of evapotranspiration has included efforts to identify the effect of random and systematic errors in measurements used to calculate potential ET (Meyer et al., 1989) as well as efforts to improve the projections of potential ET (Meyer, et al. 1988). The AWDN has also been essential to determining appropriate limits for potential ET in the very arid parts of the High Plains region (Hubbard, 1992).

Monitoring of drought conditions is another research focal point. Robinson and Hubbard (1990) evaluated the potential use of network data in the assessment of soil water for various crops grown in the High Plains. A Crop Specific Drought Index

(CSDI) for corn has been developed and tested (Meyer, et al. 1992a). Results from the studies indicate that the CSDI for corn will be valuable when applied to drought assessment (Meyer, et al., 1992b). A CSDI for sorghum (Paes de Camargo, 1992) was later developed.

Accuracy of interpolation between stations in a network is a topic of research. The spatial interpolation of potential ET (Harcum and Loftis, 1987) was examined using AWDN data. On a related topic, the AWDN data were used to examine spatial variability of weather data in the High Plains (Hubbard, 1994). Another study examined whether it is better to interpolate the weather variables for computing potential ET at a site or to interpolate the potential ET calculated at the surrounding stations (Ashraf, et al., 1992).

The AWDN system has been used to collect basic meteorological data for various field experiments (e.g. Hubbard, et al., 1988). Data taken by the system are also being used in urban water use studies and in project Storm.

5.0 SERVICE NETWORK

Self-Service Access. The HPRCC staff developed an On-Line Internet system (http://www.hprcc.unl.edu/online/home.html) for users which features interactive use of the entire historical archive of the HPRCC. A revised system was released on May 1, 1996 and users transistioned to the new system.

Digital data disseminated by the HPRCC from the new system can be redistributed several times by HPRCC clientele to their user audiences.

On-Line Access System

The current On-line System offers both opportunities and challenges. The positive features of the system are:

- accessible via the web
- the computing power of a work station.
- clientele have on-line access to the historical data archives that date to the late 1800's.
- users can make general summaries according to their own specifications
- up-to-date data is available for decision makers who require it
- an autopilot feature allows users to schedule future summaries, saving the time otherwise required to logon and re-create the summary

- automated information delivery by email or ftp
- greater simplicity of interface
- decreased learning curve
- navigation by 'mouse' point-and-click

The combined accesses to HPRCC internet resources is currently about 12M per year.

6.0 NEW APPLIED CLIMATE INFORMATION SYSTEM

NOAA's National Climatic Data Center (NCDC) and NOAA's Regional Climate Centers (RCCs) are developing a new internet based system designed to provide directed access for user specified queries to the entire combined climate data archives. The new system is called the Applied Climate Information System (ACIS).

ACIS is a distributed and synchronized system that provides consistent and timely climatic products. The implementation of the system at multiple centers provides redundancy and ensures timely availability. The synchronization and standardization ensures that users will receive the same information regardless of the point of contact. The system was designed with layers of independent modules interconnected by Common Object Request Broker Architecture (CORBA) to ensure flexibility in both the location and programming language of the modules. We have used 'open source' and standards based software to reduce any barrier to usage.

ACIS was designed to allow access through three interfaces that provide a different balance of detail, customization, and ease: 1) low-level CORBA, 2) mid-level XML-RPC and 3) high-level web-based interfaces (html). Even the low-level interface provides a fairly abstracted and coherent view of the climate data. Figure 1 shows a series of program steps in the python programming language. In part A, the program gets the acis_id for a station associated with a Cooperative Observer Network station identifier that reports daily maximum temperature (TMAX). The acis_id is an internal id that will define a climatologically coherent record regardless of how the data is reported (NCDC TD3200 format, shef-encoded or locally keyed). Part B of the program creates a TSVar (time series variable) that represents the TMAX values from that station. When a date range is set and data requested, the data server will collect data from local or remote data stores and return it to the client. The client program does not need to know the data format or location. These data stores will change dynamically to return the best available data at the time of the request.

To avoid a single point of failure and regulate traffic, redundant ACIS computer servers are maintained around the country at the six Regional Climate Centers. Data are available from NOAA networks including the Cooperative Observer Network, the Hourly Surface Airways Network, and the Historical Climatology Network. Additional meso-net data such as the Automated Weather Data Network in the High Plains region is also available. Future plans include access to other network data including the USDA's SnoTel Data and NOAA's Climate Reference Network, and several state networks. ACIS provides seamless access to a continuously updated data stream. As a result, standardized products and maps are available for various climate variables and time frames right up to the current time. Climate data users may subscribe to ACIS to obtain access to both near-real time and historical climate information and will receive the same information regardless of which RCC interface they choose. An example of the RCC user interface (UI) is illustrated in Fig. 2 with the UI from the Northeast Regional Climate Center. The UI is standardized for all RCCs with the exception of organizational logos and locally developed products. The UI provides direct access to products that are available for both single station and multiple station analyses and can include listings, comparisons to normal,rankings, extremes of record, first and last occurrence dates and other statistical information on a daily, monthly, or seasonal basis.

The ACIS system is now available to the public. The link to the ACIS system is available at http://hprcc2.unl.edu/Climod/ . Additional links can be found at http://rcc-acis.org. These links take the user to the UI where it is possible to view sample products and use ACIS to set up "individualized" requests on-line, although you will not be able to receive the actual summaries until you become a subscriber. This approach gives you the opportunity to try out the system and see what stations and years are available, as well as see samples of the product/summary before subscribing. Subscription information is available at the bottom of each UI.

7.0 FUTURE ISSUES

The AWDN network must be properly maintained. Personnel for this network include a field technician, a data QC technician, and a computer support person. The projected cost of the network in Nebraska, not including any expansion, is approximately $200,000 per year.

Further research into the factors affecting crop coefficients for the Nebraska Potential Evapotranspiration equations as well as the utility of using the Penman-Monteith equations for ET is needed. Another challenge is the transformation of variables (like wind speed) from a reference weather station site into a crop field of interest.

Table 1. Sensor installation, accuracy and sampling information.

Sensor	Variable	Installation Ht.	Accuracy	Hourly
Thermistor	Air temperature	1.5 m	0.25 C	Avg.(C)
Thermistor	Soil temperature	-10 cm	0.25 C	Avg.(C)
Si Cell Pyranometer	Radiation-Global	2 m	2%	Flux ($W\ m^{-2}$)
Cup Anemometer	Wind speed	3 m	5%(0.5m/s start-up)	Total Passage (ms^{-1})
Wind Vane	Wind direction	3 m	2°	Vector Direction
Coated Circuit	Relative humidity	1.5 m	5%	Avg. (%)
Tipping Bucket	Precipitation	0.5 to 1 m	5%	Total (mm)

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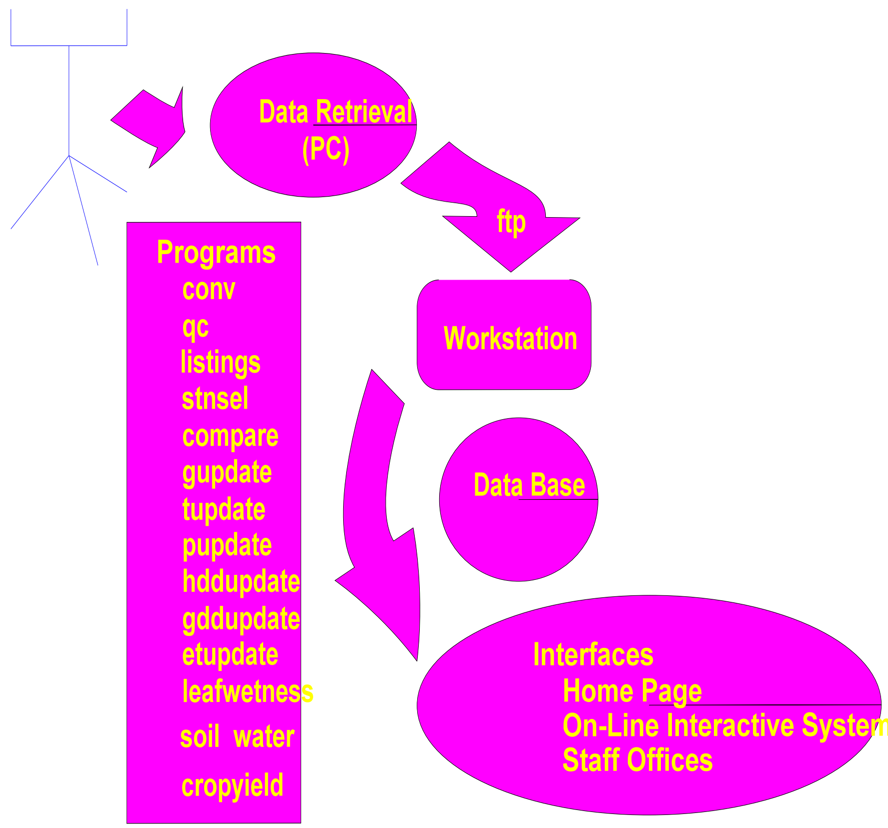


Fig. 1. The flow of data through the automated weather network.

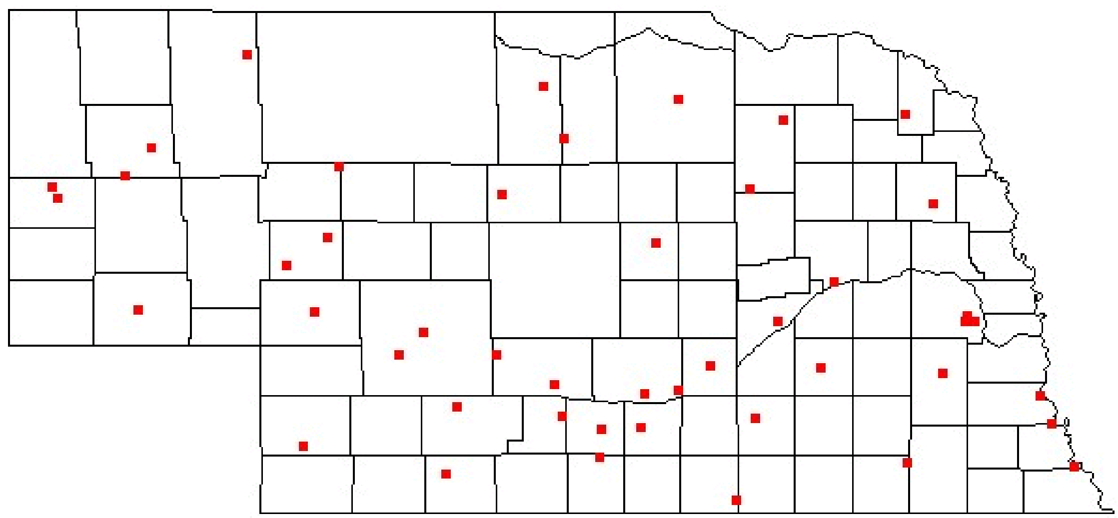


Fig. 2. The AWDN stations in Nebraska. There are eight stations located in the Lincoln vicinity where only one symbol is shown. See other state maps on-line at http://hprcc.unl.edu/awdn/.

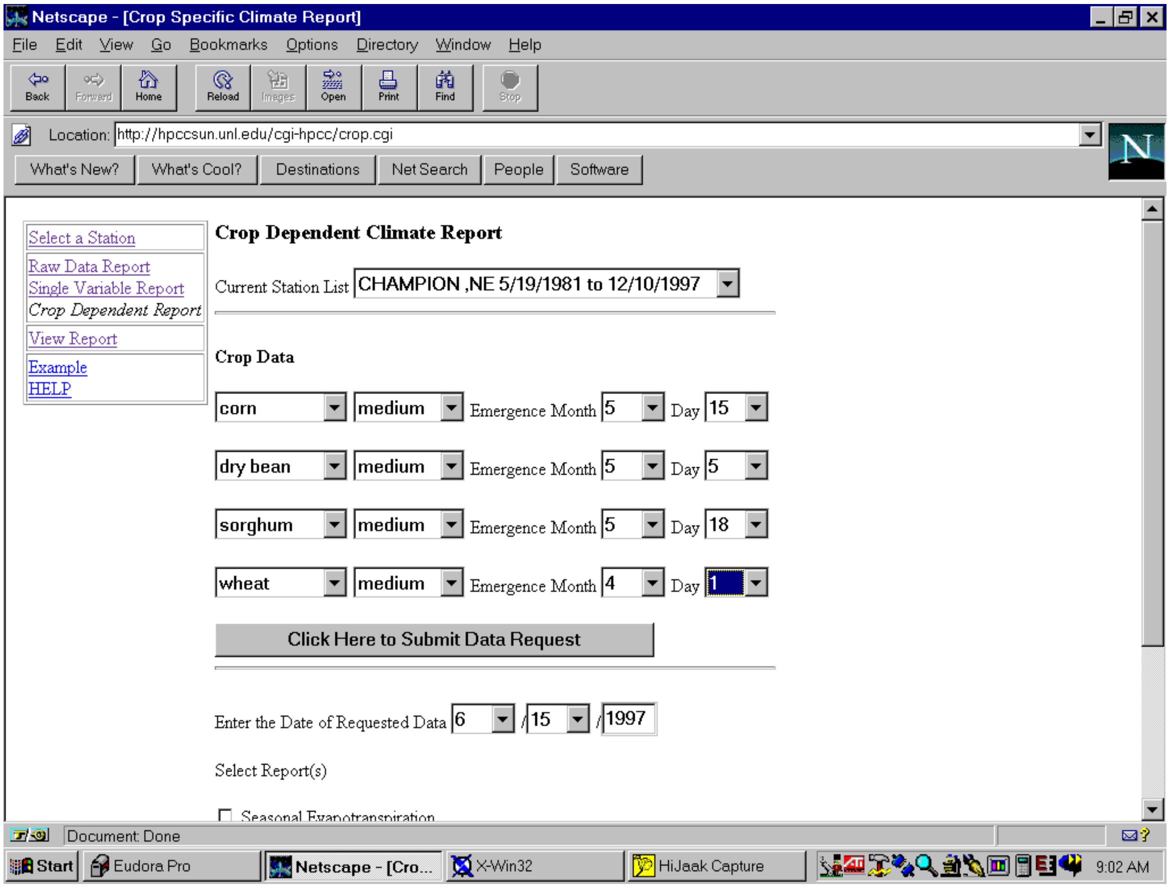
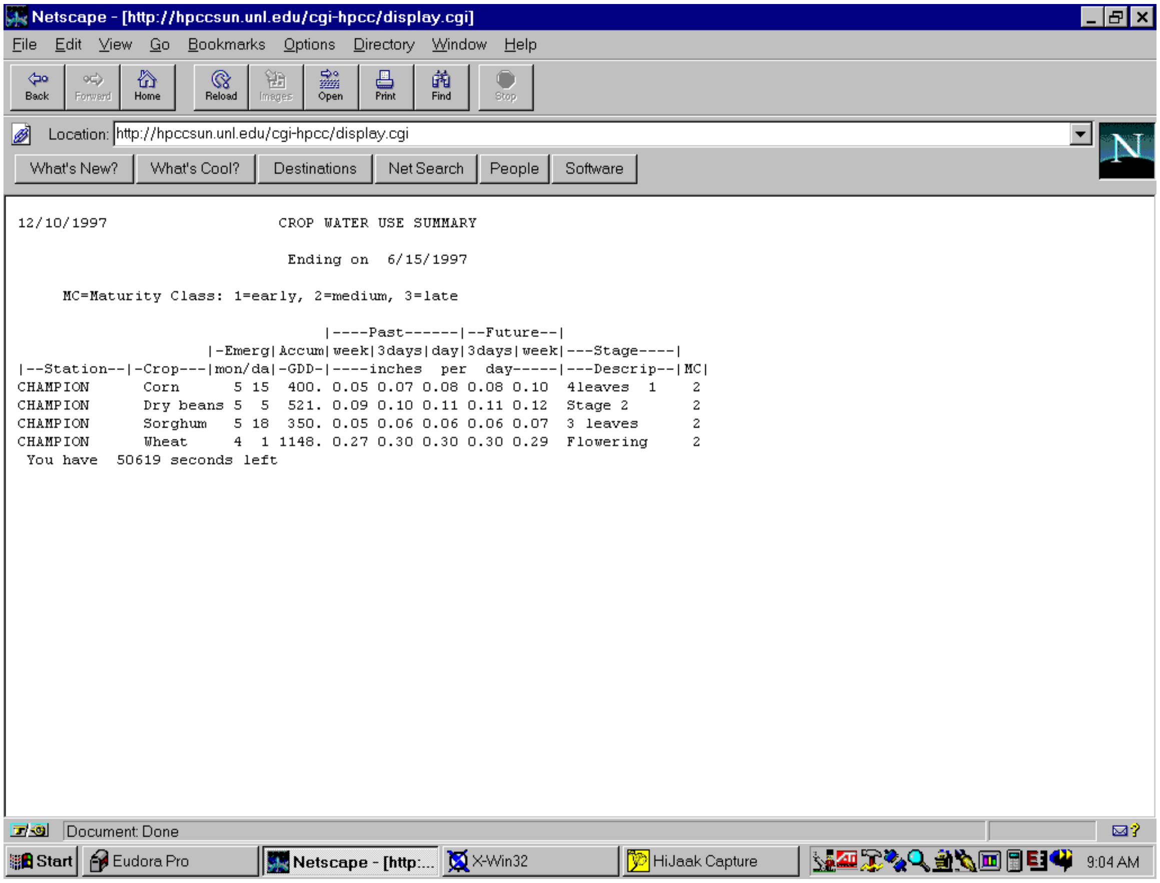


