

Colorado High Plains Irrigation Practices Guide

Water Saving Options for Irrigators in Eastern Colorado

by

Rachel Barta, Israel Broner, Joel Schneekloth and Reagan Waskom

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Introduction

Irrigated agriculture diverts and consumes well over 80 percent of the surface and ground water used in Colorado, leading to a widespread public perception that agricultural water use is inefficient. For these reasons, water derived from irrigation water conservation is often suggested as a viable mechanism for providing additional water supplies to meet growing demands for urban, industrial, recreation and environmental water needs in Colorado. Several factors, however, limit the extent to which this strategy can be used to deliver additional water to meet these alternative demands. State water law quantifies the amount of actual water transferable from a given water right as the historic consumptive use, or that amount evaporated and transpired by crops as water is put to beneficial use. Thus, water conservation options that result in salvageable water from irrigated agriculture are limited to those that reduce evaporation or crop consumptive uses. As a result, management practices that result in improved irrigation efficiency do not yield transferable supplies. Diverted water that is not consumed by senior appropriators belongs to the stream system and thus other water right holders. These return flows are critical to the proper functioning of our water allocation system in Colorado's river basins and alluvial aquifers and are not available to satisfy new water demands. As such, economic incentives for irrigators in river basins to stretch their water supplies are most apparent only in dry or water short years.

Irrigators who rely on deep ground water aquifers have a greater incentive for conservation. Reducing the amount of water pumped decreases energy costs. Also, as ground water levels decline, sustaining the economic life of the aquifer becomes a further incentive. While irrigation system efficiencies have improved considerably in Colorado over the last several decades, a number of practices that may further reduce gross irrigation application remain underutilized.

The Colorado state office of the USDA Natural Resources Conservation Service (NRCS) asked Colorado State University faculty in 2003 to summarize irrigation practices that offer potential water savings at the field or farm level. The purpose of this report is to provide a summary of the documented water savings options for irrigators in Colorado. The report provides a significant amount of detail regarding what options are available for water conservation, how these options are used to conserve water, and expected water savings that can be achieved through various irrigation conservation practices.

The presentation of the water savings options consist of eleven stand-alone practices. A significant amount of literature review and analysis was put in to the formulations of these options and is included in the documentation as a guide for users who desire to obtain more information about a particular option. The literature reviewed is believed to be the most up-to-date and scientifically defensible literature available, specifically for regions surrounding Colorado.

Several best management practices for various aspects of irrigated agriculture have already been produced for Colorado, but none have specifically addressed the practices that are available for water conservation purposes. While this material provides a comprehensive review of options available to irrigators in Colorado, it is not meant to serve as a "how-to" guide for irrigators seeking to conserve water. Rather, they contain a general overview of options and direct irrigators and water managers to the literature sources that can provide a more detailed level of information. Consult with your crop adviser, local NRCS office, or irrigation specialist to determine the specific practices and equipment options that are most economically advantageous for your operation.

From a regional perspective, the only certain way to achieve significant conservation of agricultural water is to fallow land or convert irrigated lands to dryland or non-irrigated crops. On a field or farm scale, there are a number of water conservation practices that may be employed to reduce the amount of water pumped or diverted. Due to the site specific nature of agricultural operations, no one set of practices is universally appropriate. Irrigators must evaluate their cropping system, management constraints and water supplies to determine the right mix of irrigation practices for their farm or ranch.

INFORMATION SHEET No. 1

Irrigation Delivery Systems

Irrigation delivery systems are considered conveyance systems used to deliver irrigation water from the water source to the farm irrigation system.

The farm water supply is delivered either from surface storage by conveyance ditches or from irrigation wells. Irrigation water is conveyed from its source and is delivered to the farm to the point where it is applied for use through unlined ditches, lined ditches, or pipe. Often, water supply is stored temporarily on the farm in small reservoirs or ponds so water application can be timed according to crop needs, not according to time of water delivery at the farm. The type of delivery system has significant influence on the overall efficiency of an irrigation system. More efficient delivery systems will save water.

The four main delivery systems that are discussed in this information sheet include:

- Unlined ditches
- Lined ditches
- Buried pipe
- On-farm storage systems

Unlined Ditches

Unlined or earthen ditches are typically used to distribute water received from a farm headgate to surface irrigation systems including furrow, borders, basins and corrugations. Earthen lined ditches are the least efficient irrigation delivery system because water loss from seepage through the soil can be significant (Table 1). Irrigation canals that are placed in native soil or are lined with earth have seepage water losses varying from 20% to more than 50% (Hill, 2000). Well designed and compacted earthen canals can reduce seepage losses to a level that is similar to concrete lined canals. However, consistent and regular maintenance is required to keep seepage losses low. Compaction and proper maintenance can greatly increase the efficiency of delivery in medium and fine textured soils, but does little to decrease seepage losses that occur in coarse textured soils. Lining or piping a canal with coarse textured soils may be the best option for decreasing seepage losses.

Delivery systems are typically less efficient on larger field sizes because water is conveyed longer distances and for greater lengths of time (Table 1).

Lined Ditches

To minimize water losses there is an increasing tendency to line ditches with impermeable materials. This practice is particularly applicable in more arid regions, where irrigation water supplies are limited and crop needs are highly dependent on irrigation water (Schwab et al., 1993). The main

Table 1. Potential on-farm conveyance efficiencies

Fields larger than 50 ac	Conveyance Efficiency
Unlined	80%
Lined or Piped	90%
Fields up to 50 ac	
Unlined	70%
Lined or piped	80%

Source: Doorenbos and Pruitt (1992)

Water Savings Potential

- A potential increase in on-farm conveyance efficiency of nearly 10% is possible if earthen ditches with medium and fine textured soils are compacted and well maintained.
- A potential increase in on-farm conveyance efficiency of 10% is possible if earthen or unlined ditches are lined or piped.
- To calculate the amount of water savings, multiply the water supply at the farm by the percent increase in on-farm conveyance efficiency.

types of linings are: (1) paved or hard surface, (2) exposed membrane, (3) buried membrane, and (4) polyacrylamides (PAM) (Hill, 2000).

Paved or hard surface linings include Portland cement concrete, shotcrete, soil-cement, asphaltic concrete, and masonry. Exposed membrane linings include asphaltic membranes or plastics and synthetic rubber films. Buried membranes linings include prefabricated asphaltic membranes, plastic and synthetic rubber films, and bentonite membranes. Soil sealants and stabilizers include bentonite, cinders, admixtures, and various chemicals (Hill, 2000). For a discussion on how these materials are used to line canals, refer to Hill (2000).

Research has shown that polyacrylamide (PAM) can be used to reduce seepage in earthen canals. The U.S. Bureau of Reclamation in western Colorado has shown in a model that seepage can be reduced by as much as 60% by adding PAM and a soil mixture to model troughs (Valliant, 1999). Also, Valliant (2002) of Colorado State University Cooperative Extension has demonstrated that adding PAM to water in an earthen canal carrying 6,000 to 7,000 gal/min can substantially reduced water seepage. In this study, water levels in two wells located approximately 125 ft from the PAM treated irrigation canal were significantly lower than well water levels tested for non-treated irrigation canals.

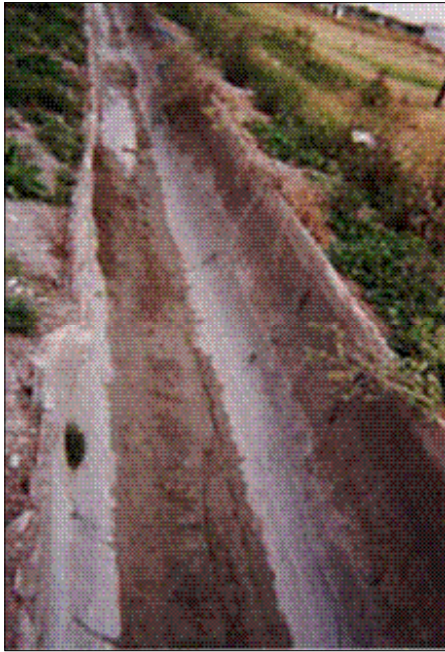


Figure 1. Out of condition lined canal
Source: West Texas A&M University

Table 2 shows how effective the different types of canal linings are for reducing seepage. The percentage figures in Table 2 are the percent reduction in seepage that is expected when an unlined ditch is lined with one of the various methods for reducing seepage.

Table 2. Seepage reduction for lined canals

Type of Lining	Percent Seepage Reduction
Concrete only	70%
Exposed membrane	90%
Concrete with buried membrane	95%

Lined canals more efficiently convey water than unlined canals. However, old lined canals with deteriorated joints and that are not well maintained can be as inefficient as unlined canals. Figure 1 shows an old concrete canal that is in need of rehabilitation.

Delivery System	Advantages	Disadvantages
Unlined	<ul style="list-style-type: none"> * Can be efficient in medium and fine textured soils if well compacted and maintained * Inexpensive 	<ul style="list-style-type: none"> * Inefficient in coarse soils * High seepage losses
Lined	<ul style="list-style-type: none"> * Highly efficient if properly designed and maintained * Can greatly reduce seepage losses 	<ul style="list-style-type: none"> * Evaporation losses are still present * Expensive to install * Can be as inefficient as unlined canals if not maintained
Piped	<ul style="list-style-type: none"> * Most efficient * Eliminates seepage and evaporation losses 	<ul style="list-style-type: none"> * Very expensive * Not maintenance free

Pipelines

Pipeline delivery systems convey water through pumping or through gravity flow and consist of buried pipe, surface installed pipe, or both. Pipelines can be used to deliver water for surface, sprinkler, and microirrigation systems. Buried pipe distribution systems are the most efficient because they eliminate problems associated with open channel delivery systems such as: maintenance problems, evaporation from the water surface, and seepage losses through the unlined or lined material of the canal (Schwab et al., 1993). Portable pipe or large diameter plastic tubing may also provide an efficient alternative to open channel delivery systems in surface irrigation systems. Pipeline delivery systems eliminate almost all the conveyance losses expected under open channel delivery systems.

Water Savings Potential

- Conveyance efficiencies for most buried pipe systems are between 90% and 100%.
- To calculate the amount of water savings, multiply the water supply at the farm by the percent increase in conveyance efficiency.