Fig. 3. Input specification screen for the ET Product.




```
12/10/1997                   CROP WATER USE SUMMARY

                              Ending on  6/15/1997

     MC=Maturity Class: 1=early, 2=medium, 3=late

                                  |----Past------|--Future--|
                     |-Emerg|Accum|week|3days|day|3days|week|---Stage----|
|--Station--|-Crop---|mon/da|-GDD-|----inches  per  day-----|---Descrip--|MC|
CHAMPION      Corn       5 15  400. 0.05 0.07 0.08 0.08 0.10  4leaves  1    2
CHAMPION      Dry beans 5  5  521. 0.09 0.10 0.11 0.11 0.12  Stage 2        2
CHAMPION      Sorghum    5 18  350. 0.05 0.06 0.06 0.06 0.07  3 leaves       2
CHAMPION      Wheat      4  1 1148. 0.27 0.30 0.30 0.30 0.29  Flowering      2
 You have  50619 seconds left
```

Fig. 4. Format of the ET product from the On-line System.

TOOLS TO USE FOR WATER MANAGEMENT

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Introduction

There are always new products on the market to improve water management or system efficiency. Sometimes we tend to focus on the newest things rather than those things that make sense for our operation. For example, most producers would prefer having a center pivot over irrigating with gated pipe, yet economics for a given enterprise may not make that change possible for a number of years. At the same time, furrow irrigation should not be considered as an inferior method to manage water any more than a center pivot considered inferior compared to subsurface drip (SDI). With each system comes opportunities to make improvements in irrigation efficiency but each system also requires different changes in management practices to achieve those improvements.

An important water management issue for any irrigation system is determining how much and when to apply water. Installing SDI offers improved system efficiency, but with that improvement comes changes the operator must use to obtain rewards from this technology. For example, SDI offers the ability to apply water on a daily basis which means knowing daily crop water requirements is important to prevent crop stress.

For center pivots, the primary differences among systems are sprinkler packages. Sprinkler packages perform differently due to crop, soil type and slope, therefore water application varies. Although daily water use is important, it's more likely water use from a series of 3 - 4 days will be summed to determine when and how much to irrigate.

Those that are using furrow irrigation will find that their scheduling practices will be much different than either SDI or center pivot irrigation. Furrow systems tend to fill a significant portion if not all of the soil profile where roots are actively growing. This difference means that scheduling irrigations will be based on matching water use over a longer period of time, perhaps a week or more.

In any case, SDI, center pivot or furrow, the same basic information was needed but used in a different way to properly manage water for irrigation. Finding the desired management information often proves to be a challenge in itself. To find information on irrigation scheduling, other irrigation topics and general crop production recommendations, visit one of the university websites listed below. These are examples of the type of information available. Browse the sites for even more information. Production information is added on a weekly basis to provide answers to your production questions.

University of Nebraska Websites:
www.ianrpubs.unl.edu/ - For irrigation related topics at this site you need to select either Irrigation Engineering or Water Management under the Browse Publications section. For information on a specific crop, click Field Crops to find information on irrigating crops such as corn and winter wheat.

www.extension.unl.edu/farm_ranch.htm - At this site is a self paced study guide on water quality(Irrigation(Managing) and Nitrogen to Protect Water Quality). There is also information on Nebraska's Irrigation Home Study Course.

www.cropwatch.unl.edu/ - Crop Watch presents timely crop production information from researchers and extension specialists.

Kansas State Websites:
www.oznet.ksu.edu/sdi - This is K-States subsurface drip irrigation website which offers an array of information from design and pictures to publications, reports and fact sheets going back to 1990.

www.oznet.ksu.edu/irrigate - This site provides answers to general questions. It includes a number of reports and also access to the faculty at K-State.

www.oznet.ksu.edu/mil - At K-States Mobile Irrigation Lab website you can find what the Mobile Irrigation Lab provides and by clicking on "MIL Tool Kit and Resources", access KSU's fact sheets. Using their quick links find a center pivot depth calculator for determining pivot application at different panel settings.

Colorado State Websites:
www.ext.colostate.edu/menuwater.html - Get answers to water resource questions, including questions concerning the drought in the High Plains.

www.colostate.edu/Depts/SoilCrop/extension/WQ/ - This site provides a number of publications related to CSU's water quality program. One of their newer publications at this site is "Best Management Practices for Colorado Corn", and includes a number of irrigation topics.

http://ccc.atmos.colostate.edu/~coagmet/extended_etr_form.php - This site provides ET (crop water use data) for irrigation scheduling. The site allows you to choose planting date, crop and the closest weather station to your farm.

KanSched An ET-Based Irrigation Scheduling Tool for Kansas Summer Annual Crops

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KanSched is a computer software program that is designed to help monitor the root zone soil profile water balance and schedule irrigation events on a field using evapotranspiration (ET) data. The program can also be used to monitor the soil profile water content of non-irrigated fields. ET-based irrigation scheduling is a tool that can help you determine when and how much irrigation water to apply. The basic process involves using data on crop water use (crop evapotranspiration or ETc), rainfall, and soil water storage to assess when an irrigation event is needed and how much water could be applied. KanSched was developed to be user friendly with minimal training requirements and operational inputs.

This program was developed as part of the Mobile Irrigation Lab, which is supported by a partnership between K-State Research and Extension, the Kansas Water Office with State Water Plan Funds, Kansas Water Resources Research Institute, and the Kansas Corn Commission.

General Overview

Irrigation scheduling that uses ET information is much like checkbook accounting procedures where the valued commodities are tracked. In this case, soil water, rather than money, is the valued commodity and the debit is crop water use while credits are rainfall and irrigation. One notable difference is that the water balance can be too high as well as deficient. ETc, short for crop evapotranspiration, is the amount of water that a crop withdraws from the soil water reserve. Deposits to the soil water reserve are rainfall and applied irrigation. The major goal of the accounting procedure is to help the irrigation manager keep the amount of water in reserve above a minimum soil water balance level to prevent water stress to the growing crop. The upper limit to the account is the amount of water that can be physically stored in the root zone area of the soil profile. Deposits of water, once the upper limit is exceeded, result in the water being lost as either deep percolation or surface runoff.
Irrigation scheduling can help minimize deep percolation losses, although even the most rigorously followed schedule cannot prevent all losses since large rainfall events can exceed soil water storage capacity by themselves. The benefits of irrigation scheduling generally translate into increased net returns

through several possible avenues. Irrigation scheduling may also reduce irrigation labor and equipment operation pumping cost, and may also result in improved yields due to less water stress or less loss of fertilizer due to leaching.

One of the major obstacles to adoption of on-farm irrigation scheduling has been the time management problem of gathering, processing, and implementing scheduling on a daily irrigation cycle period. Computer technology presents the opportunity for information gathering, transferring, and processing to be done much more easily, efficiently, and sometimes automatically. Scheduling software, communication, and control technology exists that can provide management recommendations which could then be remotely implemented. This text will describe the basics of KanSched and illustrate some of the input windows and help screens.

The Start Screen

Each time KanSched is started the screen in Figure 1 appears and the operator has several options to choose from depending on how the program is to be used.

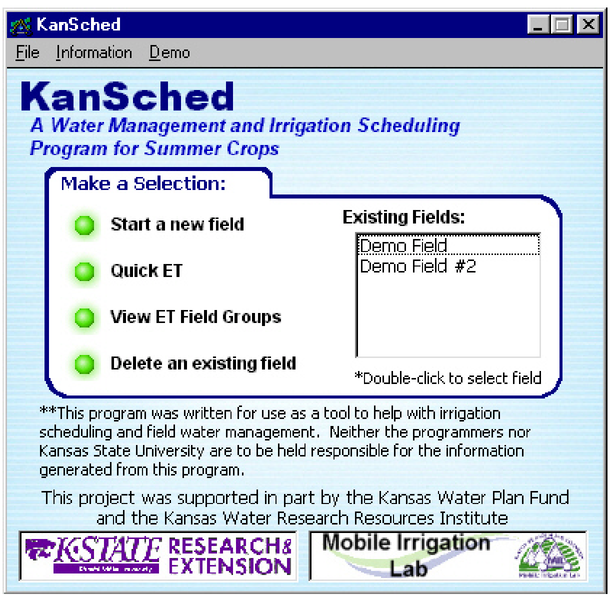

Figure 1 – The start screen of KanSched

To initialize a new field, click the green button labeled "Start a new field". A new window will appear displaying the input boxes for the initial field information and soil information (Figure 2). The input screen will be discussed in detail later.

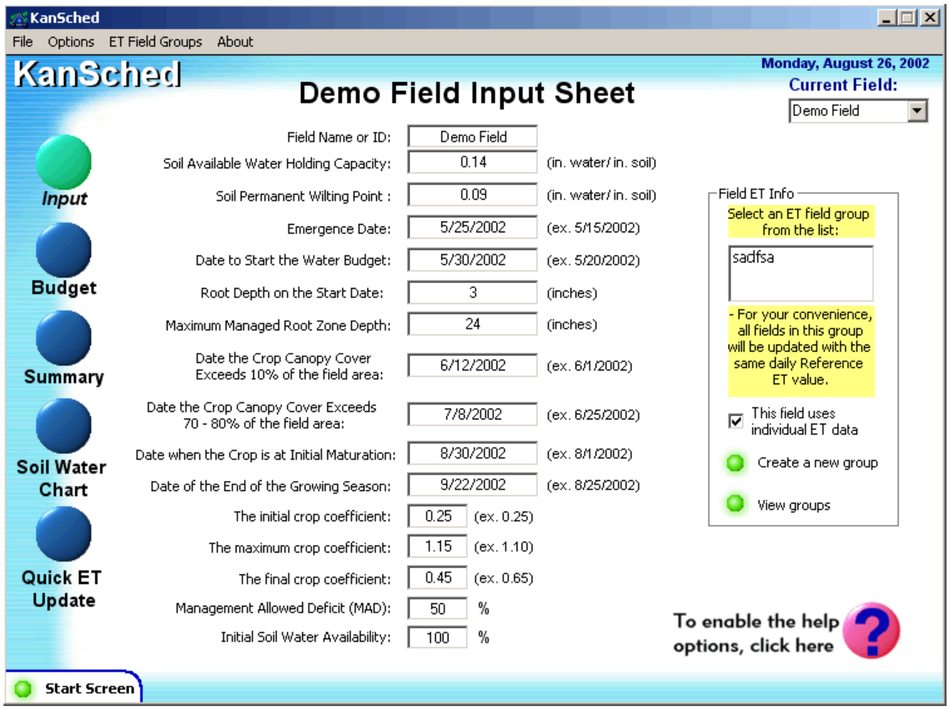

Figure 2 – The input data screen of KanSched

KanSched can be set up to allow quick entry of daily reference ET data for a group of fields that are in the same region with the use of the "Quick ET Update". When an ET group is selected, the fields within the group can all be updated with ET values at one time.

Entering Information Into KanSched

Before KanSched can begin tracking the field's soil water content and crop water usage, information about the soil type, growing season, and crop for each field are needed as follows. The Input Screen

The Input screen (Figure 2) requires some information that characterizes the soil type, growing season, and crop type for a field. All of the inputs on this screen must be entered before KanSched can track your field's soil water content and crop water usage. If some of these values are unknown, simply click the question mark button  in the lower right corner of the screen to obtain a help screen. Help is available in any of the sections that become highlighted, and accessed by clicking on the question mark button associated with a section. Help screens are available for soil characteristics, crop growth characteristics, and crop coefficients.

Soil Available Water Holding Capacity and Soil Permanent Wilting Point:

The soil available water (AW) holding capacity value is a measure of the maximum amount of water a soil can hold that is usable to the crop. The soil permanent wilting point (PWP) value is the water content of the soil when the crop cannot pull the water from the soil, causing the plant to wilt. Both of these values are measured in inches of water per inch of soil. If these values are not known, simply click the help button in the lower right hand corner of the input screen to enable the help options, then select the help button in the soil characteristics section. The help screen for the soil section is shown in Figure 3. The soil's water holding characteristic value can be selected based on the soil texture from the drop-down list at the top of the screen. The default values on this help page are from the NRCS soil characteristic database.

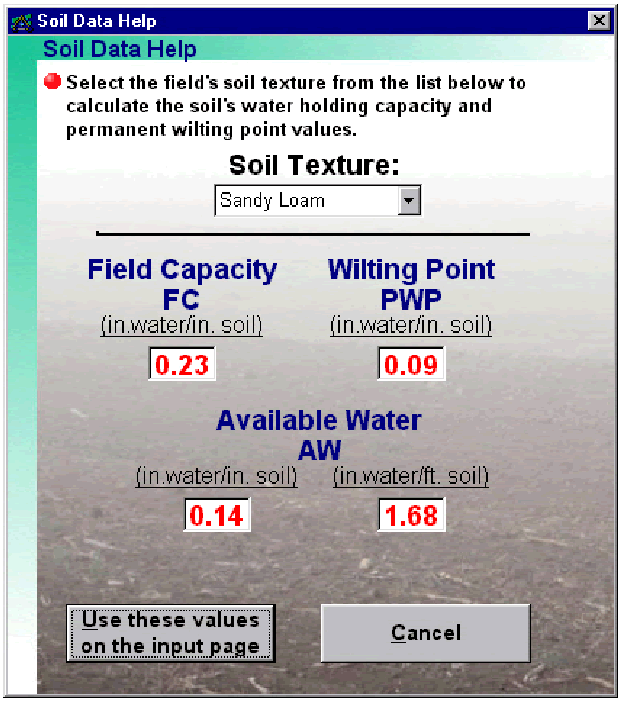

Figure 3 – The Soil Help Screen

Emergence Date:

KanSched needs to know the emergence date of the crop in order to start tracking water usage. The emergence date is simply the date your crop emerges from the ground after planting.

Date to Start the Water Budget:

The water budget start date is the date that KanSched will actually start tracking the soil water content. This date must be after the emergence date.

Root Depth on the Start Date:

KanSched tracks root growth throughout the season. In order to do this, it must know the root depth on the date it starts the water budget. This can be determined by going out to the field on the start day and dig around the crop to measure the root depth. The root depth can also be set to the desired management depth at this time as well.

Maximum Managed Root Zone:

Entering a maximum managed root zone lets KanSched calculate the maximum depth of the soil profile that your crop can draw water from. While the actual root depth may be deeper, this value is the managed depth for the crop's roots.

Normally, managed root zone depth is 3 to 4 feet unless the root-depth is limited by restrictive soils.

Date the Crop Canopy Cover Exceeds 10% of the field area, Date the Crop Canopy Cover Exceeds 70-80% of the field area, Date when the Crop is at Initial Maturation, and Date of the End of the Growing Season :

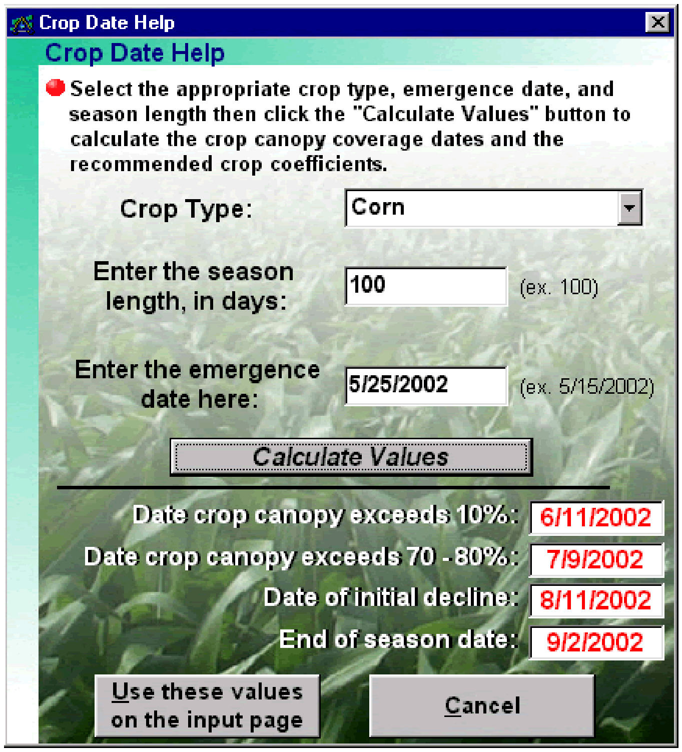

Figure 4 – The Crop Date Help Screen

The above dates are required by KanSched in order to monitor the growth stages of the crop and to create a crop coefficient curve. Assistance with calculating these values is available using the help option in this section, shown in Figure 4. Select the crop type, enter the season length and emergence date and press the **Calculate Values** button. The calculated values are displayed at the bottom of the screen. Click the “Use these values on the input page” button to automatically enter these values on the input screen; however, they can be adjusted later if needed.

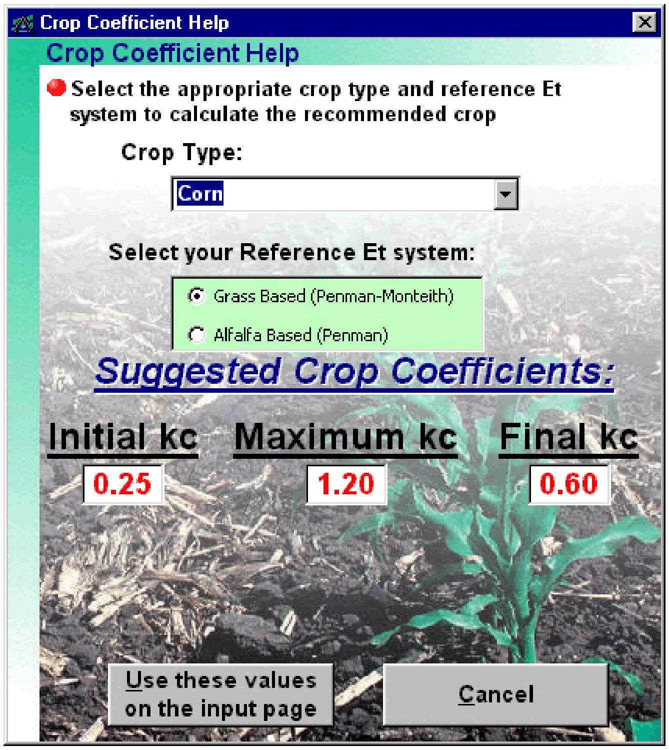

Figure 5 – The Crop Coefficient Help Screen

The Initial Crop Coefficient, The Maximum Crop Coefficient, and The Final Crop Coefficient:

To determine how much water the crop is using, KanSched uses crop coefficients. The crop coefficient changes over the season; starting very small, increasing as the crop grows, peaking at the beginning of reproduction, then declining as the plant's water usage stops with maturation. To gain assistance with calculating these values, enable the help options and click the associated question mark button. The Crop Coefficient Help screen is shown in Figure 5. Select the crop type and the reference ET system.

Management Allowed Deficit (MAD):

The Management Allowed Deficit is the guideline on the percentage of the available water in the soil that will be removed by the crop before crop water stress is likely. The MAD value will vary across different crops and according to how risk adverse a producer is a MAD of 50 percent is recommended for most row crops.

Initial Soil Water Availability:

Before KanSched starts tracking your soil water content, it must have an initial value to start with. The initial soil water availability is the percentage of available water to the crop on the budget start date entered earlier. A value of zero (0%) is associated with the permanent wilting point water content while a value of 100% represents a full profile at the field capacity level. KanSched defaults to 100%, but this value usually needs to be changed to reflect the initial soil water value.

The Budget Screen

The Budget screen (Figure 6) consists of rows of input for each day. These inputs include reference ET, rainfall, and gross irrigation. When these inputs are entered into

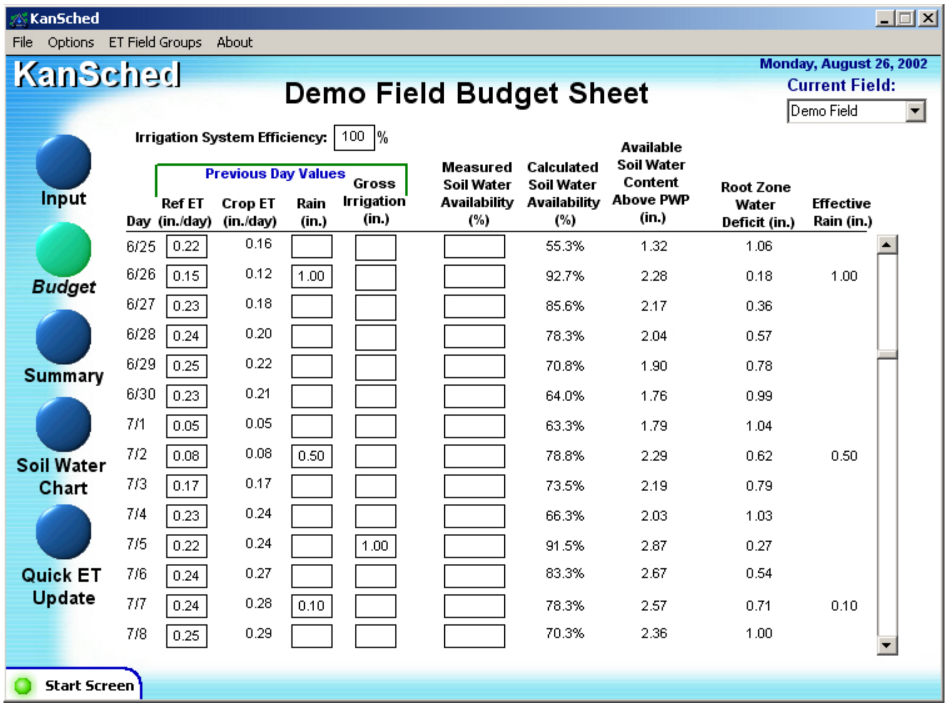

Figure 6 – The Budget Sheet

KanSched, it can track the soil water that is available to the crop. The following sections describe the individual inputs needed and the program's output.

Reference ET and Crop ET

The reference ET values can be obtained from on-site measurements or from an automated weather station in the region. This value needs to be entered for each day of the season as KanSched tracks the water content. However, ET values from several days can be entered at one time. The reference ET can also be updated using the Quick ET button from the start screen.

After the daily reference ET value is entered, KanSched will calculate and display the crop ET. This value is the amount of water (in inches) the crop used during each of the listed days. KanSched uses the crop coefficient values and the reference ET values to calculate the crop ET value.

Rain and Effective Rain

Whenever the crop receives rainfall, the value is entered for the appropriate day and it will then be used to calculate the soil's current water content.

How does KanSched handle rainfall events on a soil that is already at field capacity? Basically, when the soil profile is at field capacity, any water that is applied to the field will either run off or be lost in the soil through deep percolation. KanSched keeps track of the soil's current profile status and will ignore any rainfall or irrigation events that occur on the soil when it has reached field capacity. This ensures that the program will not credit the soil with more water than it can hold when it receives many rainfall events (or one large rainfall event) in a short period of time.

Gross Irrigation

Input gross irrigation amounts into KanSched whenever an irrigation event occurs. At the top of the budget sheet (Figure 6) is an input box labeled *Irrigation System Efficiency*. By default, a value of 100% is entered, meaning that KanSched uses the exact value entered into the Gross Irrigation box. The estimated efficiency of the system should be entered into this box. Then, each Gross Irrigation value will be recalculated to a Net Irrigation value.

Measured Soil Water Availability

KanSched allows the option of entering a new Soil Water Availability value any time during the irrigation season. KanSched tends to be a conservative estimate of soil water. Therefore, if KanSched is indicating that the soil is drier than it actually is, simply enter a new value for the soil water availability, automatically recalibrating KanSched to the accurate field-based values.

Calculated Soil Water Availability

KanSched's calculation of the available water in the soil is displayed in the *Calculated Soil Water Availability* column. This value can be defined as the percent of water that is available for the crop to use from the available water profile. When this value drops below the MAD value, the *Calculating Soil Water Availability* numbers turn red, alerting the manager to the current situation. A value of zero (0%) represents PWP while 100% represents field capacity.

Available Soil Water Content Above PWP

Another way that KanSched interprets the soil's current water content is in the *Available Soil Water Content Above PWP* column. This is an estimate of approximately how much water is in the soil that the crop can use before it enters the permanent wilting point. Keep in mind that when the water content reaches the MAD value, crop stress is beginning to occur.

Root Zone Water Deficit

The *Root Zone Water Deficit* value displays how much water (in inches) the managed root zone soil profile needs before the water would be lost either to runoff or deep percolation.

Soil Water Chart

One of KanSched's most useful features is the Soil Water Chart, shown in Figure 7. This chart shows a visual representation of the field soil water content as it changes

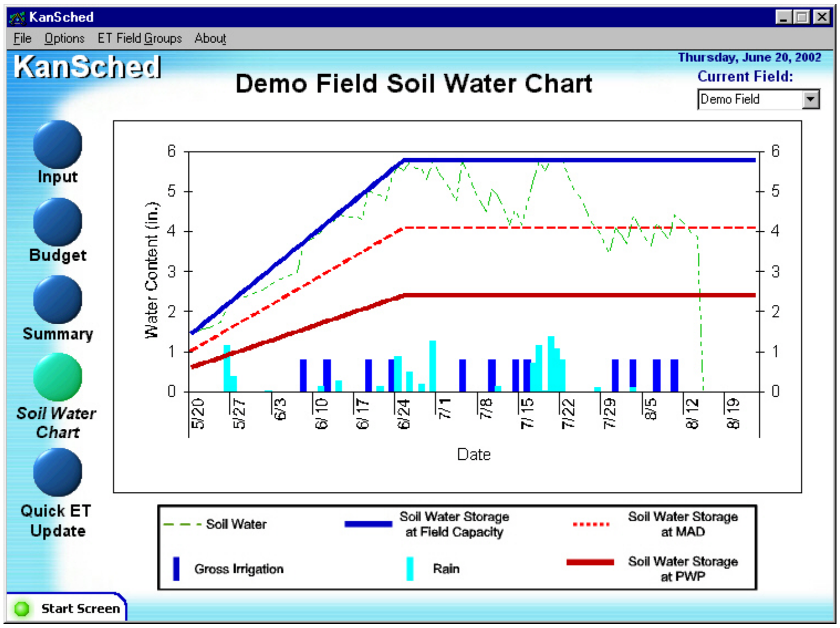

Figure 7 – Soil Water Management Chart

throughout the season. In addition, each rainfall and irrigation events are displayed at the bottom of the chart. The horizontal axis of the chart is labeled with the dates of the crop season, while the vertical axis is in units of inches of water contained within the defined soil profile. Before fully utilizing the Soil Water Chart, one must understand how to read the chart. The following section describes each component of the Soil Water Chart.

The Soil Water Chart has the ability to get detailed information about any point on the chart. Using your mouse, position the cursor arrow and click on any line or column in the chart to get information about that point. This is an easy way to see how much rain or irrigation was received on a particular day, without having to scroll through the budget page to find the information.

Soil Water Storage at Field Capacity, PWP, and MAD

The dark blue line that forms the upper boundary of the chart is called the *Soil Water Storage at Field Capacity* line. This line represents the total amount of water that your soil can hold before runoff or deep percolation occurs. This line also represents a water availability value of 100%. This value is determined using the soil characteristics from the input screen and the depth of the root zone, as are the PWP and MAD values described next.

The dark red line that forms the lower boundary of the chart is called the *Soil Water Storage at PWP* line. This line represents the moisture content of the soil where plants are unable to pull the water from the soil, causing them to wilt and die. This line also represents a water availability value of 0%.

The dotted red line represents the MAD level that was chosen during the initial input process for the field. One way to manage a field's soil water content is to attempt to keep the dotted green line (the calculated soil water content) close to the dotted red line (the MAD value). Of course, the MAD value is only a visual representation of an individual's management preference. As the water content goes below the MAD value, plants may wilt and experience some stress. Therefore, KanSched derates or reduces crop coefficients when this occurs and simulated crop water use is reduced.

Current Soil Water-
The dotted green line represents the calculated soil water content of the soil. As the line approaches the upper dark blue line, the soil's water content is increasing. Likewise, as the dotted green line approaches the lower dark red line, the soil's water content is decreasing

Gross Irrigation-
Each irrigation event is represented by a dark blue column and is plotted on the date the irrigation was received. The height of the column reflects the amount of the irrigation event.