On-Farm Storage Systems

Farm ponds and reservoirs are used to store surface water and groundwater on-farm. Producers will often build storage facilities so that more water is available for release during drier periods. This practice may actually increase water savings because it allows producers to better time water application according to an irrigation schedule, rather than relying on delivery at an allocated time. However, farm ponds can be relatively inefficient with high evaporation and seepage losses. Annual free surface evaporation rates in the Colorado High Plains range from 40 to 60 in. The same liners that are used to increase water savings in unlined ditches can be used for farm ponds. Expect the same amount of water savings in ponds from these linings. Evaporation losses cannot be reduced from farm ponds unless the surface of the pond is covered. It should be noted that storing water in on-farm systems can, in some cases, be limited by Colorado water law.

References

- Doorenbos, J. and W.O. Pruitt. 1992. Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24. Food and Agriculture Organization of the United Nations. <http://www.fao.org/docrep/x0490e01.htm> .
- Hill, R. 2002. How Well Does Your Irrigation Canal Hold Water? Does it Need Lining? Utah State University Extension Electronic Publishing. Logan, Utah. <http://extension.usu.edu/files/engrpubs/biewm03.pdf> .
- Schwab, G.O., D.D. Fangmeier, W.J. Elliot, R.K. Frevert. 1993. Soil and Water Conservation Engineering Fourth Edition. John Wiley & Sons, Inc. New York.
- United States Bureau of Reclamation (USBR). 2002. Canal-Lining Demonstration Project Year 10 Final Report. Pacific Northwest Region Water Conservation Center. <http://www.pn.usbr.gov/wat/pdf/finalcanal/front.pdf>
- Valliant, J. 2002. Canal Seepage Reduction Demonstration Using Polyacrylamides In the Ditch and Water: Arkansas River Valley of Colorado. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 131-138.
- Valliant, J. 1999. PAM: A cost effective tool for improving irrigation and protecting soil and water resources. Colorado State University, Soil and Crop Sciences, Drought Newsletter 1999. www.colostate.edu/Depts/SoilCrop/extension/Newsletters/1999/gujune99.htm

INFORMATION SHEET No. 2

Farm Irrigation Systems

Farm irrigation systems are the methods of applying water to crops and are classified as surface irrigation, sprinkler irrigation, and microirrigation.

The decision to select an irrigation system or convert to a more efficient irrigation system is complicated. From a water conservation standpoint the choice is simple, with water savings increasing as surface irrigation systems are changed to sprinkler systems and as sprinkler systems are changed to microirrigation systems. However, the success of an irrigation system will be highly dependent on site and situation factors as well as the level of management employed. Existing irrigation systems should be carefully evaluated before switching to alternative irrigation systems.

This information sheet will:

- Provide a brief overview of surface, sprinkler, and microirrigation systems
- Provide potential field efficiency values for a variety of irrigation methods
- Provide a framework for comparisons between different irrigation systems

Surface Irrigation Systems

Surface irrigation systems are classified in order of increasing efficiency as: (1) flood irrigation, (2) border irrigation, (3) furrow irrigation, and (4) basin irrigation. The two features that distinguish surface irrigation from other methods of irrigation are that the water flows freely in response to gravity, and the on-field means of conveyance and distribution is the field surface (Walker, 1989).

Flood Irrigation

Uncontrolled flooding is the application of irrigation water from field ditches whereby little attempt is made to control the flow on the field by means of levees or other methods that restrict water movement (Schwab et al., 1993). This method is frequently referred to as wild flooding. Although these systems are advantageous for their low initial cost and labor requirements, they are disadvantageous for their low efficiency and uniformity. This method is mainly used on rolling land where border, basins, and furrows are not feasible and where adequate water supply is available.

Border Irrigation

Border irrigation is the application of water to sloping, long rectangular lands, and free draining conditions at the lower end of the field (Walker, 1989). Border strips are typically placed in the direction of the greatest slope, are 30 to 65 ft in width, 300 to 1300 ft in length, and have small ridges between the strips to prevent water from overtopping during irrigation (Schwab et al., 1993). Land between borders should be leveled perpendicular to the direction of flow. Border irrigation is suitable for most crops and soil types, but is favored by slow to moderate intake soils and crops that can tolerate prolonged ponding. In Colorado, basin irrigation is primarily used on closely spaced crops such as alfalfa, grass and small grains, but not row crops.



Figure 1. Furrow irrigation with siphon tubes

Furrow Irrigation

Although water covers the entire surface area of a field in other surface irrigation methods, irrigation by furrows covers one-fifth to one-half the surface. Furrows vary in size and can be placed up and down the slope or on the contour. Small, shallow furrows are called corrugations and are typically used for close growing crops such as small grains and alfalfa. Larger, deeper furrows are suitable for row crops such as corn.

Furrows provide better on-farm water management flexibility under many surface irrigation conditions. The discharge per unit width of the field is substantially reduced and can therefore be practiced on slopes as steep as 12%, if furrows are placed on the contour with the appropriate non-erosive stream size. If furrows are not placed on a contour the maximum recommended slope is 3% or less. A smaller wetted area in furrow irrigation also reduces evaporation losses. Furrows provide the irrigator with more opportunity to efficiently manage irrigations as field conditions change throughout the season. However, furrow irrigation is not always efficient and can produce significant runoff if a constant inflow rate is maintained throughout the application period. Several methods can be used to reduce runoff such as cutback operations, surge irrigation, and reuse systems (See Information Sheet No. 5).

Basin Irrigation

Basins are typically rectangular in shape, level in all directions, and are encompassed by a dyke to prevent runoff. Inflow to basins is generally undirected and uncontrolled and can be relatively efficient if high rates of flow are available to quickly cover the field (Schwab et al., 1993). There are few crops and soils not amenable to basin irrigation, but it is best suited for moderate to slow intake soils, deep-rooted, and closely spaced crops (Walker, 1989). Precision land leveling is very important to achieving high uniformity and efficiency in all surface irrigation methods (See Information Sheet No. 5).

Sprinkler Irrigation Systems

Sprinkler irrigation is a versatile means of applying water to any crop, soil, and topographic condition (Schwab et al., 1993). Sprinkler systems can be efficient on soils and topography that is not suitable or efficient for surface irrigation methods. In general, systems are described according to the method of moving the lateral lines on which various types of sprinklers are attached. Laterals may be solid set or rotating, the latter which can be moved by hand or mechanically. Sprinkler systems are highly efficient but there are general concerns about the labor requirements and investment costs for these systems.

Hand-move laterals have the lowest investment cost but the highest labor requirement. These systems are only suitable for low-growing crops.

The side roll lateral system uses the irrigation pipe as the axle of large diameter wheels that are spaced about 40 ft apart. These laterals are moved by a gasoline powered motor and thus require less labor than hand-move systems. Side rolls should be used for crops that will not interfere with the movement of the lateral or sprinkler pattern.



Figure 3. Center pivot irrigation system



Figure 2. Side roll sprinkler system

Center pivots consist of radial pipelines that rotate around a central pivot by water pressure, electric motors, or oil hydraulic motors (Schwab et al., 1993). A variety of nozzle types, nozzle heights, and application rates can be used in center pivot systems. Sprinkler packages should be selected according to the field conditions for the most efficient operation (See Information Sheet No. 4).

Linear move laterals use hardware similar to that of a center pivot, but move in a straight line across the field. Solid-set systems have sprinklers that are placed over the entire field, where all or some of the sprinklers may operate at the same time.

Center pivots are the most common sprinkler irrigation method used in the High Plains of Colorado. Sprinkler packages vary greatly from older impact heads to more modern spray heads that have an assortment of application and placement modes (Howell, 2003). See Information Sheet No. 3 for more on center pivot irrigation systems.

Microirrigation Systems

Microirrigation is a method for delivering slow, frequent applications of water to the soil using a low pressure, low volume distribution system and special flow-control outlets (Schwab et al., 1993). If managed properly, microirrigation can increase yields and decrease water, fertilizer, and labor requirements. Microirrigation includes: microsprinklers, drip irrigation, and subsurface drip irrigation (SDI).

Microsprinklers, often referred to as minisprayers, microsprayers, and misters, typically consist of small emitters placed on short risers above the soil surface. Water is conveyed through the air, but travels only a short distance before reaching the soil surface. The wetted area of emitters in these systems is small, can be controlled fairly easily, and has different shapes to match desired distribution patterns. The advantages of microsprinkler irrigation systems are the potential for controlling frost, greater flexibility in applying water, and lower susceptibility to clogging.

Drip systems deliver water directly to the soil surface or subsurface (SDI) and allow water to dissipate under low pressure in a predetermined pattern. These systems are advantageous because water is applied directly to or just above the root zone of the plant, thereby minimizing deep percolation losses, reducing or eliminating the wetted area from which water can evaporate, and eliminating losses associated with runoff. These systems are also advantageous because they reduce water consumption by weeds, while operating at a lower pressure.

Microirrigation systems apply water on a high-frequency basis and create near optimal soil moisture conditions for the crop. Under proper management, microirrigation saves water because only the plant's root zone is supplied with water and little, if any, is lost to deep percolation, consumption by nonbeneficial plants, or soil surface evaporation. In addition to being highly efficient, these systems also require relatively little labor input if designed properly. Yields of some crops have been shown to increase under these systems because the high temporal soil water level needed to meet transpiration requirements is maintained (Colaizzi et al., 2003).

Table 1. Potential field efficiency ranges

Irrigation System	Field Efficiency (% Range)
Surface Irrigation Systems	
Graded Furrow	50-80
w/tailwater reuse	60-90
Level Furrow	65-95
Graded Border	50-80
Level Basins	80-95
Sprinkler (non-center pivot)	
Periodic Move	60-85
Side Roll	60-85
Moving Big Gun	55-75
Lateral Move	
Spray heads w/hose feed	75-95
Spray heads w/canal feed	70-95
Center Pivot Irrigation Systems	
Impact heads w/end gun	75-90
Spray heads w/o end gun	75-95
LEPA w/o end gun	80-95
Microirrigation Systems	
Surface Drip	70-95
Subsurface Drip Irrigation (SDI)	75-95
Microsprinklers (microspray)	70-95
Source: Howell (2002)	

The major disadvantages of microirrigation systems are high initial cost and potential for system clogging, especially the emitters. In some cases, labor inputs may be quite high if rodents burrow and chew system components. Proper design, operation, and maintenance can overcome many of these issues.