Rain-
Much like the irrigation events, a light blue column represents the rainfall events on the date the rainfall was received. The height of the column reflects the amount of rain received.

The Summary Screen

The summary screen (not shown) gives a snapshot of the current total season amounts for the crop of total reference ET, crop ET, rainfall, effective rainfall, gross irrigation amounts, and net irrigation amounts. A periodic check-up on this screen shows the current water-use statistics at a glance.

Extra Features in KanSched

KanSched has several built in utilities to increase the functionality of the program. The following section will describe each of these utilities that allow an individual to archive a field and export the field information to a text file. Archive a field allows the beginning of a new season for the same field without having to create a new field or delete the old data. Exporting the data allows individuals to do additional analysis of their data using spreadsheet programs.

KanSched Availalbility

KanShed is available via the web at www.oznet.ksu.edu/mil. CD copies are available at KanSched training meeting in Kansas and by request by contacting a Kansas County Extension Office.

ENVIRONMENTAL QUALITY INCENTIVE PROGRAM AND PRACTICING IRRIGATION WATER MANAGEMENT

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All conservation water management practices done in cooperation with the Natural Resources Conservation Service (NRCS) Environmental Quality Incentive Program (EQIP) Ground and Surface Water Management (G&SW) involve some level of irrigation water management. The EQIP project does not end with the installation of an irrigation practice, it is only the beginning.

Once the NRCS and an EQIP Participant have entered into a contract it is the goal of NRCS to be involved “in the field” by demonstrating and showing the irrigator how to utilize the available water management tools. Although the irrigator is in control of when and how much to irrigate; NRCS teaches that irrigation water management is a balance of science and forecasts predictions to determine when and how much to irrigate. NRCS hopes to improve upon the current water management techniques while preserving and sustaining our natural resources.

The level and techniques of irrigation water management are a function of how the irrigator wishes to manage the irrigation system. NRCS traditionally teaches and demonstrates conventional techniques such as: using soil moisture probes for soil sampling, using the appearance-feel method for available soil moisture content, and using locally published crop Evapotranspiration (ET_c) data to forecast crop water use. These measurement techniques, or versions there-of, can be a very effective means of practicing irrigation water management.

NRCS also recognizes the technological advances in the arena of automated irrigation water management. These automated techniques can use data logging and/or telemetry type equipment with soil moisture sensing equipment to provide continuously recorded real time soil moisture readings. This information can then be readily available to the system operator in order to adjust and schedule the irrigation system for real time field conditions.

Once the technique of irrigation water management has been established record keeping and documentation become a vital means of implementing the irrigation water management part of the EQIP Contract. Every EQIP Ground and Surface Water Contract contains a clause in which the irrigator agrees to practice and document his or her particular irrigation water management program for a specified time. Typically this is for two to three irrigation seasons after the practice has been installed on the field. Subsequent records are provided to the NRCS for the items agreed to within the EQIP Contract.

The primary documentation tool that NRCS has offered to irrigators for use in documenting their irrigation water management program is the attached NE-ENG-80 Form (IRRIGATION WATER MANAGEMENT RECORD SHEET). Instructions on how to complete and use this form are also attached. Assistance in completing this form can also be provided through your local NRCS Office. Populating and utilizing this form regularly can aid in the process of deciding when and how much to irrigate. It will also allow the irrigator to know exactly how much water has been pumped per irrigation and how much has been pumped over the course of an irrigation season. An irrigator can use a different version of this form if they so chose, as long as the form is equivalent in content.

The irrigation water management tools, techniques, documentation forms and one-on-one NRCS Technical Assistance all work toward sustaining and preserving our natural resources. It is also the hope that after EQIP contractual requirements have been met the irrigator will continue to utilize these tools to fine tune their irrigation water management techniques.

U.S. Department of Agriculture
Natural Resources Conservation Service

NE-ENG-80
10/94

IRRIGATION WATER MANAGEMENT RECORD SHEET

Name (1) ______________________________ Field (2) ______________ Tract (3) ______________

Irrigated Area (4) ________ acres Length of Run (gravity irrigated) (5) ______________ Average Furrow Grade or Slope(6) ______________

Well/Water Source Output (7) ____________ GPM Date Measured (8) ____________ Crop (9) ____________ ET Station (10) ____________

Soil Type (11) ____________ Available Water at Field Capacity in Root Zone (12) ________ inches Maximum Allowed Depletion (13) ________ inches

Irrigation Record

Date (14)													
Soil Moisture Def[1] (15)													
(ET) Rate[2] (16)													
Inches Appl.[3] (17)													
Meter Read – Start (18)													
Meter Read – Stop (19)													
No. Gates Open (20)													
Out Time[4] (21)													
Set or Rev. Time (22)													

Rain Gauge Record

Date (23)																		
Inches (24)																		
Date																		
Inches																		

Notes (25)

[1] Soil Moisture Deficit in inches beginning of day in root zone.
[2] The ET rate used for scheduling the current irrigation.
[3] Gallons pumped /27,154/acres = inches applied (gross).
[4] Average time for water to reach the end of 50% of the rows (conventional furrow).

Seasonal Water Application (26) ____________ inches Seasonal Rainfall (27) ____________ inches

INSTRUCTIONS FOR IRRIGATION WATER MANAGEMENT RECORD SHEET

(1) Name of producer.
(2) Field number in which IWM is being applied.
(3) ASCS tract number.
(4) Number of acres in field.
(5) Length of furrows if gravity irrigated.
(6) Average furrow grade if gravity irrigated or slope of field if sprinkler irrigated.
(7) The well or water source output in gallons per minute.
(8) The date that the water source output was last checked or measured.
(9) Crop grown.
(10) Location, phone number, radio station, of evapotranspiration (ET) data for the nearest weather station.
(11) Soil type.
(12) Available water at field capacity in the crops root zone for the soil listed (normally 3 foot).
(13) The maximum allowed depletion of the available water before irrigation should be scheduled.
(14) The date each irrigation is started.
(15) The soil moisture deficit on the day that irrigation is started, this is the amount in inches that the soil will hold, without runoff or deep percolation.
(16) The evapotranspiration (ET) rate, or the average daily crop water use rate on the day the irrigation is started.
(17) Inches applied, this is the gross amount of water pumped or delivered to the field or to the set, whichever applies. The sum of this line equals the gross amount delivered to the field for the season.
(18) This is to record the meter reading, clock time or hour meter reading at the beginning of each irrigation.
(19) Meter reading at the end of each irrigation. (Same as above)
(20) The number of furrows being irrigated for this set or irrigation. The average gallons per minute flowing down the furrows may be substituted when furrow length varies or set size is not constant.
(21) This is the average time it takes for one half of the furrows in any given set to reach the end of the field, and the data can be used to evaluate the irrigation to make adjustment to achieve higher efficiency, more uniform distribution, or decrease deep perk.
(22) This line is used to record the time water is allowed to run on the set being evaluated. In cases where this record is being pushed on Center Pivot irrigation, record the hours for one revolution of the pivot.
(23) Record the dates of rainfall during the growing season.
(24) Record the rainfall amounts for the field.
(25) Keep factors that need explanation in the notes.
(26) Total irrigation water application for the season.
(27) Total rainfall for the growing season, at a minimum rainfall from May through September must be kept.

Note: The use of this form is intended to satisfy requirements to record irrigation information for various water quantity or quality programs in Nebraska. It is not intended for this form to be considered a water management plan or complete scheduling tool. The information included on this form will be used to evaluate the irrigation system to determine the effectiveness of the system.

Water Savings from Crop Residue in Irrigated Corn

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Introduction

During the past 10-15 years, there has been a great deal of emphasis in sprinkler applications to move closer to the target. The thinking has been to decrease the exposure to potential evaporation in the air. At the same time sprinkler manufacturers have produced heads with lower operating pressures producing fewer fine spray particles leaving far fewer particles subject to evaporation. The result is that application efficiencies have improved.

What remains are the same wet soil surfaces beneath the crop canopies. We need to spread the water to gain infiltration, but then evaporation from the soil surface takes over after irrigation stops. It has been assumed that evaporation from the soil surface in irrigated crop canopies is relatively small. The objective of this paper is to report on some of the research in the area of evaporation from soil surfaces.

Evaporation-Transpiration Partition

Transpiration, or the process of water evaporating near the leaf and stem surfaces, is a necessary function for plant life. It is literally the final driving force for water flow through the plant. It provides plant cooling. Transpiration relates directly to grain yield in the crops we produce. Transpiration rates are driven by atmospheric conditions and by the crop's growth stage. As a crop grows it requires more water until it matures and generally reaches a plateau. Daily weather demands cause fluctuations in transpiration as a result. Soil water begins to limit transpiration when the soil dries below a threshold generally half way between field capacity and wilting point. Irrigation management usually calls for scheduling to avoid water stress.

Evaporation from the soil surface may have some effect on transpiration in the influence of humidity in the crop canopy. However, the mechanisms controlling evaporation from soil are independent of transpiration. The combined processes of evaporation from soil (E) and transpiration (T) are measured together as evapotranspiration (ET) for convenience. Independent measurements of E and T are difficult. Independent measurements are becoming more important as we strive to tighten management of sprinkler irrigation to achieve more efficient water use.

Field research has shown that in sprinkler irrigated corn as much as 30% of total evapotranspiration is consumed as evaporation from the soil surface (Klocke et. al., 1985). These results were from bare soil conditions for sandy soils with sprinkler irrigation. For a corn crop with total ET of 30 inches, 9 inches would be going to soil evaporation and 21 inches to transpiration. This indicates a window of opportunity if the unproductive soil evaporation component of ET can be reduced without reducing transpiration.

Evaporation from Soil Trends

Evaporation from the soil surface after irrigation or rainfall is controlled first by the atmospheric conditions and by the shading of a crop canopy if applicable. Water near the surface readily evaporates and does so at a rate that is only limited by the energy available. This so called energy limited evaporation lasts as long as a certain amount of water that evaporates, 0.47 in (12 mm) for sandy soils and 0.4 in (10.2 mm) for silt loam soils. The time it takes to reach the energy limited evaporation depends on the energy available from the environment. Bare soil with no crop canopy on a sunny hot day with wind receives much more energy than a mulched soil under a crop canopy on a cloudy cool day with no wind.

After the threshold between energy limited and then soil limited evaporation is reached, evaporation is controlled by how fast water and water vapor can move through the soil to the soil surface. The relationships that have been developed to describe soil limited evaporation are shown in Fig 1 for a silt loam soil. There is a diminishing rate of evaporation with time as the soil surface dries. The soil surface insulates itself from drying as it takes longer for water or vapor to move through the soil to the surface.

The challenge for sprinkler irrigation is the high frequency that the soil surface is put into energy limited evaporation. With twice-weekly irrigation events it is likely that the soil surface will be in the higher rates of energy limited evaporation during the entire growing season. Only during the early growing season with infrequent irrigations and little canopy development would there be a possibility for lower rates of soil limited evaporation.

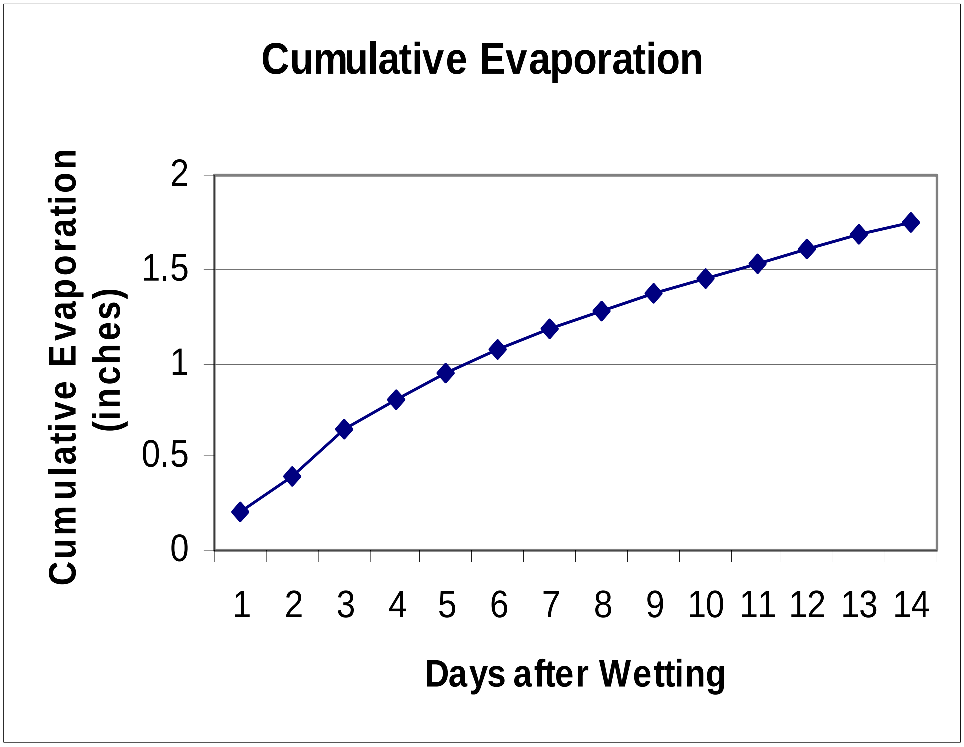

Fig.1. Soil limited evaporation after day 2 as described by E = C*t^-1/2.

Evaporation and Crop Residues

For many years, crop residues in dryland cropping systems have been credited for suppressing evaporation from soil surfaces. Evaporation research dates back into the 1930's when Russel reported on work with small canister type lysimeters (Russel, 1939). Stubble mulch tillage and Ecofallow have followed in the progression of innovations with tillage equipment, planting equipment, and herbicides to allow for crop residues to be left on the ground surface. These crop residue management practices along with crop rotations have increased grain production in the Central Plains. Water savings from soil evaporation suppression has been an essential element. In dryland management saving 2 inches of water during the fallow period from wheat harvest until planting corn the next spring was important because in meant an increase of 20-25 bushels in the corn crop. This difference came from the presence of standing wheat stubble during the fallow period versus bare ground.

The question is to what extent water savings could be realized from crop residue management in sprinkler irrigation. A research project was conducted during the mid 1980's to begin to address this question. Four canister type lysimeters were placed across the inter-row of sprinkler irrigated corn. The lysimeters were 6 inches in diameter and 8 inches deep and were filled by pressing the outer wall into the soil. The bottoms were sealed and the lysimeters were weighed daily to obtain daily evaporation from changes in daily weights. Increases in soil water over time due to elimination of root extraction in the lysimeters were compensated with a procedure of switching a duplicate set of lysimeters immediately after each irrigation or significant rainfall. When a set of lysimeters was not in field use it was dried and brought to field soil water content immediately before replacement in the field.

Half of the lysimeter treatments were bare and half were covered with flat wheat straw at the rate of 6000 pounds/acre or the equivalent to the straw produced from a 60 bu/acre wheat crop. The other variable was irrigation frequency. One treatment was dryland, receiving no irrigation. The next treatment was limited irrigation, receiving three irrigation events, one during vegetative growth, one during flowering, and one during grain filling. The last irrigation treatment was full irrigation with nine irrigation events. The first seven irrigations were delivered at week intervals and the last two and approximately two week intervals. The sprinkler irrigation system was a solid set equipped with low angle impact heads on a grid spacing of 40 ft X 40 ft. The corn population varied with the irrigation variable and was appropriate with the expected water application and yield goal for that treatment. The resulting leaf area, shading, and biomass followed accordingly.

The results of the field study conducted near North Platte Nebraska are in Figures 2 and 3. The soil for the study was a silt loam. The first striking result was in the dryland treatment. The unshaded bare and straw covered lysimeters nearly tracked each other for daily evaporation. There were only six rainfall events that measured over 0.4 in (10 mm) of precipitation. The pattern of cumulative evaporation for the bare dryland treatment indicates brief periods of energy limited evaporation. This indication is more subtle for the straw covered treatment. Even more interesting is that the straw mulched treatment has the same evaporation as the bare treatment for dryland management under the crop canopy. The straw mulch did not play an additional role in reducing the energy limited evaporation beyond the roll of the crop canopy.

For limited irrigation, three irrigation events were added, 2.0, 2.0, and 1.75 in. depths. The cumulative evaporation for bare soil, unshaded treatment showed the classic patterns of energy limited-soil limited evaporation. These patterns were suppressed in the other treatments indicating that the canopy and residue

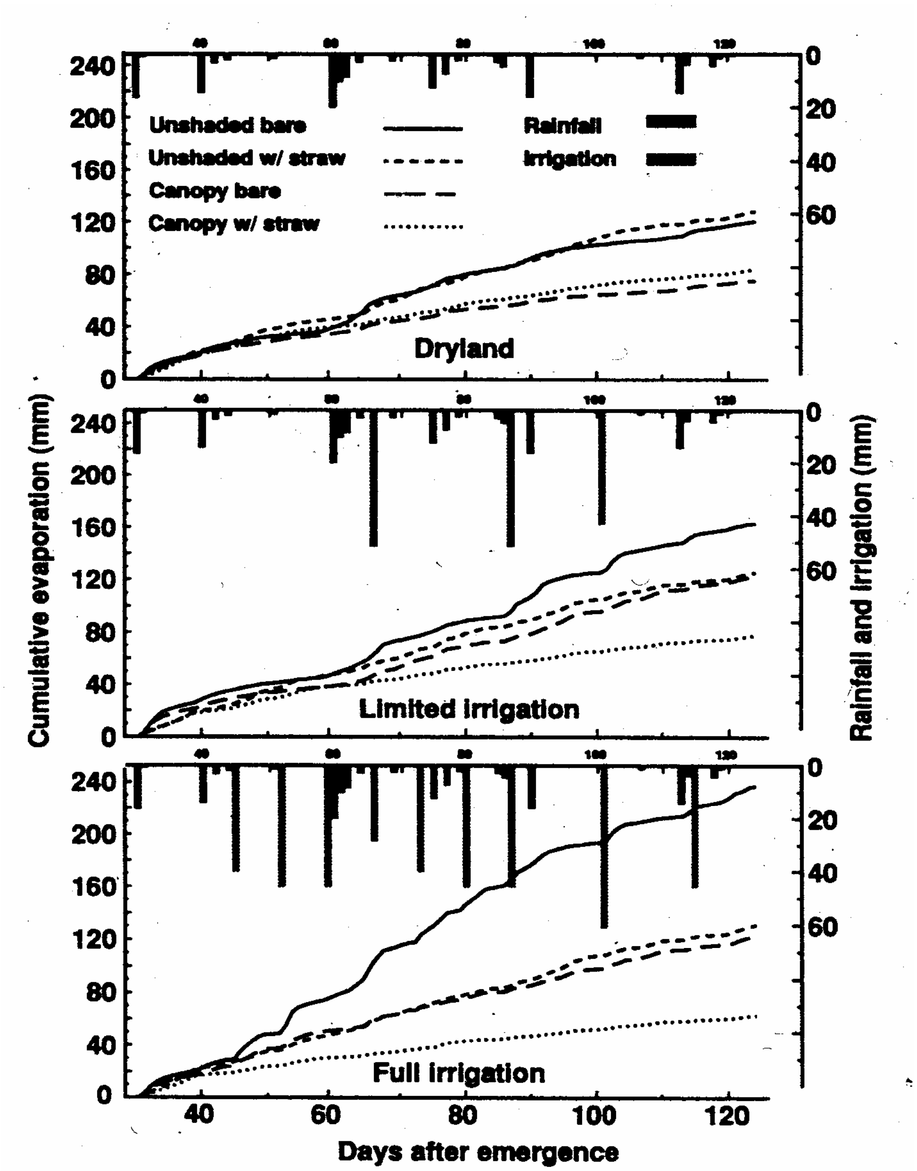

Fig. 2. Cumulative evaporation for dryland. limited irrigation, and full irrigation management. (Todd et, al., 1991)

prolonged the transition from energy limiting to soil limiting evaporation. During the last 40 days of the season the mulched unshaded treatment and bare treatment under the canopy closely tracked one another and ended with similar cumulative evaporation. The singular contribution of the straw mulch and crop canopy, each acting alone, were the same. However, in limited irrigation straw mulch added a benefit to the canopy effect that was not evident in dryland management.

Full irrigation included nine irrigation events, seven of which were at weekly intervals and two were at two-week intervals. The pattern of cumulative evaporation from the unshaded bare soil treatment indicated periods of both energy and soil limited evaporation. These patterns are more subtle early in the bare soil treatment under the crop canopy. The magnitude of unshaded bare soil

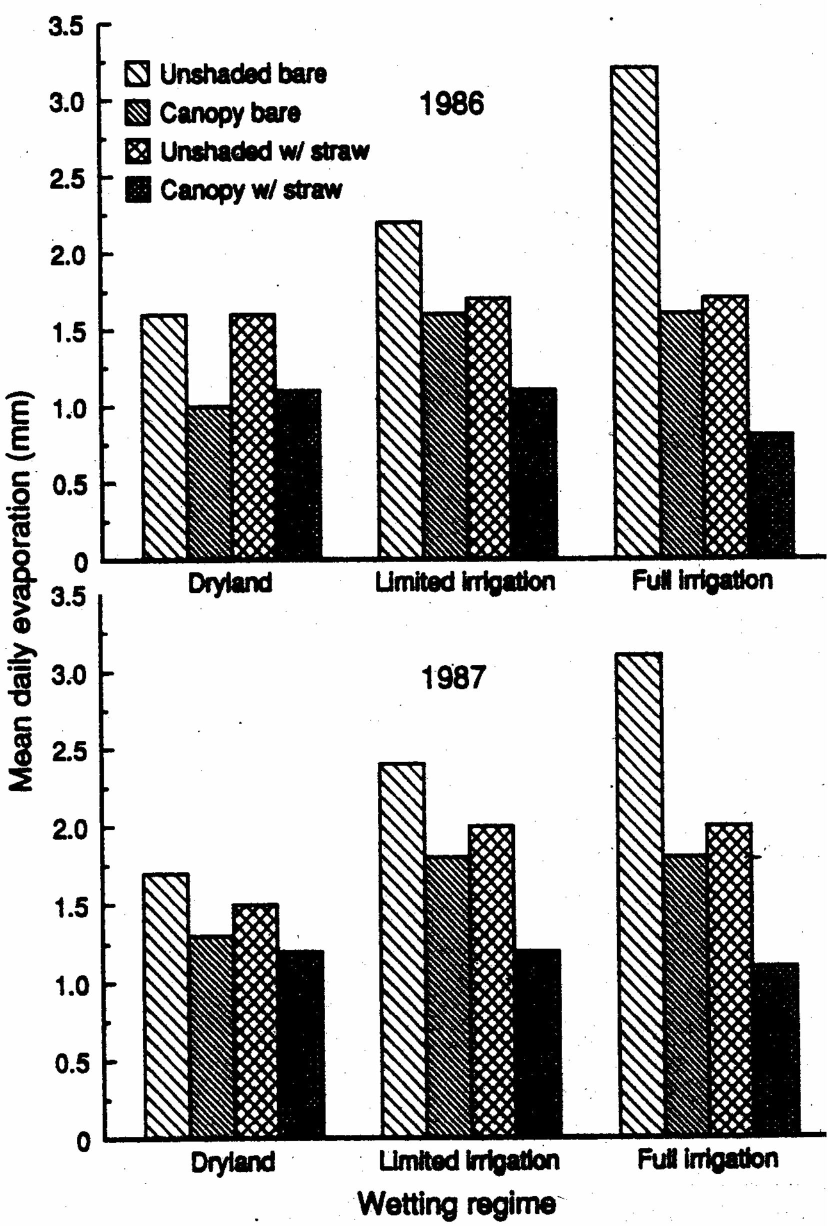

Fig. 3. Mean daily evaporation for dryland, limited irrigation, and full irrigation management. (Todd et. al., 1991)

evaporation is far greater in the fully irrigated treatment, but the unshaded mulched and bare soil evaporation under the canopy is similar to the limited values. These latter two treatments also track each other closely as they did in they limited management. The mulching effect was even greater in the fully irrigated management than the limited and dryland management. This effect started early and carried on throughout the growing season.

Table 1. Full growing season evaporation including irrigation and rainfall days.

Year	---Unshaded------ Bare	Straw	---Shaded------- Bare	Straw
	------------------in/season----------------			
	-----------------Dryland--------------------			
1986	7.6	7.6	4.7	5.2
1987	8.0	7.1	6.1	5.7
	---------------Limited Irrigation----------			
1986	10.4	8.5	7.6	5.2
1987	11.3	9.4	8.5	5.7
	------------Full Irrigation------------------			
1986	15.1	8.5	7.6	3.8
1987	14.6	9.4	8.5	4.7

Table 2. Full Season Water Savings From Straw Cover.

Year	---Unshaded-----	----Shaded------
	----------------in/season------------------	
	--------------------Dryland-----------------	
1986	0.0	0.0
1987	0.9	0.5
	---------------Limited Irrigation----------	
1986	1.9	2.4
1987	1.9	2.8
	---------------Full Irrigation---------------	
1986	6.6	3.8
1987	5.2	3.8

Full Season Results

Cumulative evaporation results in figure 2 do not include days with occurrences of irrigation or rainfall. Measurements were not taken on these days. Data were collected from June 10 to September 13 in 1986 with 78, 75, and 75 days of collection from dryland, limited irrigation, and full irrigation, respectively. In 1987, data were collected from May 28 to August 20 with 65, 64, and 59 days of collection, for dryland, limited irrigation, and full irrigation, respectively.

To understand the possible full season implications of this study, the average daily evaporation rates were applied to the missing days of data. The results are shown in Table 1. These evaporation values may still be conservative since evaporation rates are highest immediately after wetting. The potential full season reduction in evaporation by the wheat straw cover is then shown in table 2.

Soybean Study Results

A similar study was conducted in Garden City, Kansas during 2003 in soybean canopy. Two twelve inch diameter PVC cylinders that held 6-inch deep soil cores were placed between adjacent soybean rows. The soybean rows were spaced 30 inches apart. The lysimeters were either bare or covered with corn stover or standing wheat stubble, which were cored into natural field settings. The treatments were replicated four times and the plots were irrigated twice weekly.

The results are in Table 3. The field measurements were taken from July 18 until September 6. A projection of evaporation from July 17 to planting was made to estimate full growing season savings from crop residue covers. Future research will be carried out to confirm these projections. However, these results give the same possibilities for reductions in evaporation as the results from the previous Nebraska corn study. Also, the role of corn stover is shown. The corn stover in the lysimeters covered 87% of the soil surface, which equivalent t very good no-till residue cover. These results reflect the maximum capability of the residue for evaporation suppression.

Table. 3. Total evaporation and savings by crop residues in soybean.

	Data Period		Pre Data Period		Season
Surface Cover	Total in	Savings In	Total in	Savings in	Savings in
Bare Soil	3.1		4.1*		
Corn Stover	1.8	1.3	2.4*	1.7*	3*
Wheat Straw	1.5	1.6	2.1*	2*	3.5*

*Projected

Summary

No matter how efficient sprinkler irrigation applications become, the soil is left wet and subject to evaporation. Frequent irrigations and shading by the crop leave the soil surface in the state of energy limited evaporation for a large part of the growing season. Research has demonstrated that evaporation from the soil surface is a substantial portion of total consumptive use (ET). These measurements have been 30% of ET for E during the irrigation season for corn on sandy soil. It has also been demonstrated that crop residues can reduce in half the evaporation from soil even beneath an irrigated crop canopy. The goal is to reduce the energy reaching the evaporating surface.

We may be talking about seemingly small increments of water savings in the case of crop residues. The data presented here suggests the potential for a 2.5-3.5 inch savings in water due to the wheat straw during the growing season. Dryland research would suggest that stubble is worth at least 2 inches in water savings in the non growing season. In water short areas or areas where water allocations are below full irrigation, 5 inches of water translates into at least 60 bushels of corn. During 2003, many irrigators in the Central Plains could have used an extra 5 inches of water.

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Saving Water and Energy - Crop Residue Management

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INTRODUCTION

Crop residue left on the soil surface is one of the easiest and most cost-effective methods of reducing soil erosion. Research in Nebraska and other midwestern states has shown that leaving as little as 20 percent of the soil surface covered with crop residue can reduce erosion from rainfall and flowing water by one-half compared to residue-free conditions. Greater amounts of cover will further reduce erosion. (Refer to University of Nebraska NebGuide G81-544, "Residue Management for Soil Erosion Control" [*http://www.ianr.unl.edu/pubs/fieldcrops/g544.htm*] for further details on the erosion process and the benefits of residue cover.) Crop residue also acts as a mulch, helping to reduce soil moisture losses, thus making more moisture available for crop use.

Determining the amount of residue cover can be done in several ways. Obtaining in-field measurements using the line-transect method is the most accurate. (Refer to University of Nebraska NebGuide G93-1133, "Estimating Percent Residue Cover Using the Line-Transect Method" [*http://www.ianr.unl.edu/pubs/fieldcrops/g1133.htm*] for specific procedures.)

In many instances, such as for planning purposes, estimates of percent cover may be adequate. For example, it may be desirable to determine if eliminating a certain operation from a tillage and planting system is likely to result in adequate residue cover to meet the level called for in a conservation plan. The calculation method of estimating residue cover can be useful for such a determination.

The calculation method involves first determining or estimating the amount of residue cover present after harvest. This value is then multiplied by estimates of the percentage of cover that will remain following weathering, tillage, and any other residue-disturbing operations. This article discusses many of the factors that influence the reduction of residue cover, and presents estimates of the amount of residue cover expected to remain following tillage and other residue-disturbing operations.

RESIDUE COVER AFTER HARVEST

Determining the amount of residue cover after harvest is the first step in the calculation method. This is most accurately done by measurements in the field using the line-transect method. If this is not possible, an average value can be used. Table 1 presents typical after-harvest percent residue cover values for various crops. Use these values with caution, as the actual amount of cover in a particular field can vary considerably depending on crop variety and yield, conditions throughout the growing season, and other factors. For all crops, the residue should be uniformly distributed at harvest, not left in windrows, clumps, or bunches.

FACTORS INFLUENCING RESIDUE REMAINING

Fragile or Non-Fragile Residue

Crop residues have been classified as fragile or non-fragile, Table 1. This classification is based on factors such as plant characteristics (size and amount of leaves and stems), total amount of plant material produced, and ease of residue decomposition or breakdown when the residue is disturbed or exposed to the weather. Soybean residue would be an example of a fragile residue, whereas corn and grain sorghum residues are classified as non-fragile.