Subsurface drip irrigation (SDI) is becoming more popular in the High Plains of Colorado. See Information Sheet No. 6 for a discussion on SDI systems.

Efficiency of Irrigation Systems

There are many efficiency terms used to describe irrigation system performance. Field or application efficiency is defined as:

$$E_f = 100 W_s / W_d$$

W_s = water stored in the soil root zone by irrigation

W_d = water delivered to the field being irrigated

The difference between water stored in the root zone (W_s) and the amount of water delivered to farm or field (W_d) is water loss in the form of deep percolation, runoff, and evaporation. More specifically, field efficiency includes any application losses to evaporation or seepage from surface water channels or furrows, any leaks from sprinkler or drip pipelines, percolation beneath the root zone, drift from sprinklers, evaporation of droplets in the air, or runoff from the field (Howell, 2002). For a discussion on the various water loss components associated with surface, sprinkler, and microirrigation systems, see Rogers et al. (1997). The amount and type of water loss that occurs in the transfer of water from water source to where the crop actually uses water is highly dependent on the type of irrigation delivery and distribution system used (See Information Sheet No. 1). Table 1 and Figure 4 show potential field efficiencies for the various distribution systems.

The relative difference between efficiency values of different irrigation systems is a result of changes in the amount of runoff and deep percolation and sometimes evaporation. The difference is not a result of changing the amount of water that crops actually consume (transpiration). For example, changing from a graded furrow of 65% efficiency to a well maintained SDI of 90% efficiency will result in a 25% water savings. This water savings is primarily a result of a reduction in the runoff and deep percolation associated with the furrow irrigation system. The SDI system may also reduce evaporation because water application occurs below the soil surface and the soil surface remains dry, unlike the furrow system. There is not a difference in the amount of water that is consumed by a crop grown under both systems. The E or evaporation component of ET (evapotranspiration) might change, but the T or transpiration component will not.

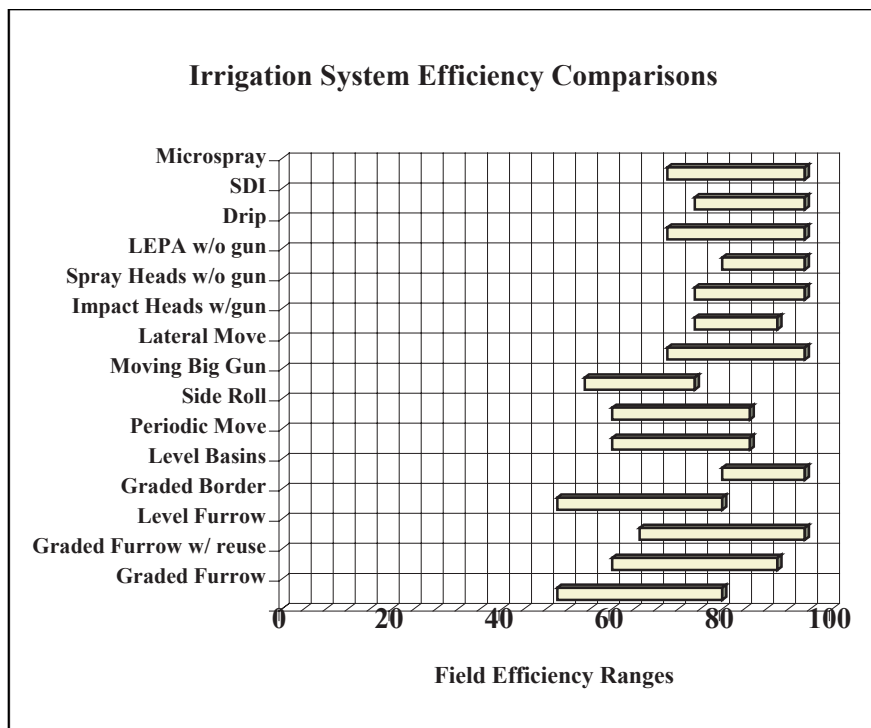


Figure 4. Potential field efficiency ranges

When the decision is made to change the method of irrigation distribution, the water savings that can be expected is the difference between the field efficiency values for the two methods. Increasing the field efficiency by 10% will reduce the amount of water needed to achieve the same yield under the original system by 10% if the new system is operated properly. Proper design, management, and maintenance of irrigation systems will ultimately determine achievable efficiency levels. These issues are particularly important when a producer chooses to convert an existing irrigation method to a more efficient, water saving method.

Table 2. Comparison of irrigation systems and the desired conditions for the different systems.

	Surface Systems	Sprinkler Systems			Microirrigation
Desired Site and System Characteristics	Improved Surface Systems	Intermittent Mechanical Move	Center Pivot	Solid-Set	Micro sprinklers, SDI, and drip
Infiltration Rate	Moderate to low	All	Medium to high	All	All
Slope	Moderate slopes	Level to rolling	Level to rolling	Level to rolling	All
Crops	All	Generally shorter crops	All but trees, vineyards, and obstructions to movement	All	High value crops to make it economically justified
Water Supply	Large stream sizes	Small streams nearly continuous	Small streams nearly continuous	Small stream sizes	Small streams, continuous and clean
Water Quality	All but very high salts	Salty water may harm plants	Salty water may harm plants	Salty water may harm plants	All
Labor Requirement	High, training required	Moderate, some training	Low, some training	Low to seasonal high, little training	Low to high, some training
Capital Requirement	Low to moderate	Moderate	Moderate	High	High
Energy Requirement	Low	Moderate to high	Moderate to high	Moderate	Low to moderate
Management Skill	Moderate	Moderate	Moderate to high	Moderate	High
Machinery Operations	Short to long fields	Medium field length	Some interference, circular fields	Some interference	May have considerable interference
Duration of Use	Short to long	Short to medium	Short to medium	Long term	Long term
Weather	All	Poor in windy conditions	Better in windy conditions than other sprinklers	Poor in windy conditions	All
Potential for Chemigation & Fertigation	Fair to Good	Good	Good	Good	Very Good

Source: Schwab et al. (1993)

Comparison of Irrigation Methods

Changing from surface irrigation to sprinkler irrigation is one of the most common conversions used to save water (Yonts, 2002). The reason for this conversion is that surface irrigation is inherently a less efficient and more labor intensive than sprinkler irrigation. Many factors should be considered before converting from a surface to a sprinkler irrigation system including: yield response, water savings, labor savings, energy savings, economic cost, climate conditions, and field characteristics. For a more complete discussion on the conversion from surface to sprinkler, see Yonts (2002), O'Brien and Lamm (1999), Heermann (1992), Heermann (1991), O'Brien and Lamm (2000), and Rogers (1991). For a more complete discussion on the conversion from sprinkler to SDI systems, see Lamm et al. (2003) and O'Brien et al. (1998).

To choose an irrigation method, the producer must know the advantages and disadvantages of the various methods. Unfortunately, in many cases there is no single best solution because all methods have their advantages and disadvantages (Brouwer et al.). Table 2 provides a comparison of irrigation systems in relation to site and situation factors (adapted from Schwab et al., 1993). This table also sets forth the advantages and disadvantages of one irrigation system relative to another system. These issues should be considered before conversion to a more efficient system. If an irrigation system is not well suited for a particular situation, it may not be any more efficient or save any more water than the original method of irrigation.

Water Savings Potential

- The water savings that can be expected by changing to a different irrigation method is the difference between the field efficiency values for the two methods.

References

- Broner, I. 1995. Microirrigation for Orchard and Row Crops. Colorado State University Cooperative Extension Crop Extension Series Irrigation No. 4.703. Colorado State University, Fort Collins, CO.
www.ext.colostate.edu/pubs/crops/04703.htm .
- Brouwer, C., K. Prins, M. Kay, M. Heibloem. Irrigation Water Management: Irrigation Methods. Training Manual No. 5. Food and Agriculture Organization of the United Nations. Rome, Italy.
<http://www.fao.org/docrep/s8684e/s8684e00.htm#Contents> .
- Colaizzi, P.D., A.D. Schneider, T.A. Howell, S.R. Evett. 2003. Comparison of SDI, LEPA, and Spray Efficiency for Grain Sorghum. ASAE Annual International Meeting. July 27-30, 2003, Las Vegas, Nevada. American Society of Agricultural Engineers.
- Heermann, D.F. 1992. Is One Sprinkler System Good for All? Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.1-4.
- Heermann, D.F. 1991. Sprinkler Irrigation Basics. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.52-58.
- Howell, T.A. 2003. Water Loss Comparisons of Sprinkler Packages. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.54-69.
- Howell, T.A. 2002. Irrigation System Efficiencies. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 80-92.
- Lamm, F.R., D.M. O'Brien, D.H. Rogers, T.J. Dumler. 2003. Center Pivot Sprinkler and SDI Economic Comparisons. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.199-211.

- O'Brien, D.M, F.R. Lamm. 2000. The Economics of Converting from Surface to Sprinkler Irrigation Systems for Lower Pumping Capacity Wells. Proceedings of Central Plains Irrigation Short Course and Exposition. February 9-10, 2000, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.88-98.
- O'Brien, D.M. and F.R. Lamm. 1999. Economics of Surface and Sprinkler Irrigation System Conversion for Lower Capacity Systems. Proceedings of Central Plains Irrigation Short Course and Exposition. February 9-10, 1999, Sterling, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp.86-96.
- O'Brien, D., D.H. Rogers, F. Lamm, G. Clark. 1998. Economic Comparison of SDI and Center Pivots For Various Field Sizes. Proceedings of Central Plains Irrigation Short Course and Exposition. February 17-19, 1998, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.27-38.
- Rogers, D.H., F.R. Lamm, M. Alam, T.P. Trooien, G.A. Clark, P.L. Barnes, K. Mankin. 1997. Efficiencies and Water Losses of Irrigation Systems. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/mf2243.pdf> .
- Rogers, D.H. 1991. Considerations When Converting from Flood to Pivot Irrigation. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.101-104.
- Schwab, G.O., D.D. Fangmeier, W.J. Elliot, R.K. Frevert. 1993. Soil and Water Conservation Engineering Fourth Edition. John Wiley & Sons, inc. New York.
- Walker, W.R. 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drainage Paper No. 45. Food and Agriculture Organization of the United Nations. Rome, Italy.
<http://www.fao.org/docrep/t0231e/t0231e00.htm#Contents> .
- Yonts, C.D. 2002. Technical Considerations of Converting from Surface Irrigation. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 149-151.