Residue-Disturbing Operations

Estimates of the percentage of residue cover remaining after various residue-disturbing operations are listed in Table 2. For a given implement, the actual amount of residue remaining will be influenced by many factors, including implement design, adjustments, speed, depth of soil disturbance, previous residue disturbance, and soil and residue condition. The ranges of values given for both fragile and non-fragile types of residue account for some of these factors.

Be conservative and use careful judgement when selecting values from the table. Do not use all high values; the result is usually overestimation of final cover. This is especially true on land that is designated as highly erodible. For these areas, values near the lower end of the range usually result in better estimates of actual cover. However, if all implements are designed, adjusted, and operated with the specific goal of preserving residue cover, values near the middle or upper end of the range may be appropriate.

Moisture and Climate

Biological processes cause a general deterioration of residue condition. Moisture and warmer temperatures increase the rate at which this occurs.

One way that residue cover is affected by moisture and climate is an actual reduction of percent cover due to decomposition or decay of the residue, particularly the leaves and small pieces. In a study of soybean residue, a 31 percent loss of cover occurred between measurements taken after harvest and again before spring field operations in southeast Missouri. Approximately 25 inches of rainfall was received between these two measurements. In northwest Missouri, with cooler temperatures and about eight inches of rainfall during the same time period, losses averaged 12 percent. Conditions in southeast Nebraska and northeast Kansas are generally similar to those in northwest Missouri, and some actual residue cover loss is likely over the winter. However, in much of Nebraska, over-winter losses do not appear to be a significant factor. For example, in a northeast Nebraska study, the amount of soybean residue cover was comparable both after harvest and in the following spring.

Even though actual decreases in percent cover may be minimal, with exposure to the weather, residue becomes more fragile over time. This is most pronounced for residue that has been tilled or otherwise disturbed, but it also occurs with undisturbed residue. Because of less annual precipitation, this change takes place more slowly in western Nebraska than in the eastern part of the state.

Timing of Operations

Weathering and when the residue-disturbing operations are performed are closely related. If residue is disturbed in the fall by grazing, tillage, stalk chopping, manure incorporation, or knifing-in fertilizer, subsequent spring operations reduce cover more than if all operations are conducted in the spring. This is because fall tillage and knifing operations cut or break the residue into smaller pieces, mix soil and residue, and speed over-winter weathering, thus making the residue more susceptible to decomposition and burial in the spring. University of Nebraska research showed that for the same sequence of field operations used in corn residue, residue cover measured after planting averaged 12 percent less when one or more operations were conducted in the fall, compared to performing all operations in the spring. For operations that are done in the fall, use values towards the lower end of the ranges in Table 2 or include an additional weathering reduction factor for fall operations, also listed in Table 2.

In contrast, when operations are conducted with little elapsed time between them, less reduction of residue occurs. In these cases, values near the upper end of the range are generally appropriate. For example, when disking and field cultivating on the same day, the field cultivator may cause little additional loss of cover. The field cultivator simply redistributes the residue that is on the soil surface. Under certain conditions, the field cultivator may also bring buried, coarse residue to the surface, resulting in a slight increase in cover, perhaps up to five percentage points. However, if there are more than a few days and it rains between disking and field cultivation, field cultivation generally results in reduced levels of cover.

Results from a residue grazing study provide an example of the effects of prior residue disturbance on the amount of cover reduction. No-till planting into un-grazed corn residue reduced the cover by 10 percent, from 83 percent cover to 75 percent; whereas no-till planting into residue that had been grazed reduced the cover by 16 percent, from 62 percent cover to 52 percent.

A winter wheat/fallow rotation provides an illustration of the combined effects of weathering and timing of tillage operations. Shortly after harvest, the wheat residue often appears to be quite resistant to breakup and burial by tillage. But, by late the next summer at the end of the fallow period, the residue has become quite fragile. Percent residue cover following a tillage operation near the end of the fallow period is likely to be less than what it would have been following the same tillage operation done shortly after harvest. However, when additional operations are conducted, greater cover reductions will typically occur for the system where tillage was first done shortly after harvest and the disturbed residue was exposed to the weather, compared to the system where the residue remained undisturbed during much of the fallow period and operations were delayed until near the end of the fallow period.

Use values at or near the upper end of the ranges listed in Table 2 when an operation is performed within two or three days of the previous operation. Use values near the middle of the range if a week or more elapses between operations, especially if more than about one-half inch of precipitation or irrigation also occurs. Use values near the lower end of the ranges if operations are conducted over a month apart.

Chopping or Shredding of Residue

Chopping or shredding the residue may result in reduced amounts of cover. In University of Nebraska research on corn residue, tillage and planting systems that included a stalk chopping operation had an average of 22 percent less cover after planting than when the residue was not chopped. Although percent cover appeared to increase immediately after chopping because the residue had been cut into smaller pieces and was redistributed, the chopped residue deteriorated more from the weather and subsequent field operations than non-chopped residue. If the residue is chopped, this additional reduction needs to be included in the calculations to estimate the amount of cover that is expected to remain.

For small grains, if a rotary combine or a combine with a straw chopper is used, the residue should be considered to be fragile. In these cases, use the values in Table 2 that are for fragile residue.

Livestock Grazing

Livestock grazing will reduce the amount of residue cover. The amount of reduction depends on factors that include stocking density (number of animals per acre), animal size, length of the grazing period, whether the residue is from irrigated or dryland crops, how much ear drop or other losses occurred during harvest, how much supplemental feed is supplied, and weather conditions. As an approximation, the Natural Resources Conservation Service estimates that each 1000 pound cow will remove 15 percent of the available cover per acre per month; or 0.5 percent cover removed per cow per acre per day.

Although estimates of cover reduction can be used, the best procedure for grazed residue is to use the line-transect method to measure the amount of cover at the end of the grazing period. This value can then be used for the calculations instead of percent cover after harvest.

Residue Cover Carry-Over

Under certain conditions, residue cover may remain on the soil surface for more than one cropping year. Carry-over is most likely to occur under dry climatic conditions when residue that is classified as non-fragile has received only minimal disturbance, such as with no-till planting. In a long-term experiment using a grain sorghum/soybean rotation, residue cover measured after planting grain sorghum averaged approximately 15 percentage points less for a no-till planting system with row cultivation than no-till without cultivation. Some grain sorghum residue remained on the soil surface during the year that soybeans were grown and was also present the following spring. However, residue cover carry-over is highly variable, and generally should not be relied on to provide significant amounts of cover.

ESTIMATING PERCENT RESIDUE COVER

An approximation of the percent residue cover after planting can be obtained by multiplying the percent residue cover after harvest by the appropriate values from Table 2 for weathering and for each residue-disturbing operation that is conducted or planned.

Selecting appropriate values to use in the calculation method is a key to obtaining reasonably accurate results. All operations and other factors that affect residue cover need to be accounted for. Think in terms of a complete sequence of operations. For each operation, evaluate how the residue will be affected by both prior and subsequent operations and by weathering.

<u>Examples</u>

The following examples illustrate how to use information from Table 2 to estimate residue cover by the calculation method. Assume that a tillage and planting system used in a field of irrigated corn residue in southeast Nebraska consists of three field operations:

1) anhydrous ammonia application in the fall using a knife-type applicator with rigid shanks;
2) tandem disking in the spring; and
3) planting soon after disking using a conventional planter with double disk openers and no coulters.

95% initial cover	x	0.75 knife applicator	x	0.90 winter weathering	x	0.60 disk	x	0.95 planter	=	37% final residue cover

Using the same tillage and planting system in soybean residue would result in only about nine percent cover, which is not enough for effective erosion control.

70% initial cover	x	0.45 knife applicator	x	0.85 winter weathering	x	0.40 disk	x	0.85 planter	=	9% final residue cover

If the corn residue example was changed to dryland production on highly erodible land in northeast Nebraska, and rainfall occurred between the disking and planting operations, less than 20 percent cover would remain after planting.

80% initial cover	x	0.75 knife applicator	x	0.99 winter weathering	x	0.35 disk	x	0.85 planter	=	18% final residue cover

Consider the calculation method to be only a rough estimate since the variables involved prevent accurate determination of percent residue cover. However, this method can be useful in residue management planning by offering a general idea of how much residue cover will remain after a specific sequence of operations. There are also computer programs available to predict percent residue cover. However, these programs use the calculation method and average values for residue cover reduction, and as such should be used only when a rough estimate is satisfactory.

SUMMARY

Crop residue management, or maintaining residue on the soil surface, is the most cost-effective method of reducing soil erosion available to Nebraska farmers. Accurate estimates of percent residue cover are necessary to determine if sufficient cover is available to adequately reduce erosion and to comply with conservation plan specifications. When accurate estimates are needed, percent cover should be measured using the line-transect method.

When only rough estimates of percent cover are adequate, the calculation method is often useful and appropriate. This method can be used for initial planning purposes to evaluate certain crop residue management goals and/or to compare potential residue cover remaining for a variety of tillage and planting systems.

Table 1. Crop residue classification and typical percent residue cover after harvest of various crops in Nebraska. Actual percent cover can vary substantially from these values. Use these values for estimation purposes only when the percent cover for a particular field cannot be more accurately determined using the line-transect or photo-comparison method.

Crop	% Cover
Non-Fragile Residue	
Alfalfa or Other Hay Crops	
Immediately after cutting	35
After regrowth	85
Barley*	85
Corn	
Harvested for grain	
60 to 120 bu/ac grain yield	80
120 to 200 bu/ac grain yield	95
Harvested for silage	15
Forage Silage	
Immediately after cutting	25
After regrowth	85
Grain Sorghum	75
Millet	70
Oats*	80
Pasture	85
Popcorn	70
Rye*	85
Wheat*	
30 to 60 bu/ac grain yield	50
60 to 100 bu/ac grain yield	85
Fragile Residue	
Dry edible beans	15
Dry peas	20
Potatoes	15
Soybeans	70
Sugar beets	15
Sunflowers	40
Vegetables	30

*For small grains, if a rotary combine or a combine with a straw chopper is used, or if the straw is otherwise cut into small pieces, consider the residue to be fragile.

Table 2. Estimated percentage of residue remaining on the soil surface after specific implements and field operations.[1] (Change to decimal value before multiplying. Example: 90% is changed to 0.90.)

Implement	Non-Fragile Residue	Fragile Residue
	Percentage of Residue Remaining	
Plows:		
Moldboard plow	0-10	0-5
Disk plow	10-20	5-15
Machines that fracture soil:		
Paratill/Paraplow	70-90*	60-85*
V ripper/subsoiler		
(12" to 14" deep; 20" shank spacing)	60-80*	40-60*
Combination tools:		
Chisel-subsoiler	50-70	40-50
Disk-subsoiler	30-50	10-20
Chisel plows with:		
Sweeps	70-85	50-60
Straight spike points	35-75*	30-60*
Twisted points or shovels	25-65*	10-30*
Combination chisel plows:		
Coulter chisel plows with:		
Sweeps	60-80	40-50
Straight spike points	35-70*	25-40*
Twisted points or shovels	25-60*	5-30*
Disk chisel plows with:		
Sweeps	60-70	30-50
Straight spike points	30-60*	25-40*
Twisted points or shovels	20-50*	5-30*
Undercutters:		
Stubble-mulch sweeps or blade plows with:		
V-blades greater than 30" wide	75-95*	60-80*
with mulch treader attached	60-90*	45-80*
V-blades 20" to 30" wide	70-90*	50-75*
with mulch treader attached	55-85*	40-70*
Disks:		
Tandem or offset		
Heavy plowing	25-50	10-25
Primary tillage	30-60	20-40
Secondary tillage	40-70	25-40
Light tandem disk after harvest, before other tillage	70-80	40-50
Field cultivators: (including leveling attachments)		
Used as primary tillage:		
Sweeps 12" to 20" wide	60-80	55-75
Sweeps or shovels 6" to 12" wide	35-75	50-70
Duckfoot points	35-60	30-55
Used as secondary tillage:		
Sweeps 12" to 20" wide	80-90	60-75
Sweeps or shovels 6" to 12" wide	70-80	50-60
Duckfoot points	60-70	35-50

Finishing tools:		
Combination finishing tools with:		
Disks, shanks, and leveling attachments	50-70	30-50
Spring teeth and rolling basket	70-90	50-70
Harrows:		
Springtooth (coil tine)	60-80	50-70
Spike tooth	70-90	60-80
Flex-tine tooth	75-90	70-85
Roller harrow (cultipacker)	60-80	50-70
Packer roller	90-95	90-95
Rodweeders:		
Plain rotary rod	80-90	50-60
Rotary rod with semi-chisels or shovels	70-80	60-70
Row-crop planters:		
Conventional planters with:		
Runner openers	85-95	80-90
Staggered double disk openers	90-95	85-95
Double disk openers	85-95	75-85
Planters with:		
Smooth coulters	85-95	75-90
Ripple or bubble coulters	75-90	70-85
Fluted coulters	65-85	55-80
Strip-till planters with:		
2 or 3 fluted coulters	60-80	50-75
Row cleaning devices (8" to 14" wide bare strip using brushes, spikes, furrowing disks, or sweeps)	60-80	50-60
Ridge-till planter	40-60	20-40
Drills:		
Hoe opener drills	50-80	40-60
Semi-deep furrow drill or press drill (7" to 12" spacing)	70-90	50-80
Deep furrow drill with 12" spacing	60-80	50-80
Single disk opener drills	85-95*	75-85
Double disk opener drills	80-95*	60-80
Drills with the following attachments used in residue laying on the soil surface:		
Smooth coulters	65-85	50-70
Ripple or bubble coulters	60-75	45-65
Fluted coulters	50-70*	35-60*
Drills with the following attachments used in standing stubble:		
Smooth coulters	85-95	70-85
Ripple or bubble coulters	80-85	65-85
Fluted coulters	50-80*	40-70*

Air seeders:
(Refer to appropriate field cultivator or chisel plow depending on the type of ground-engaging device used.)

Air drills:
(Refer to corresponding type of drill opener.)

Row cultivators: (30" and wider)		
Single sweep per row	75-90	55-70
Multiple sweeps per row	75-85	55-65
Finger wheel cultivator	65-75	50-60
Rolling disk cultivator	45-55	40-50
Ridge-till cultivator	20-40	5-25
Other implements:		
Knife-type applicator with:		
Rigid shanks	75-85[*]	45-70[*]
with coulters	80-90[*]	50-75[*]
Coil shanks	70-80[*]	40-65[*]
with coulters	75-85[*]	45-70[*]
Closing disks	55-70[*]	30-50[*]
Manure injector/applicator with:		
Chisel or sweep injectors	30-65[*]	5-15[*]
Disk-type applicators	40-65[*]	15-40[*]
Coulter-type applicators	80-95[*]	65-80[*]
Rotary hoe	85-90	80-90
Bedders, listers, and hippers	15-30	5-20
Furrow diker	85-95	75-85
Mulch treader	70-85	60-75
Climatic effects of over winter weathering:		
Summer harvested crops	70-90	65-90[*]
Fall harvested crops	80-100[*]	75-100[*]
Fall operations (additional weathering)[*]	85-95[*]	80-95[*]

Weathering losses are highly dependent on precipitation and temperature. In winters with long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly. In warmer winters without much snow or during wet years, weathering losses may reduce residue levels significantly.

Grazing impacts:
Estimate reduction of residue cover for either fragile or non-fragile residue at 15 percent per 1000 pound cow per acre per month, or 0.5 percent per cow per acre per day. Use the following formulas to estimate residue cover reduction due to grazing and the percentage of residue remaining factor.