Center Pivot Irrigation Systems

*A center pivot is a moving irrigation system (lateral) that rotates around a fixed point (pivot).
With proper design and installation, a center pivot sprinkler system can achieve
high irrigation efficiency and water application uniformity.*

There are a variety of sprinkler packages and operating methods for center pivot systems. Because there is a large variety, there are many choices a producer must make when converting to or upgrading a center pivot system. With so many choices, it is often difficult to fully understand how each variable affects the efficiency and uniformity of a particular system. This information sheet provides the following insights for efficiently operating the most common center pivot systems used on the High Plains of Colorado.

- Consideration of sprinkler package (nozzle type, nozzle height, operating pressure, and flow control devices)
- Considerations for sprinkler package conversion
- Consideration of sprinkler spacing and operation (application amount and system capacity)
- Consideration of the various water loss components of sprinkler systems

Classification of Sprinkler Systems

Center pivot sprinkler systems are classified according to pressure, nozzle type, and nozzle height. Table 1 provides a summary of several sprinkler systems, their typical operating pressures, nozzle heights, and advantages and disadvantages of each system.

Nozzle Type

Center pivot sprinklers can be classified according to two general types of sprinkler nozzles-impact sprinklers and spray heads (Howell, 2003). Impact nozzles are either brass or plastic and are typically mounted on the center pivot pipeline above the crop at a low angle (6-15 degrees) or high angle (23 degrees). Impact nozzles are advantageous because they have a large wetted radius and low instantaneous application rate (lower potential for runoff). Impact nozzles require high to medium operating pressures.

Spray heads are a much more diverse class than impact sprinklers. They range from simple nozzles and deflector plates to more sophisticated designs involving moving plates that slowly rotate or spin rapidly. Spray nozzles also include types with spinning and oscillating plates with various drop discharge angles and trajectories (Howell, 2003). Spray heads operate at low to medium pressures. These heads are installed on the lateral pipeline, on drop tubes below the trusses, or in-canopy. Spray nozzles include all sprinkler types included in Table 1 except for the first two types, which are impact sprinklers.

Operating Pressure

Although there is no definite boundary between high, medium and low pressures, these categories are generally used to classify sprinkler systems according to operating pressure (Figure 2). High pressure systems have pressures at the pivot of more than 50 psi, medium pressure systems have pressures from 35 to 50 psi, and low pressure systems have pressures less than 35 psi at the pivot.



Figure 1. Center pivot with adjustable drop using spray pads

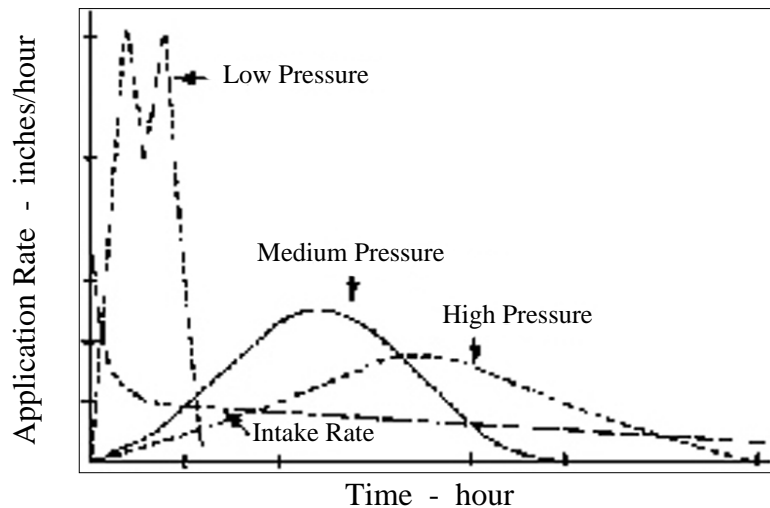


Figure 2. Typical application rates for various pressures at 1,000 ft from pivot

Low pressure sprinkler devices have become more common because lower operating pressure requires less energy to pressurize and thus lowers cost. Lower pressure sprinkler devices can only effectively reduce energy costs, conserve water, and maintain crop yields if a sprinkler package and operation scheme properly match the conditions of a particular field. Lowering pressure without adjusting nozzle height, application rate, and tillage practices can increase runoff and negate any benefits of lowering operating pressure.

Nozzle Height

In addition to lowering operating pressure, newer center pivot systems have been designed for water application within or below the crop canopy. Operating low pressure sprinkler devices closer to the crop canopy is considered more efficient than high pressure systems, which apply water above the crop canopy. In-canopy irrigation reduces the amount of water lost through evaporation and wind drift (Yonts et al., 2000; Yonts et al., 1999; Yonts, 2000).

Above crop canopy nozzles are mounted on the center pivot pipeline or on drops just below the

Acronyms
MESA - mid elevation spray application (5-8 ft above ground)
LPIC - low pressure in canopy (1-6 ft above ground within mature crop canopy)
LESA - low elevation spray application (near the ground surface 1-2 ft)
LEPA - low energy precision application (near ground with bubblers or drag socks)

trusses while nozzles within or below the crop canopy are mounted on drop tubes from the center pivot pipeline. Because different crops have different canopy heights at any growth stage, these classifications can be somewhat arbitrary. The major difference between the numerous low pressure sprinkler packages (LESA, LEPA, LPIC, and MESA) is primarily the height of nozzle placement. LEPA and LESA systems contain nozzles mounted near the ground and LPIC and MESA systems contain nozzles within the crop canopy or just above the mature crop canopy (Howell, 2003). See Table 1 for nozzle height ranges for a variety of sprinkler packages.

Although lowering the nozzle to within or below the crop canopy reduces evaporation and losses associated with wind drift, there is significant potential for greater runoff potential in these sprinkler packages as well as decreased application uniformity (Yonts, 2000; Yonts et al., 1999; Howell, 2003; Lamm, 1998; Lamm, 2000; Yonts et al., 2000). Lowering the nozzle and operating at a lower pressure decreases the size of the wetted radius of the sprinkler

primarily due to interception by the crop. The reduced size of wetted radius significantly increases the instantaneous application rate. A higher instantaneous application rate can often lead to runoff if proper tillage is not applied.

The nominal operating pressures at the head of the water emitting devices are constant for a particular head. Table 1 shows a more specific classification of common center pivot systems and their nominal pressures at the head of water emitting devices (Howell, 2003).

Pressures needed at the pivot depend on pressure losses in the lateral due to friction losses and elevation differences along the lateral. To find the necessary pressure at the pivot, work back from the last emitting device and add pressure losses or gains due to friction and elevation.

In a Nebraska study (Yonts, 2000), runoff was measured for three different sprinkler devices: a LEPA system, Spinners located 42 inches above the ground, and Spinners located above the crop canopy. The experimental field had slopes that varied between 1-3%, was irrigated with an average depth of 0.7 in, and was cultivated under conventional practices with and without furrow diking. The LEPA system resulted in over 15-25% runoff, Spinners at 42 inches resulted in runoff of 10-15% and the spinners at truss height resulted in runoff as low as 8% under furrow diking. Research in Texas (Schneider and Howell, 1995) indicates that the potential water savings from evaporation and wind drift that is expected when moving nozzles from truss height to within the canopy (42 inches above ground) and below the canopy (LEPA) is 1-2% and 10%, respectively.

Water Savings Potential

- The potential water savings from evaporation and wind drift when moving sprinkler nozzles from truss height to within the canopy is 1% to 2%, if proper system design and operation.
- The potential water savings when moving sprinkler nozzles from truss height to below the canopy is 10% if proper system design and operation.

The results of the Nebraska runoff study show that the amount of water saved by moving nozzles below the crop canopy or operating a LEPA (10% or 0.07 in) was significantly lower than the amount of water lost to runoff (0.25 in). The significance of these results is that water savings cannot be expected by just lowering the height of the sprinkler nozzle, especially in LEPA irrigation systems. Applying proper application rates and viewing each sprinkler package as a “systems” relationship to operation, management, and the physical field conditions is very important. See Rogers et al. (1994b), Howell (2003), Buchleiter (1991), Lyle (1991), Schneider and Howell (1995), and Schneider and Howell (2001) for a more in-depth discussion on proper use of LEPA irrigation systems.

There is also evidence that moving nozzles within the crop canopy significantly affects the uniformity of water applied (Solomon, 1990). Uniformity depends on nozzle spacing, nozzle height, row orientation with respect to center pivot travel, and nozzle type (Lamm, 1998). Research in Kansas (Lamm, 1998) has shown that for corn planted under a center pivot system, uniformity of application increases when: nozzle spacing is decreased from 10 ft to 5 ft, when nozzles are placed at heights 2 ft and 7 ft above the ground rather than 4 ft in a mature crop canopy, and when circular rows (parallel to sprinkler travel) are planted instead of straight rows (perpendicular to sprinkler travel).

Flow Control Devices for Center Pivot Irrigation Systems

Center pivot irrigation systems that operate on rolling terrain experience large pressure differences in the pivot pipeline, which can lead to non-uniform water application on the field. Increases in elevation decrease pressure in individual sprinkler heads, thereby reducing the amount of water applied by these heads and decreasing uniformity. Both the discharge and wetted diameter of an individual sprinkler head are dependent on the operating pressure. These variations in pressure distribution affect the wetted area under a sprinkler head as well as the depth applied (Jordon et al., 1999). Pressure regulating devices that equalize the flow of water from individual sprinklers have become more common since uniform water application saves water and increases crop production (Kranz, 1988). Sprinkler output can be controlled by regulating the flow rate out of the sprinkler using flow control devices, or by regulating the pressure supplied to the sprinkler using pressure regulators. Control of sprinkler flow is desirable when (Kranz, 1988):

- Elevation differences exist between sprinkler nozzles or heads
- Pipeline friction loss causes large differences in pipeline pressure
- Excessive pressure is supplied to small sprinklers located on the first few spans of the center pivot
- A constant pressure is required for installations where more than one set of sprinklers is supplied by the same pump

As a general rule, regulators and flow control devices are not needed if operating pressure between the first and last nozzles does not vary more than 10 to 20% (Kranz, 1988; New and Fipps, 2002). Table 2 presents percent variation in system operating pressure created by changes in land elevation for a quarter-mile pivot. The goal should be to maintain less than 20% variation in pressure.