Percent Grazing Reduction = (0.5) x (number of animals) x (average animal weight in pounds) x (number of days grazed) ÷ (number of acres grazed) ÷ 1000

Percentage of Residue Remaining Factor = (100 - Percent Grazing Reduction)

[1]Adapted from the pamphlet "Estimates of Residue Cover Remaining After Single Operation of Selected Tillage Machines, published by the Soil Conservation Service and Equipment Manufacturers Institute, February 1992.

[*]Values adjusted based on University of Nebraska research and field observations.

PUMPING PLANT EFFICIENCY
HOW MUCH EXTRA ARE YOU PAYING?

FOR CENTRAL PLAINS CONFERENCE

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The energy cost of operating a pumping plant is dependent on three variables: the amount of work output the pump is producing, the efficiency of the power unit and the efficiency of the pump.

In this paper we will address the question, “Could you reduce irrigation costs? The first step in answering that question is to ask the more basic question, “How much energy should your pumping plant be using?”

Power is defined as the rate of doing work. One horsepower is defined as performing 33,000 foot-pounds of work per minute (33,000 ft-lb/min). Irrigation water is assumed to weigh 8.34 lb/gal. 33,000 / 8.34= 3960. Therefore the horsepower imparted to the water, known as water horsepower (Whp) can be calculated using the equation:
Whp = gallons /min (gpm) x head (ft) / 3960.

Example 1: Find the water horsepower output of a pump supplying 800 gpm to a center pivot. The pumping water level is116 feet below the level of a pressure gauge installed on the pivot that is reads 45 PSI while operating.

Whp = 800 gpm x ((45 PSI x 2.31 ft/PSI)[a] + 116 ft) /3960
= 800 gpm x (104 ft + 116 ft) /3960
= 800 gpm x 220 ft /3960
Whp = 44.4

[a] Lift and pressure are components of the total head that the pump is working against. To convert PSI to feet of head multiply PSI by 2.31.

If the power unit for this pumping plant is consuming 4.6 gallons of diesel per hour, what is the performance of this pumping plant?

The performance of the pumping plant is found by dividing the work output (whp-h) by the units of energy consumed. The performance of this pumping plant is therefore 44.4 whp / 4.6 gal/h = 9.625 whp-h / gallon of diesel.

The University of Nebraska has conducted hundreds of tests over the years on farmer-owned pumping plants. Based on these field tests and on tests of engine efficiency in the laboratory, the University developed the Nebraska Pumping Plant Performance Criteria, (NPC). The NPC states the brake horsepower output from the engine and drive unit (hp-h) and the amount of useful work output one should expect from a pumping plant (whp-h) per unit of energy consumed.

Table 1. The Nebraska Pumping Plant Performance Criteria (NPC)

Energy Source	hp-h[a] / unit of energy	whp-h[b,c] / unit of energy	Energy Units
Diesel	16.66	12.5[d]	Gallon
Gasoline	11.50	8.6	Gallon
Propane	9.20	6.89	Gallon
Natural Gas[e]	82.20	61.7	mcf
Electricity[f]	1.18	0.885	kWh

[a] hp-h (horsepower hours) is the work accomplished by the power unit with drive losses considered. This is the horsepower imparted to the lineshaft that drives the pump impellers.
[b] whp-h (water horsepower hours) is the work accomplished by the pumping plant (power unit and pump).
[c] Based on 75% pump efficiency.
[d] Criteria for diesel formerly 10.94 revised in 1981to 12.5,
[e] Assumes an energy content of 925 BTU/cubic foot.
[f] Assumes 88% electric motor efficiency.

Once the work output (Whp-h) is known, one can use the NPC to estimate the amount of energy a pumping plant should be using. The pumping plant in Example 1 on the previous page had a work output of 44.4 Whp-h. If this diesel powered pumping plant were operating at 100% of the NPC, it would consume 44.4 Whp-h / 12.5 Whp-h/gal = 3.55 gallons of diesel per hour.

Another application of the NPC is to give the pumping plant a performance rating. Once the performance of a pumping plant is known, it can be divided by the NPC resulting in a ratio which when multiplied by 100% results in a performance rating. A rating of 100% indicates that the pumping plant is operating at the expected performance level. A rating below 100% indicates the pumping plant is using more energy for the work that it is doing than the criteria calls for. For example, a pumping plant operating at 70% of the NPC is only producing 70% of the useful work it should for the energy it is consuming.

The pumping plant in Example 1 would have a performance rating of (9.625 whp-h/gal / 12.5 whp-h/gal) x 100% = 77% of the NPC.

If a pumping plant's performance rating is less than100% of the NPC. There are two methods to estimate the amount of excess energy being consumed. One method is to subtract the energy consumption at 100% of the NPC from the actual energy consumption. For the pumping plant in Example 1 the excess energy consumption is 4.6 gal/h (actual) - 3.55 gal/h = 1.05 gal/h excess energy consumption.

The second method for finding the excess energy consumption is to subtract the performance rating of the pumping plant from 100% divide by 100% to convert to a decimal and multiply the difference by the actual fuel consumption. For the pumping plant in Example 1, the performance rating was 77% of the NPC. 100% - 77% = 23%. 23% / 100% = 0.23. 0.23 x 4.6 gal/h = 1.06 gal/h excess energy consumed.

Nebraska conducted a statewide pumping plant efficiency study in 1980-81. In this study, they tested 180 farmer-owned pumping plants. As one might expect, the performance ratings of the pumping plants varied considerably. Some pumping plants were found to be very efficient. In fact, 15% actually exceeded the NPC.

The fact that some pumping plants exceeded the criteria indicates the criteria is a reasonable target for all pumping plants. The 85% of the pumping plants tested in the study which fell short of the criteria were using more energy per unit of work output (whp-h) than the criteria calls for. A few were found to be consuming over twice the amount of energy than was called for by the NPC.

When the performance ratings of all pumping plants tested were tallied, the average pumping plant in the study was found to be operating at only 77% of the NPC . Stated differently, the average pumping plant was using (100% / 77% = 1.3) times as much energy as expected. These test results compare with average ratings of 76% and 77.8% found in two earlier Nebraska studies and 78% found by a consulting firm in Kansas in the late 1970s.

When the efficiency of a pumping plant is not what it should be, the problem can either be in the power unit or in the pump or both.

Adjustments

Internal combustion power units on irrigation pumps can have the same problems as those in cars and trucks. Many had improperly adjusted air/fuel mixtures or spark timing. When indicated, the technicians performed adjustments to the air/fuel mixture and spark timing on spark ignition engines. No adjustments were attempted on diesel engines and none are possible on electric motors.

The decision of whether to make pump adjustments was based on the an examination of how closely the output of the pump matched the manufacturer's

pump curve. If the pump was operating on the curve, no adjustment was necessary.
When tests were run on wells that were being over-pumped (pumping air), pump adjustments were made when the rotational speed of the pump could be reduced (internal combustion engines) but not made if the speed could not be reduced (direct coupled electric motors).

Following the initial pumping plant tests, 57% were determined to potentially benefit from adjustments that could be made in the field. Pumping plants that received adjustments were then retested. Adjustments either to the engine or pump or both resulted in 14% average savings in energy costs compared to the initial test results on those units receiving adjustments.

Aside from the direct savings resulting from in-field adjustments, technicians were able to calculate the feasibility of making repairs beyond the field adjustments. On some pumping plants, major repairs or even replacement of the pump could be paid for in only a few years using projected savings in energy costs.

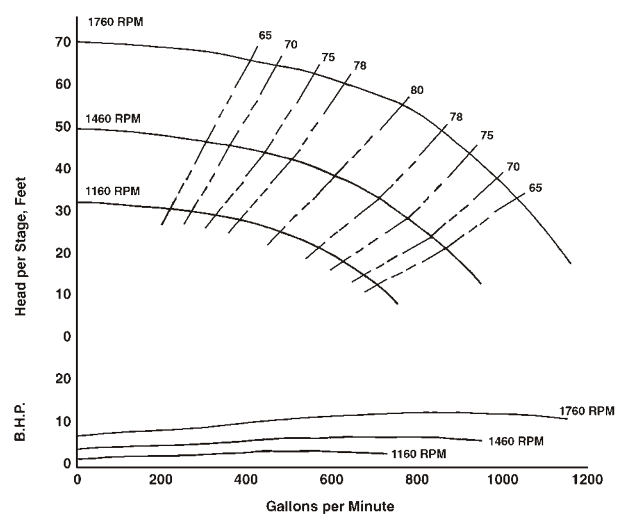
What Causes Poor Pump Performance?

The three main causes for poor pump performance are: (1) pump designs that are poorly matched to the job they are currently doing (as when the operator has switched from gated pipe to a center pivot sprinkler or has switched from a high pressure to a lower pressure sprinkler package), (2) pumps that had worn impeller vanes and/or internal seals as a result of pumping sand, (3) impellers that were not properly adjusted within the pump bowls.

There are many pump manufacturers and each manufacturer can have dozens of pump designs in their catalog. At a given rotational speed, each impeller design operates on unique head versus capacity curve. In all cases, the greater the head (ft) the pump is working against, the lower the capacity (gpm output).

As can be seen by examining a typical head/capacity curve in Figure 1, the pump's efficiency changes, depending on the operating conditions. Each pump design will have a best efficiency point at a certain head/capacity condition,

Figure 1. Typical head/capacity curve for a vertical turbine irrigation pump.



with lower efficiencies on either side of the best efficiency point. This pump achieves a best efficiency of 80% at 55 feet of head/stage and about 800 gpm at 1760 rpm.

The job of the pump installer is to select an impeller design that will operate efficiently when pumping the volume of water required for the application and while producing the total head required using some multiple number of stages.

Because no two irrigation systems or situations are exactly alike, fuel costs are hard to compare between different irrigation systems. Therefore most irrigators did not know, prior to the pumping plant test, whether a pumping plant was using too much energy for the conditions under which it was operating, even those that were using 50% more energy than the NPC in many cases.

Conduct a Short Term Pumping Plant Test

If there isn't a water meter installed on the system, a short-term pumping plant test can be run using one of a variety of devices to measure the flow rate. The pumping water level, system pressure measured at the pump discharge, and the rate of energy consumption must also be measured. Contact a reputable well driller and ask if they are equipped to run a short term pumping plant efficiency test.

Estimate Long-Term Pumping Plant Performance and Potential Energy Savings From Records

If a water meter is installed on the system and if the operator has records of total water volume pumped and fuel consumed over a period of time (a week, a month, or the pumping season) and if he/she has a measurement of the pumping water level and system pressure during the same time period, the performance rating of the pumping plant can be estimated. If the performance rating is below 100% of the NPC, the potential savings from adjustment or repair can be calculated.

The information required to estimate long term performance includes: total volume pumped (acre-inches), the lift (pumping water level), pressure at the pump discharge head (psi) and energy consumed over the period corresponding to the water meter readings.

Note: When the pressure gauge is not located at the discharge head, the elevation difference between the discharge head and the gauge must be added to the lift.

1. Whp-h = total volume pumped (ac-in) x total head (ft) / 8.75

2. Performance = whp-h (from 1.) / fuel used for the test period

3. Performance Rating = (Performance (from 2.) / NPC) x 100%

4. Potential fuel savings = ((100% - %NPC (from 3.) / 100%) x fuel used for the test period

Example: Using records to estimate long term pumping plant performance

- Test period = entire irrigation season
- System = Center Pivot Sprinkler and a diesel powered pump.
- Pumping water level = 140 feet
- Pressure at the discharge head = 40 psi
- Ac-in of water pumped (from water meter readings) = 1,500 ac-in (12 inches x 125 acres)
- Total fuel used for test period = 4,139 gallons of diesel

1. whp-h = acre-inches pumped x total head (ft) / 8.75
   = 1,500 x (140 + (40 x 2.31)) / 8.75
   = 1,500 x (140 + 92.4) / 8.75
   = 1,500 x (232.4) / 8.75
   = 39,840

2. Performance = whp-h (from 1.) / fuel used for the test period
   = 39,840 whp-h / 4,139 gallons
   = 9.625 whp-h / gallon

3. Performance Rating = Performance (from 2) / NPC x 100%
   = (9.625 whp-h / gallon / 12.5 whp-h / gallon of diesel) x 100%
   = 77.0%

4. Potential fuel savings = ((100% - %NPC) / 100%) x fuel used
   = ((100% - 77%) /100%) x 4,139 gallons of diesel
   = 0.23 x 4,139 gallons
   = 952 gallons/season

At $1.00 / gallon for diesel, the potential energy savings resulting from bringing this pumping plant up to the NPC would be $952 per year. If repairs were financed at 7% interest with annual payments, one could borrow $5,125 for repairs and pay the loan off in seven years using annual savings in energy costs.

- If the water meter totalizer registers in gallons, divide gallons by 27,154.
- If the water meter totalizer registers in acre-feet, multiply ac-ft by 12.
- If the water meter totalizer registers in cubic feet, divide cubic feet by 3,630.

Current Drought Conditions and Scenarios for this Winter

Allen Dutcher
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Overview:

Drought conditions continue to plague much of the western United States. As of January 22, 2004, severe to exceptional drought conditions were reported over 90 percent of the Rocky Mountain States according to the National Drought Monitor. In addition, much of the western half of Nebraska and Kansas reported severe drought conditions, with a pocket of extreme conditions reported across the western 1/3 of Nebraska, northwestern 1/4 of Kansas, and eastern 1/4 of Colorado.

The lack of strong snow storm activity during the last 4 years has led to significant problems within the Republican and Platte river valleys. Without significant snowfall this winter, projections for these regions continue to point to below normal to record low flows during the spring runoff season. Even with normal precipitation during the next 5 months, many reservoirs within this region will not have enough stored water to deliver full irrigation needs during the 2004 production season.

Forecasts:

The latest Climate Prediction Center (CPC) outlook for the upcoming 18 months (issued in mid-January) calls for above normal temperatures across most of the southern half of the Rocky Mountain states through the remainder of the winter season. There are equal chances for above normal, normal, or below normal temperatures across the central Plains region through February. The models project a tendency toward below normal temperatures during the March - June period for a small pocket of the central Plains that includes Nebraska, northern Kansas, along with eastern Colorado and Wyoming. There is a weak chance for above normal temperatures across the southwestern 1/3 of the United States during the July through October period, which includes Colorado, Kansas, and the southern half of Nebraska. There are no significant precipitation trends in the outlooks for the central Plains until the September through December period, where a weak tendency for above normal precipitation is indicated.

During last winter, a weak El Nino event led to above normal precipitation across much of the southern United States in a region from eastern Oklahoma and Texas through the southeastern United States. This area generally has a positive response to above normal precipitation during El Nino events. However, the typical response to above normal precipitation in the desert southwest failed to materialize. This in part allowed the semi-permanent high pressure system that occurs during the summer in the middle layers of the atmosphere to strengthen and expand toward the northeast. The resulting pattern during the second half of last summer was a large pocket of drier than normal conditions from New Mexico northeastward into the upper Great Lakes region.

This region of high pressure weakened during the late fall and early winter period. Strong low pressure systems were to enter the Pacific northwest and carve out occasional upper air troughs across the central and northern Rocky mountains. Several strong storms developed across the central and northern High Plains region, but precipitation coverage was disappointing. In many locations where rain and snow did fall, precipitation totals in excess of two inches per storm event were not uncommon. However, most locations of western Nebraska and Kansas, as well as eastern Colorado and Wyoming missed out on major moisture during the critical fall soil moisture recharge period. In fact, many of these areas have received less than one inch of liquid equivalent moisture since October 1, which is less than 25 percent of normal.