Table 1. Characteristics of common center pivot sprinkler types

Sprinkler Type	Nominal Pressure at the Head [psi]	Typical Height [ft]	Advantages	Disadvantages
Impact-high angle	25 to 50	6 to 15	Low application rate	High energy requirement, exposure to wind effects
Impact-low angle	25 to 35	6 to 15	Low application rate	High energy requirement, still impacted by winds
360° Spray head, Rotator, Spinner-high location	10 to 30	6 to 15	Low energy requirement, closer spacing	High application rate, only over canopy chemigation
360° Spray head, low location LESA or LPIC	10 to 30	1 to 6	Lower energy requirement, less wind effect, close spacing, under canopy chemigation	High application rate
Low Drift and Multiplate Spray Heads	10 to 30	Varied, pipeline truss level	Lower energy requirement, lower drift and wind effects, many configurations	High application rate
Rotator	15-50	Varied, pipeline truss level	Larger wetted diameter, lower application rate, good resistance to wind effects	Can have higher energy requirement, limited in-canopy chemigation
Spinners	10 to 20	Varied, pipeline truss level	Low energy requirement, gentler droplet applications	Limited in-canopy chemigation
Oscillating/ Rotating Spray Plates	10 to 20	3 to 6	Low energy requirement, low misting from small droplets, low application rate, gentler applications	Limited in-canopy chemigation
LEPA Bubble	6 to 10	1 to 3	Low energy requirement, less evaporation, excellent in-canopy chemigation	Extremely high application rate, requires furrow dikes or surface storage (1-2 inches of water volume)
LEPA Drag Sock	6 to 10	0	See LEPA bubble, less erosion of furrow dikes	See LEPA bubble

Source: Howell (2003)

When changes in elevation are high, the choice should be to either increase both pressure and pumping costs or to use pressure regulators or flow control devices. This decision is site-specific and should be made by comparing the extra costs of flow control or regulator devices to the increasing pumping costs without them (New and Fipps, 2002). However, if the purpose is to conserve water, installing regulators or control devices is the best option because the total amount of water that is pumped is reduced. For a more complete discussion on flow control devices and pressure regulators see Kranz (1988) and New and Fipps (2002). Pressure regulators are also used in microirrigation systems to better distribute water application in a uniform manner.

Table 2. Percent pressure variation

Elevation Difference	Pressure Change	System Design Pressure (psi)				
		6	10	20	30	40
<i>ft</i>	<i>psi</i>	<i>% Variation</i>				
2.3	1	16.5	10	5	3.3	2.5
4.6	2	33	20	10	6.6	5
6.9	3	50	30	15	10	7.5
9.2	4		40	20	13.3	10
11.5	5		50	25	16.6	12.5
13.9	6			30	20	15
16.2	7				23.3	17.5
18.5	8				26.6	20

Source: New and Fipps (2002)

Sprinkler Package Conversion

Producers are often interested in converting sprinkler packages to take advantage of new technology, overcome poor design on an original package, reduce energy requirements, and save water (Cahoon et al., 1992). The most common conversion is from a high to a medium or low pressure system. This conversion reduces energy costs by lowering pressure. Also, the lowering of nozzles associated with lower pressure systems reduces evaporative water losses by placing water application within or below the crop canopy. A disadvantage of this conversion is that low pressure systems require sprinkler heads that have a smaller wetted radius, which results in higher instantaneous application rates (higher potential for runoff) (Lamm, 2000). Although higher application rates for lower pressures is the main trade-off between high and low pressure systems, several other factors should be considered before making a conversion. Table 3 summarizes some of these trade-offs.

Table 3. Trade-offs between high pressure, low pressure and LEPA systems

System (pressure)	High	Low	LEPA
Typical pivot pressure (psi)	80	35	25
Application rate	Low	High	Very high
Droplet size	Large	Small	Variable
Evaporation and drift losses	Depends on wind speed	Small if using drop tubes	None
Potential runoff	Small	Moderate	Very high
Effect of elevation differences	Small	High	High
Energy Cost* \$ (lift of 200 feet)	\$12,764	\$8,799	\$7,650
Energy Cost* \$ (lift of 400 feet)	\$19,399	\$15,064	\$13,586

* Pumping cost for applying 24 in, system capacity 850 GPM irrigating 126 ac, pump efficiency 65% and power cost of \$0.07 kwh.

Sprinkler Spacing

The spacing of sprinklers on a center pivot lateral is an important component for uniform water application. There are several spacing designs for center pivot systems including: constant spacing-variable discharge, variable spacing-uniform discharge, and semi-uniform spacing-variable discharge (Howell, 2003). The sprinkler package used typically dictates the spacing of nozzles along a lateral. The key to achieving uniform water application is to provide adequate overlap of water application patterns between successive sprinklers (Martin, 2003). All sprinkler systems require that the water application pattern overlap other nozzle application patterns on either side of that nozzle. Overlap is not considered in

LEPA systems, because LEPA nozzles are placed in every-other row for proper water application.

Because closer spacing typically requires more capital input, many producers try to stretch sprinkler spacing to minimize expenses. This practice generally results in reduced uniformity, which can reduce application efficiency and crop yield.

When water is applied to a field through sprinkler irrigation methods, there is a potential for wind to not only decrease the efficiency of these systems, but to also decrease the application uniformity by moving water away from the intended location. Although wind is

not a controllable variable, it can significantly affect irrigation uniformity. Therefore, sprinkler system design should anticipate wind effects on performance (Solomon, 1990). Uniformity, under given wind conditions, can be increased by properly designing the spacing of sprinklers. Table 4 provides general guidelines for sprinkler spacing. These are recommended for high pressure, above canopy center pivot systems. For more information on spacing for low pressure systems, see Howell (2003) and New and Fipps (2000). Also, selecting sprinkler packages that produce larger droplet sizes will reduce how wind influences application uniformity.

Table 4. Maximum sprinkler spacing for above canopy nozzles.

Wind Conditions	Sprinkler Spacing
Low	60-65% of wetted diameter
Moderate	50% of wetted diameter
High	30-50% of wetted diameter

Source: Solomon (1990)

Center Pivot Operation

Selecting a sprinkler package is important for efficient irrigation, and it is a decision that should be made at the time of sprinkler design. Without retrofitting or replacing an existing center pivot system, there is little a producer can do to make the sprinkler package more efficient once installed. However, a producer does have control over the application rate with a given system capacity used in a particular center pivot system.

Application Rate

The application rate is the depth in inches of water that an irrigation system applies per hour. The application rate of a center pivot varies laterally because the center pivot lateral covers more area per unit length toward the outer end of the lateral in the same time period. The desired application rate of an irrigation system depends upon the wetted diameter, capacity, and soil type.

Application time is the time that it takes to sprinkle any place in the field or the time that each point receives water. The application time depends on the radius of throw of the sprinkler head. The larger the radius of throw, the longer any point in a field will receive water under a given speed of travel. As the radius of throw decreases the instantaneous application rate increases. Again, wetted radius is a function of nozzle type, nozzle height, and operating pressure.

More traditional center pivot systems recommend that the application rate not exceed the infiltration rate of the soil so that water soaks into the soil where it lands (Klocke et al., 1997). The application rate in more modern, low pressure center pivot systems greatly exceeds the soil infiltration rate (Rogers et al., 1994a). Low pressure systems such as LEPA call for tillage practices that hold the water

on the soil where it lands until it is infiltrated into the soil. The shift to low pressure systems has changed peak application rates from 1 in/hr for high pressure impact nozzles to 6 in/hr or more for 360° spray nozzles (Heermann, 1991). Few soils have intake rates that can absorb this rate of application without runoff unless physical changes such as furrow diking are made to the soil surface. Without sufficient soil surface storage, runoff is likely to occur in these high application rate methods. Aside from tillage practices for increasing soil surface storage (See Information Sheet No. 8), options for reducing runoff from application rates that are too high include speeding the center pivot to decrease the amount of water applied per irrigation, decreasing the discharge of each sprinkler head, or increasing wetted diameter (Heermann, 1991).

System Capacity

The peak irrigation requirement for a crop will determine the lower limit for system capacity. To find the gross irrigation requirement (irrigation system capacity), divide the net irrigation water requirement by the irrigation system efficiency. Also, when calculating irrigation system capacity, allow for expected down time for maintenance and expected failures. This calculation of system capacity can be reduced to some minimum value by assuming that some crop water requirements will be provided by stored soil moisture or rainfall that might occur during peak crop water use periods.

Table 5. Required gross system capacity in gpm per acre

Soil Type	Impact-low angle (85%)*	Spray Nozzle (90%)*	LEPA (95%)*
Sand	5.4	5.1	4.8
Loam	4.6	4.3	4.1
Clay	4.1	3.9	3.7

*expected irrigation system efficiency

Guides have been developed for the Northern Central Plains for recommended system capacities to insure that satisfactory crop production will result from the water applied. These guides were developed from data on soil and crop type and can be found in any of the following sources: Martin (2003), Heermann (1991), or Howell (1992).

Table 5 provides a more general guide to required irrigation system capacities (gpm/ac) for three soil types and three different center pivot systems (Broner, 1991). The available water stored in the soil is a reservoir that supplies water during peak water use periods. The higher the available soil water, the less irrigation system capacity is required. Similarly, the higher the efficiency of an irrigation system, the lower the required irrigation system capacity. These capacities assume a seven-day per week operation (24 hours per day). These recommended values may not be applicable to irrigation systems with low capacity wells. Irrigation system capacities should also be increased to allow for expected down time.

Water Savings

With so many sprinkler packages, operating schemes, and management decisions available for producers who use center pivot irrigation systems, it becomes difficult to fully understand how change in each individual component will affect system efficiency, especially when so many of the components are interrelated. Water loss from sprinkler devices can be categorized into three main areas: air loss, canopy loss and ground loss (Yonts et al., 2002; Yonts, 2000). Each type of water loss is dependent on a variety of factors, many of which have already been discussed. Table 6 indicates components of water loss for several common center pivot irrigation systems.

One of the main reasons for converting to low pressure sprinkler systems other than energy savings is the desire to reduce water losses through the air (evaporation and wind drift) and losses from the canopy (water evaporation from the plant leaves). Schneider and Howell (1995) performed a study in Texas on various air and canopy water losses among a variety of different sprinkler devices. Table 7 gives the measured water loss and application efficiency determined in this study for low angle impact sprinklers, spray heads, and LEPA irrigation systems. These losses can also be expected in similar systems in eastern Colorado (Yonts, 2000).

Table 6. Water loss components associated with various sprinkler packages

Water Loss Component	Sprinkler Package			
	Overhead	Spray or MESA	LESA LPIC	LEPA
Droplet evaporation	Yes	Yes	Yes	No
Droplet drift	Yes	Yes	No	No
Canopy evaporation	Yes	Yes	Yes (not major)	No
Impounded water evaporation	No	Yes	Yes	Yes (major)
Wetted soil evaporation	Yes	Yes	Yes	Yes (not major)
Surface water movement	No (but possible)	Yes (not major)	Yes	Yes (not major)
Runoff	No (but possible)	Yes	Yes	Yes (not major if surface storage is used)
Deep percolation	No	No	No	No

Source: Howell (2003)

Table 7. Sprinkler water losses for 1-inch application

Water Loss Component	Impact Sprinkler	Spray Head	LEPA
Air Evaporation and Drift	0.03 in	0.01 in	0.00 in
Net Canopy Evaporation	0.08 in	0.03 in	0.00 in
Plant Interception	0.04 in	0.04 in	0.00 in
Evaporation from Soil	Negligible	Negligible	0.02 in
Total Water Loss	0.15 in	0.08 in	0.02 in
Application Efficiency	85%	92%	98%

Source: Yonts (2000)

Efficiency of water application is important, however Schneider and Howell (1995) found that with similar amounts of water applied through above canopy and in-canopy sprinklers, grain yields were equal for crops such as wheat and corn. Although there are losses from air evaporation, drift, and canopy evaporation; these are minor losses compared to runoff, which can be a much greater loss.

End Guns and Corner Systems

A typical quarter section center pivot irrigates only 130 ac of an entire 160 ac quarter section. End guns and corner systems are often used to irrigate some portion of the additional 30 ac that cannot be covered by the pivot. End guns are installed at the end of a center pivot mainline and add a few more acres to the irrigated area. The amount of additional land that can be irrigated with end guns depends on the size of the end gun used. For example, an end gun that increases the mainline radius 75 ft can irrigate approximately 14.6 more ac of land.

Corner systems are more elaborate than end gun systems and can cover most of the land that is lost because of the circular shape of a center pivot. Corner systems extend the center pivot mainline outward to the corner, start operating when the lateral approaches corners, and retract after corners are passed. While a typical center pivot system, without any corner system or end gun, can irrigate only 130 ac out of a 160 ac quarter section, corner systems can irrigate anywhere between 145 and 152 ac out of a 160 ac quarter section (Scherer, 1998).

While it is commonly believed that end guns can increase the amount of land in production for a relatively small increase in the net cost of the system per acre, there are some problems associated with these systems. When using an end gun with pressure regulated nozzles, the system is designed to work at a higher pressure when the end gun starts. When the end gun doesn't operate, the high pressure is dissipated by the pressure regulators and the result is a waste of energy. For non-regulated nozzles, when the end gun doesn't operate, the high pressure results in greater nozzle output and non-uniform water application over the field. Non-uniformity of water application results in the over watering of parts of the field, while other parts are under watered, both of which are undesirable. Insufficient water leads to high soil moisture tension, plant stress, and reduced crop yield, while excess water leads to leaching of plant nutrients, increased disease incidence, and reduced crop yields (Solomon, 1990). Booster pumps for end guns can be used to alleviate the problem of over watering, but these require significant capital cost, more maintenance, and more energy input to operate.

Booster pumps are commonly used for end guns that are operated in conjunction with low pressure center pivot systems that would otherwise leave end guns inoperable (Cahoon et al., 1992). End guns are also subject to wind drift and evaporation, which can decrease uniformity and reduce efficiency.

Uniformity issues are not as much of a concern when using corner systems as when using end guns (Heermann, 2003). The potential to increase application uniformity is better in corner systems, but it is still quite difficult to achieve. Because corner systems typically cost as much as half the capital cost of the rest of a center pivot, the increase in capital cost per acre should be considered when selecting or evaluating a corner system (Scherer, 1998). High value crops, high land values, and scarcity of irrigated lands are believed necessary to justify the additional costs of corner systems (Scherer, 1998). Although end guns and corner systems can be used to increase the amount of land in production, the marginal yield increase may not outweigh the additional costs of purchasing and operating these systems. In order to apply the optimal amount of water to a majority of the crops on a center pivot system with end guns and corner systems, it will be necessary to apply excess water to the areas irrigated by end guns and corner systems. The agronomic output from these areas may not be enough to justify purchasing these systems and using limited water supplies.

References

- Broner, I. 2002. Center-Pivot Irrigation Systems. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.704. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04704.html.
- Buchleiter, G.W. 1991. Irrigation with LEPA. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.64-68.
- Cahoon, J., N. Klocke, W. Kranz. 1992. Converting to Center Pivot Sprinkler Packages: Systems Considerations. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1124.htm.

Heerman, Dale, Colorado State University, personal communication, 2003

- Heermann, D.F. 1992. Is One Sprinkler System Good for All? Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.1-4.
- Heermann, D.F. 1991. Sprinkler Irrigation Basics. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.52-58.
- Howell, T.A. 2003. Water Loss Comparisons of Sprinkler Packages. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.54-69.
- Howell, T.A. 1992. Evapotranspiration and Irrigation Capacity. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.9-13.
- Howell, T.A., A.D. Schneider, J.A. Tolk. 1991. Sprinkler Evaporation Losses and Efficiency. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.69-89.
- Jordon, R.W., H.R. Duke, D.F. Heerman, G.W. Buchleiter. 1999. Spatial Variability of Water Application Under Center Pivot Irrigation. USDA-Agricultural Research Service, Water Management Research Unit, AERC-CSU. Fort Collins, CO. www.wmuinfo.usda.gov/publications/files/hrd137.pdf .
- Klocke, N.L., W.L. Kranz, C.D. Yonts, K. Wertz. 1997. Water Runoff from Sprinkler Irrigation—A Case Study. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1305.htm .
- Kranz, W.L., D.P. Shelton, E.C. Dickey, J.A. Smith. 1991. Water Runoff Control Practices for Sprinkler Irrigation Systems. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1043.htm .
- Kranz, W. 1988. Flow Control Devices for Center Pivot Irrigation Systems. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g888.htm .
- Lamm, F.R. 2000. Who wants to be an In-Canopy Irrigator? Proceedings of Central Plains Irrigation Short Course and Exposition. February 9-10, 2000, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.118-127.
- Lamm, F. 1998. In-Canopy Sprinkler Application for Corn: What Works and What Doesn't. Proceedings of Central Plains Irrigation Short Course and Exposition. February 17-19, 1998, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.39-48.
- Lamm, F.R. 1992. Effect of System Capacity and Nozzle Type on Corn Production. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.23-25.
- Lyle, W.M. 1992. LEPA, Concept and System. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.14-16.
- Martin, D.L. 2003. Sprinkler Design & Uniformity Consideration Overview. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.37-53.
- Musick, J.T., and B.A. Stewart. 1992. Irrigation Technologies. In: Groundwater Exploitation in the High Plains. Kromm, D.E. and S.E. White (eds.). University of Kansas Press. Lawrence, Kansas.
- New, L., G. Fipps. 2002. Center Pivot Irrigation. Agricultural Communications. Texas A&M University System. <http://soilcrop.tamu.edu/publications/pubs/b6096.pdf> .
- Rogers, D.H. 1996. Sprinkler Application and Effects on Corn Yield Tillage Practices. Proceedings of Central Plains Irrigation Short Course and Exposition. February 6-7, 1996, Burlington, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp.1-12.
- Rogers, D.H., F.R. Lamm. 1994. Large Acreage Center Pivot Systems. Kansas State University Cooperative Extension, Irrigation/Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1902.pdf> .
- Rogers, D.H., W. Spurgeon, W. Sothers. 1994a. Sprinkler Package Effects on Runoff. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1903.pdf> .

- Rogers, D.H., F.R. Lamm, W. Spurgeon. 1994b. LEPA Irrigation Management for Center Pivots. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1907.pdf> .
- Scherer, T. 1998. Selecting a Sprinkler Irrigation System. North Dakota State University Extension Service. <http://www.ext.nodak.edu/extpubs/ageng/irrigate/ae91w.htm> .
- Schneider, A.D., T.A. Howell. 2001. Comparison of SDI, LEPA, and Spray Irrigation Efficiency. 2001 ASAE Annual International Meeting, Sacramento, California, July 30-August 1, 2001. Paper No. 012019. <http://cpr.ars.usda.gov> .
- Schneider, A.D., T.A. Howell. 1995. Reducing Sprinkler Water Losses. Central Plains Irrigation Short Course and Exposition. February 7-8, 1995, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.60-63. Solomon, K.H. 1990. Irrigation Notes: Sprinkler Irrigation Uniformity. California State University, Fresno, California. <http://cati.csufresno.edu/cit/rese/90/900803/index.html> .
- Yonts, C.D., W.L. Kranz, D.L. Martin. 1999. Application Uniformity of In-Canopy Sprinklers. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1337.htm .
- Yonts, C.D. 2000. Performance of In-Canopy Sprinklers. Proceedings of Central Plains Irrigation Short Course and Exposition. February 9-10, 2000, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.107-112.
- Yonts, C.D., W.L. Kranz, D.L. Martin. 2000. Water Loss from Above-Canopy and In-Canopy Sprinklers. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1328.htm

INFORMATION SHEET No. 4

Runoff Control for Center Pivot Irrigation Systems

Runoff occurs when the rate of water application exceeds the rate at which water infiltrates into the soil.

Runoff Calculations Using Graphs

Although center pivot methods of irrigation are highly efficient, they do have the potential for significant runoff if the sprinkler package and operational practices are not suited for a particular field condition. The application rate, nozzle placement, and operation capacity should be selected according to the field conditions including slope and soil type. Improper selection can lead to significant runoff.