Snow pack accumulations in the Rocky Mountains have been above normal during the first half of the winter. As of January 1, 2004, snow packs across most major river basins were above long term normals and 20-40 percent higher than January 1, 2003. Unfortunately, the Platte river basins failed to receive as much moisture with average basin snow pack percentages between 70 and 90 percent of normal.

A dry pattern developed during the last 3 weeks of January and the cumulative snow pack dropped an average of 14 percent compared to long term normals. The snow hasn't disappeared, but has lost ground since snow should be accumulating depth until the middle of April. For each week that there is no precipitation in Colorado and Wyoming, the cumulative snow pack is declining an average of five percent.

There was a strong low pressure system that developed out of the southwestern United States during the January 24-29 period. It was able to merge with a clipper system moving out of south-central Canada and drop a significant swath of snow, ice, and rain from eastern Nebraska through the mid-Atlantic region. This may be a one-shot deal or a sign that snow activity may be taking on a more positive trend.

Under normal conditions, we would expect these upper air lows to get stronger as they develop across the central and southern Rocky mountains. The clash of early spring warmth across Texas, coupled with arctic air over the northern Plains states is the perfect ingredient for major snow storm activity. If this trend continues for the remainder of the winter, there is a fairly good chance that much of the central High Plains will experience several major precipitation events. However, if the high pressure dominates the central Rockies for the remainder of the winter, then expectations would be for below normal precipitation through the remainder of the winter.

Snowpack impacts on Drought:

As we move into this spring, a crucial component that I concentrate on in reference to drought susceptibility is the mountain snow pack. It is essentially critical that an above normal snow pack is maintained from New Mexico northward through Wyoming. Above normal snowpack in northern Colorado through central Wyoming increases the likelihood of some recovery in the depleted reservoir system within the Platte watershed. Below normal snowpack in this region would mean that most of the reservoirs in Wyoming and Nebraska will set or be near record low pools by the end of the 2004 production season. In some locations, significant water delivery restrictions will materialize.

Above normal snowpack across the southern half of the Rockies would serve three significant purposes. First, melting snow would provide above normal streamflow rates for reservoir recharge. Second, the longer the snowpack remains during the summer, the less likely that the southwestern high pressure will strengthen and expand northeastward. Third, the evaporative effects of the melting snow provides moisture and cold air aloft for thunderstorm development along the front range of the Rockies. It is these thunderstorms during the growing season that provide a substantial portion of the moisture required to complement irrigation deliveries in the semi-arid cropping environment of the western High Plains region. Without normal thunderstorm activity, most regions of the central Plains would be hard pressed to meet crop demands solely by irrigation.

El Nino and La Nina Impacts:

At present, slightly warmer than normal sea surface temperatures are being reported in the western Pacific Ocean along the equator. Although temperatures are above normal, no major El Nino event is projected to materialize during the remainder of the winter. Typically, La Nina or El Nino events begin to materialize during the late summer and reach there statistical peak around December 25^{th}. However, their peak strength can vary between December 1 and January 31. La Nina events are the opposite of El Nino and occur when sea surface temperatures remain colder than normal along the Equatorial Pacific region. Depending on the strength of the event, impacts can be felt in the United States through the late spring months.

El Nino and La Nina events occur on a frequent basis, with a general return period of 2-5 years. It is useful to understand their implications on weather patterns over the central United States. El Nino events do show a slightly positive influence on precipitation across the region during the October-March period. The best responses come from the strongest events. During this period, temperatures are typically on the warmer than normal side. During an unusually strong event, above normal precipitation tendencies do occur in the April-June period across southwestern Kansas.

La Nina events generally result in below normal temperatures during the October-December period for areas north of the Kansas-Nebraska border, with above normal temperatures likely during the January-March period across the entire central High Plains region. During strong events, there is a tendency for below normal temperatures to materialize across southeastern Nebraska and eastern Kansas. Precipitation patterns during La Nina events are less dramatic across the central High Plains. There are weak tendencies for above normal precipitation across northeast Colorado, eastern Wyoming, and the Nebraska Panhandle during the October-December period. Only northeastern Colorado shows an above normal precipitation response during the January-March period. For strong La Nina events, above normal precipitation tendencies occur across southeastern Nebraska and eastern Kansas during the April-June period.

Outside of the defined response areas stated above for the La Nina and El Nino cases, there is an equal distribution of temperatures and precipitation. This means that there are equal chances of receiving above normal, normal, or below normal precipitation and/or temperatures during the October-December, January-March, or April-June periods.

NEBRASKA WATER POLICY TASK FORCE

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In 2002 the Nebraska Legislature created a **Water Policy Task Force** to evaluate the effectiveness of and make recommendations on any needed changes to the law governing the **integrated management of surface water and hydrologically connected ground water**. The Legislature also asked the Task Force to make recommendations on water transfers, leasing and banking and on how to address inequities between surface water and groundwater users.

Task Force Activity

The 49 Task Force members were appointed by Governor Johanns to represent specific interests as required by statute *(see page 4 for membership)*. The first Task Force meeting took place on July 29, 2002; a total of eight full task force meetings were held prior to completion of Task Force work in December 2003. A 14 member **Task Force Executive Committee** met 18 times over the course of the effort. Interest in Executive Committee efforts was sufficiently strong that most of its meetings were heavily attended by other Task Force members. These meetings were all advertised and open to the public. A number of non-Task Force members also faithfully attended meetings and actively participated in the Task Force deliberations. In addition subcommittees were formed to address: surface water transfers, groundwater transfers, funding, data requirements, equities between surface water and groundwater users, and presentation of the Task Force recommendations.

Consensus Based Decision Making

The recommendations of the Water Policy Task Force are the result of a consensus-based decision-making process. A consensus is the strongest form a group decision can take, because it is a settlement or solution that all participants in the decision making process accept. The consensus by members of the Water Policy Task Force was built by identifying and exploring all parties' interests, and assembling a package agreement that satisfied these interests to the greatest extent possible. Achieving consensus involved, but did not require, unanimous support by all Task Force members for all elements of the settlement. In its consensus decisions, some parties strongly endorsed particular solutions for issues while others accepted them as workable settlements or compromises. At the end of discussions and deliberations of the Water Policy Task Force, consensus was reached, and no one blocked the approval of the package. In addition to the agreement package, some participants in the Water Policy Task Force wanted to have a section of the document where issues that need additional discussion and attention could be listed. Some of these issues were discussed by the Task Force and others were mainly mentioned as items that need future attention. Providing these comments, however, does not take away from the recommendation that the proposals be accepted by the Legislature as a package. If any one piece is changed in substance or deleted, this could change any given Task Force member's willingness to support the package and break apart the consensus that was achieved by the Task Force.

Task Force Recommendations

The Water Policy Task Force presented its report to the Governor on schedule on December 18, 2003. The Task Force recommends that the **basic components of existing surface water and groundwater law be left in place, but that Nebraska adopt a stronger, more proactive approach to the integrated management of surface water and hydrologically connected groundwater**. Key goals of the Task Force recommendations were to address potential problems between groundwater and surface water users before conflicts arise and to manage the water resources of the State to sustain a balance between hydrologically connected water uses and water supplies.

"The Task Force recommendations represent a major step forward in addressing equitable management of Nebraska's interrelated groundwater and surface water; with this step we have really bitten the bullet."
-Clayton Lukow, Task Force member

"I was skeptical of the consensus process at first, but it worked very well. The Task Force met its goal in developing a mandate for the future."
Jim Meismer, Task Force member

Key components of the Task Force Recommendations are that the State:

Maintain the basic framework of the existing laws. The Task Force, in formulating its recommendations, chose to work within the state's existing basic institutional and legal framework governing the use of surface and groundwater and its recommendations are intended to build and improve upon this framework.

Modify existing law to be more proactive and require certain management actions be taken by NDNR and the NRDs when a basin is determined to be over appropriated or fully appropriated.

Identify the Platte River Basin above Elm Creek, Nebraska as being over appropriated. The Task Force recommends that the NDNR and NRDs develop a basin-wide plan that will guide the plans of individual NRDs that will incrementally reduce the difference between the present level of development and the fully appropriated level of development in that basin.

Provide adequate funding to develop a sound scientific basis for management decisions and fair implementation of the integrated management plans. The Task Force believes that adequate funding is essential if the proposed program is to be successful both in avoiding such conflicts and in addressing current inequities between surface water and groundwater users.

Allow temporary and permanent transfers or leases of surface water and groundwater.

Copies of the report and proposed legislation may be obtained on the NDNR website at **http://www.dnr.state.ne.us** or by contacting the Department of Natural Resources.

Key Provisions of the PROACTIVE PLAN

NDNR and the NRDs will be required to make an annual determination of which basins, sub-basins or river reaches are fully appropriated and,

If a basin is declared over appropriated or fully appropriated there shall be an immediate suspension of all new uses until the NDNR or the NRD decide more can be allowed.

In basins declared over appropriated or fully appropriated, NDNR and NRDs are required to jointly develop and implement an integrated surface water and groundwater management plan within 3 to 5 years of the determination.

One goal of the Integrated Management Plan shall be to manage all hydrologically connected groundwater and surface water to sustain a balance between water uses and water supplies so that the economic viability, social and environmental health, safety and welfare of the basin, sub-basin or reach can be achieved and maintained for both the near and long term.

The Integrated Management Plan may use a number of voluntary measures as well as the controls in current law, such as allocation of withdrawals, rotation of use, reduction of irrigated acres, and other measures.

Any disputes between the NDNR and NRDs over the development or implementation of the joint action plan will go to a dispute resolution process. If the dispute is still unresolved, the disputed issues will be presented to a five member **Interrelated Water Review Board**, which will make the final decision on which components to put into the plan or how the plan shall be implemented. **The Board will consist of five members including the Governor or his or her appointee, one additional member of the Governor's choosing and three additional members appointed by the Governor from a list of at least six persons nominated by the Nebraska Natural Resources Commission.**

Key Recommendations on SURFACE WATER TRANSFERS

Transfers of water rights from one location to another will continue to be allowed.

In specified instances authorize NDNR to issue temporary and permanent permits that either change the purpose for which water is used or change from one type of permit to another.

No permanent transfers or changes are allowed if it involves a change to a different preference category.

Add safeguards to ensure changes in type of permits or changes in use will not adversely impact existing users. Some of those include:

Temporary transfers and changes are for a minimum of one year or a maximum of thirty years, with the possibility of renewal for another 30 years after the mid-point of the term of the transfer or change.

Temporary transfers will retain the same priority date as the original permit and shall revert to the original location and use at the end of the permit period.

Only the historic consumptive use can be transferred or changed to a new use. Transfers for irrigation can be on an acre for acre basis. The number of acres irrigated as a result of the transfer can be increased if:
a) The applicant can show there is not an increase in consumptive use as a result of the increase in acres involved in the transfer, or
b) In basins that are not over appropriated or fully appropriated, the increase in the number of acres irrigated is not more than 5% of the existing permit or greater than 10 acres, whichever is less. Such increases must be on the same or an adjacent quarter section as the original permit. Such increases in acreage can only be done once for any given permit.

If the transfer or change involves land served by an irrigation district, the district must approve the transfer or change.

Development of a banking system is not necessary at this time. The development of a banking process should occur if and when there appears to be a need for such a system in the future.

Key Recommendations on SURFACE WATER ADJUDICATIONS

Extend the period of allowable nonuse before cancellation without excuses from 3 years to 5 years.

If there are excusable reasons for nonuse, extend the allowable period of non-use without cancellation from 10 up to 15 years.

Extend the period of allowable nonuse before cancellation when water unavailability is the reason from 10 years to up to 30 years or, upon petition by the appropriator, even longer if the permit is in a basin that has been determined to be over appropriated or fully appropriated and water is expected to be restored for use in accordance with an integrated management plan.

When an appropriation held in the name of an irrigation district or company is cancelled, the district shall have up to 5 years to assign the right to another use.

After adjudication, allow a rate of diversion to be greater than one cubic foot per second for 70 acres if the higher rate is necessary, using good husbandry, to meet a full crop irrigation requirement. However, the total amount of the new diversion rate could not be greater than the total amount of the permitted rate before adjudication.

Key Recommendations on GROUNDWATER TRANSFERS

Allow a Natural Resources District to require as a Management Area Control: 1) District approval of transfers of groundwater off the land where it is withdrawn, and 2) District approval of transfers of rights to use groundwater that result from District allocations imposed under the Groundwater Management and Protection Act. Require the District to deny or condition the approval of transfers if needed to: 1) ensure consistency of the transfer with the purposes of the Management Area, 2) prevent adverse impacts on groundwater users, surface water appropriators, or the state's ability to comply with an interstate compact, decree, or agreement, and 3) otherwise protect public interest and prevent detriment to the public welfare.

Empower Natural Resources Districts to grant groundwater transfers off the overlying land to augment supplies in wetlands or natural streams for the purpose of benefiting fish or wildlife or producing other environmental benefits. The determination of whether to grant a permit is to be based upon stated factors, including whether the use is a beneficial use, the availability of alternative supplies, negative effects of the proposed withdrawal, cumulative effects of the proposed withdrawal, and consistency with groundwater management plans and integrated management plans.

"The proposal is good for wildlife because it provides for greater flexibility in addressing their water needs."
Dave Sands, Task Force member

"It is a doable plan that recognizes everyone's interests; it would be a shame if we lose this opportunity. Changes in the adjudication statutes will streamline the process and help both NDNR and the irrigators."
-Al Schmidt, Task Force member

Recommended FUNDING PACKAGE

The Task Force believes that water is so essential to agriculture, the environment, industry, human health and well being and to the overall economic viability of the state that leaving it to the fluctuation and uncertainty of the annual appropriations process seems unwise. The Task Force recommends a dedicated funding source.

Funding needs include data gathering and organization, modeling/analysis, and local specialized studies necessary to ensure decisions are based on sound scientific data. Without such data, the plans and regulations will not be acceptable to the public. Funding is also needed to prepare and implement the plans. Finally funding is needed to address the inequities between surface and groundwater users in over appropriated basins. Inequities could be addressed by such activities as developing alternative water supplies and providing incentives for decreasing water use.

A **Water Resource Trust Fund** should be created to provide grants for interrelated water management activities. Grants from the fund to local NRDs would require a 20% match from local funding. $4.7 million will be necessary to fund the Task Force recommendations for planning/management and to address inequities between surface and groundwater users. Also recommended for inclusion would be $6.3 million of current appropriations to the Nebraska Resources Development Fund, the Nebraska Soil and Water Conservation Fund and the Small Watersheds Flood Control Fund.

NRD groundwater management activities should be exempt from the statutory 2 1.2% budget lid placed on local subdivision budgets. The NRDs also should be able to supplement the funds they can raise through their maximum 4 1.2 ¢ property tax levy with an additional levy, imposed only in groundwater management areas. Without additional funds, some NRDs will not be able to implement Integrated Management Plans.

"An historic effort that is starting to bear fruit."
Jack Maddux, Task Force member

"In all the 30+ years I have had the honor working on water isues, this has been one of the most intense 18 months, and hopefully one of the most successful undertakings in looking at water changes that need to come about."
Dick Mercer, Task Force member