Runoff issues are of particular concern in the recent trend towards low pressure center pivot systems, which are desirable because they minimize energy cost. There has also been a trend towards placing sprinkler nozzles in the crop canopy and close to the ground to eliminate evaporation, drift losses, and canopy evaporation. However, reducing pressure and lowering the point of application has the disadvantage of reducing the wetted diameter and increasing the rate of water application. When the rate of water application exceeds the rate of infiltration, runoff will occur (Rogers et al., 1994). Excessive runoff is inefficient and does not allow for uniform water distribution over the field. Increases in runoff can far exceed the potential water savings that is associated with reducing operating pressure and lowering sprinklers into the canopy. A better understanding of the application rate, wetted radius, and system capacity in relation to a particular field condition (slope and soil type) is crucial to eliminating runoff and conserving water in sprinkler systems.

Options for Reducing Runoff

Producers can use the following options to reduce runoff, especially when using low pressure systems (Rogers et al., 1994):

- ¥ Decrease application depth
- ¥ Increase surface storage using appropriate residue and tillage management practices
- ¥ Decrease irrigation capacity
- ¥ Select sprinkler package that provides larger wetted radius

The first two options listed are management variables, meaning they can be changed through operational practice. Decreasing the application depth will require more frequent irrigation events, which will also increase soil surface and canopy evaporation. It is commonly believed that decreased application depth and more frequent irrigations promote runoff because not enough time between irrigations elapses to dry the soil. However, there have been no studies to show that runoff increases with decreasing application depth. In fact, increasing irrigation intervals (less frequent irrigations) can actually have a negative impact on yield. Bordovsky et al. (1992) and Lyle and Bordovsky (1995) have shown that for irrigation intervals less than seven days, yields can actually increase for cotton and corn. Intervals greater than seven days have a detrimental impact on crop yields.

Increasing the soil surface storage through crop residue and tillage management is important in any irrigation system for storing irrigation water and catching natural precipitation. See Information Sheet No. 8 for a discussion on proper crop residue and tillage management for sprinkler irrigation systems.

The third and fourth options require a change to the physical center pivot system and pumping plant. Decreasing irrigation capacity may not be possible in low capacity wells because crop needs will not be met and yields will be decreased. When management practices do not adequately reduce runoff, it may be necessary to make alterations to the physical center pivot system by changing the nozzle package for a more appropriate wetted radius. Wetted radius will depend on nozzle type, operating pressure, and nozzle height (Howell, 2003).

To reduce runoff, changes to operational practice should always be attempted by a producer before changing the nozzle package because the latter is usually more expensive. The importance of properly designing a new center pivot system to the conditions of the field should not be underestimated.

The zero runoff goal requires that the sprinkler package selected for the system be carefully matched to the field conditions and to the producer's management scheme (Kranz, 2000). For more information on selecting a sprinkler package and operating a sprinkler management scheme, see Information Sheet No. 3.

Calculating Runoff

CPNOZZLE is a computer program developed by the Northeast Research and Extension Center in Concord, Nebraska. The computer program provides a potential runoff analysis for center pivot systems. CPNOZZLE allows a user to input numerous variables for the center pivot, from which it determines the potential runoff. These variables include: system length, surface storage, application amount, system capacity and SCS Soil Intake Family (See box below). These variables are then used to determine what amount of runoff can be expected from a particular field condition under a particular management scheme. The program is useful in predicting how much the design or operation should be changed to eliminate a runoff problem in a center pivot system (Kranz, 2000).

CPNOZZLE Input Variables

System Length: common system lengths are 1,280 ft and large center pivots at ½ mile (2640 ft).

Surface Storage: values available in model include 0.0, 0.1, 0.3, and 0.5 inches which coincide to field slopes of >5%, 3-5%, 1-3%, and 0-1%.

Application amount: common application amounts are 0.75 in, 1.0 in and 1.5 in.

SCS Soil Intake Family: the available intake families include 0.1, 0.3, 0.5, 1.0, 1.5, and 2.0.

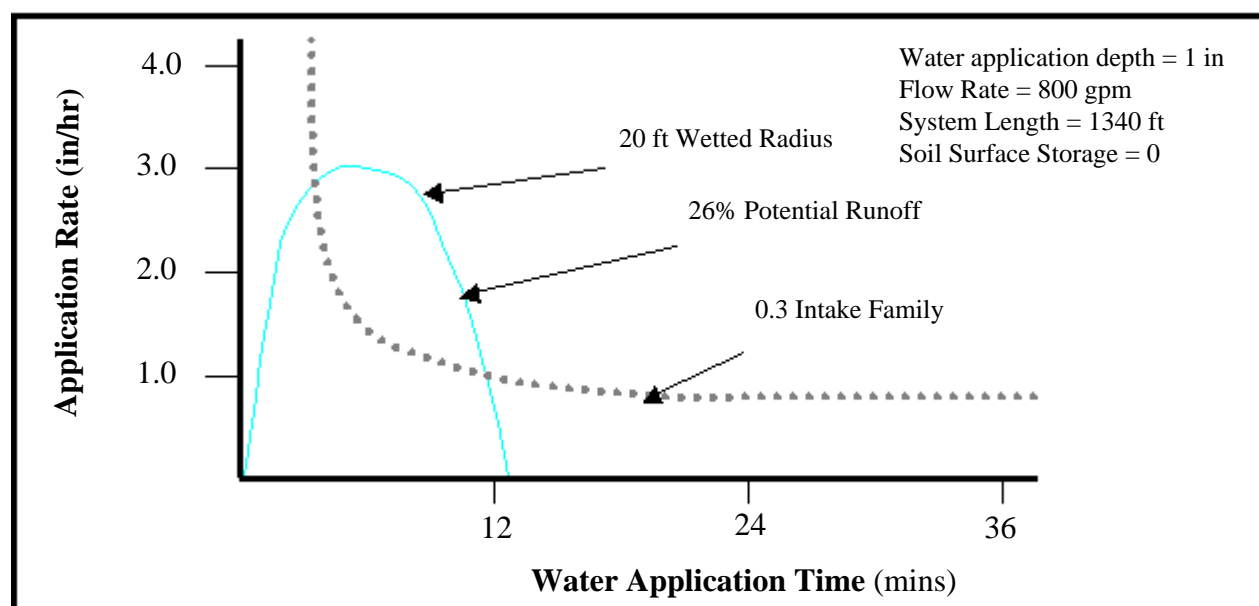


Figure 1. CPNOZZLE Example

The program works by overlaying a soil infiltration curve with a water application pattern (Kranz, 2000). Figure 1 provides an example center pivot system with a 0.3 NRCS soil intake family, surface storage of 0 (slope >5%), flow rate of 800 gpm, system length of 1340 feet, wetted radius of 20 feet, and an application depth of 1.0 inch. For this field condition and management scheme, a producer can expect 26% runoff, which is determined from the area of the water application curve that is above the transected infiltration curve.

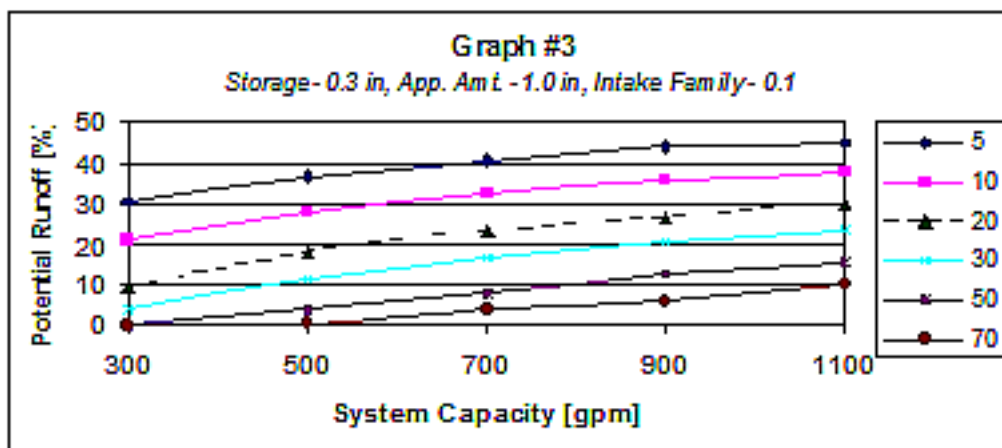
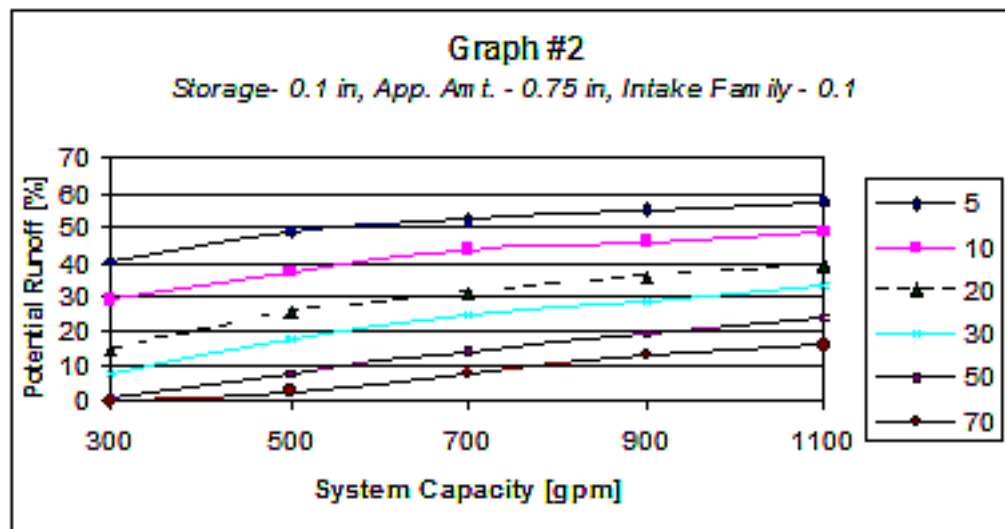
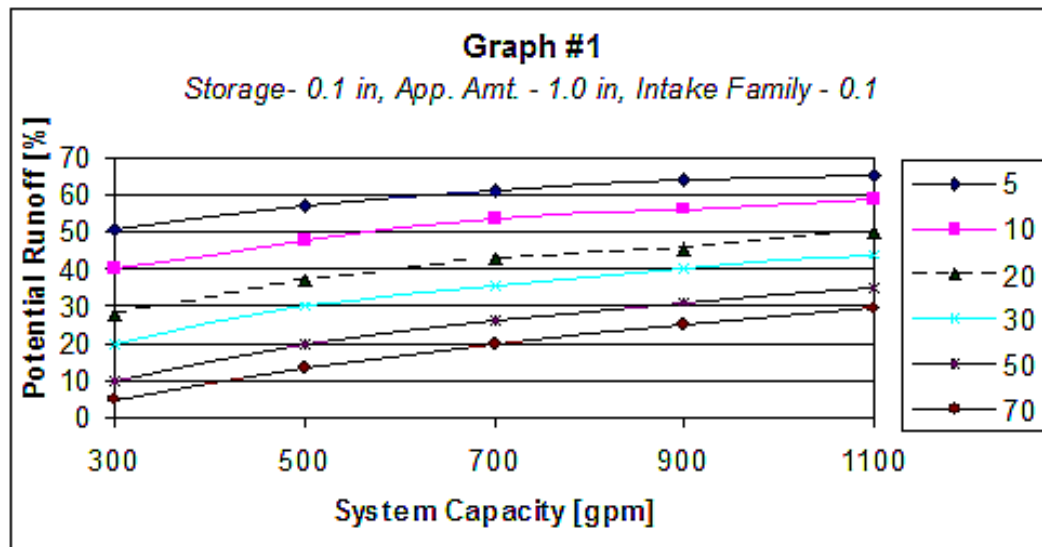
Table 1 provides a summary of different scenarios for which runoff was calculated in CPNOZZLE. Table 1 also displays corresponding graphs, which can be used to determine percent runoff for particular field conditions and management decisions. These graphs can be used to help a producer in calculating runoff for their particular field conditions and provide valuable information regarding how changes in application amount, wetted radius and system capacity will affect the efficiency of their system. Use Table 1 to guide the producer to their particular field condition and then analyze how runoff can be reduced by changing application amount, system flow rate, and wetted radius.

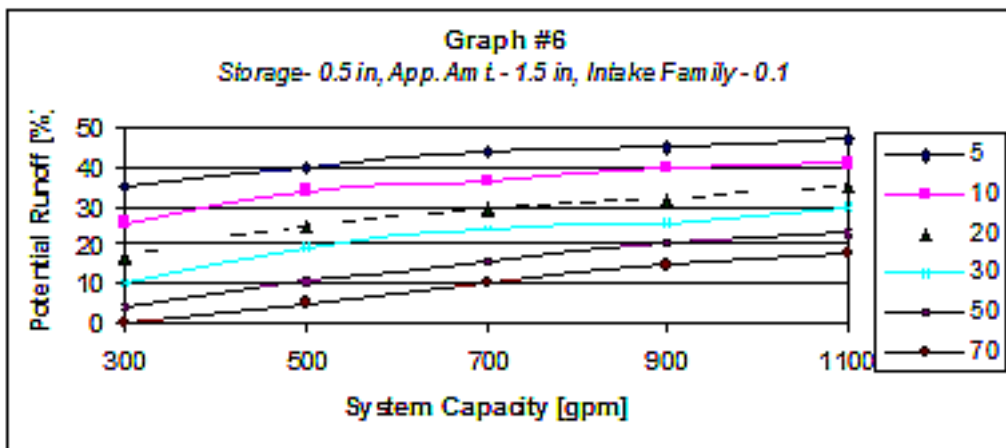
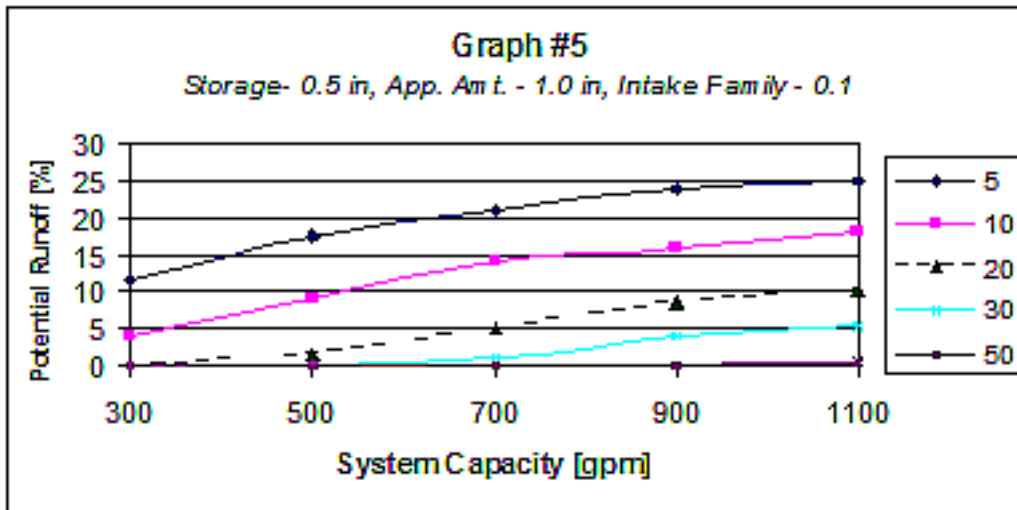
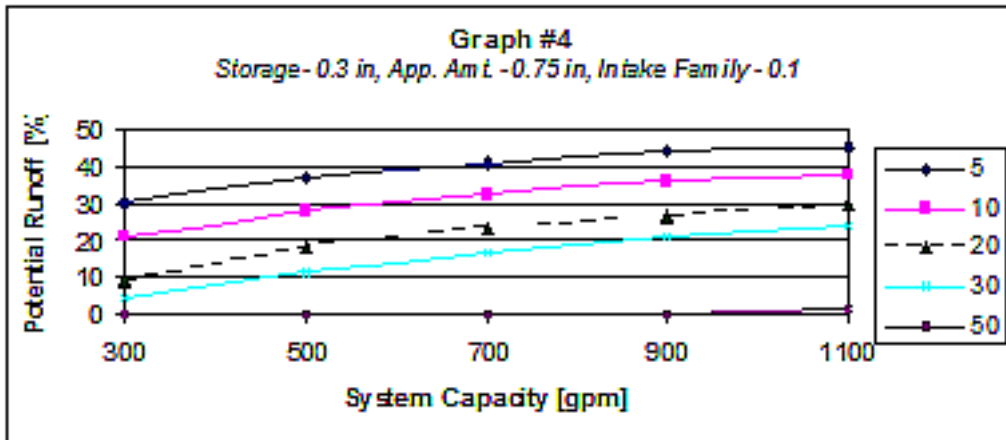
The best design of a center pivot system is the corresponding soil storage (slope), application amount (capacity), and soil intake family that results in 0% runoff. However, the trend towards using low pressure systems does not allow for 0% runoff so other measures, such as proper tillage, should be used to control runoff for these systems (see Information Sheet No. 8).

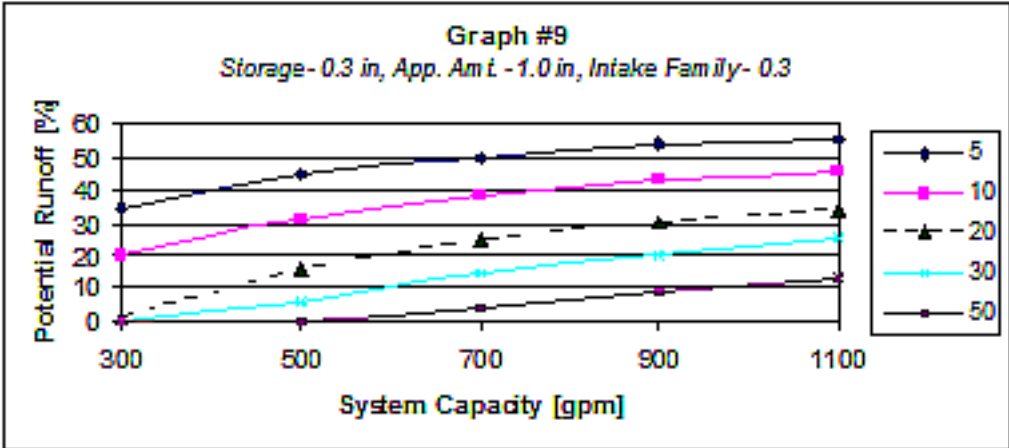
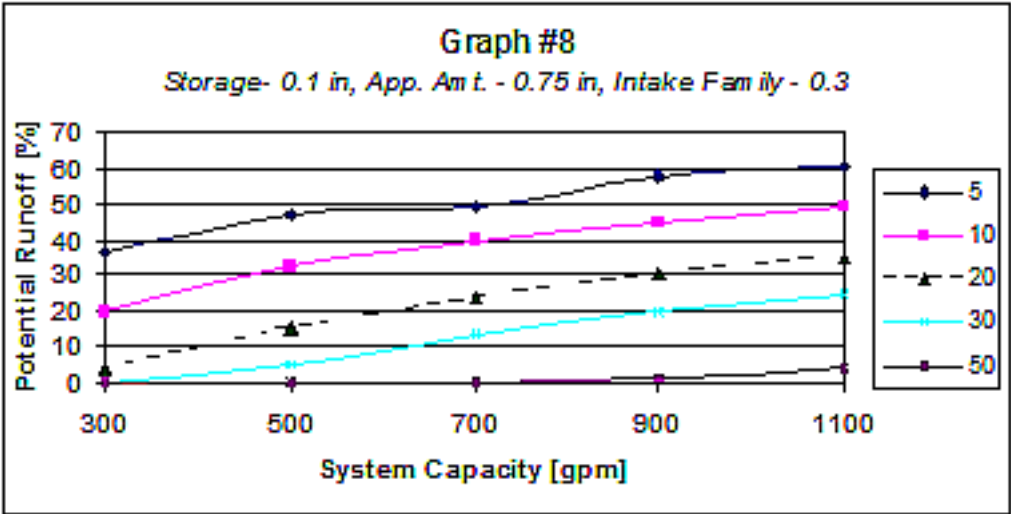
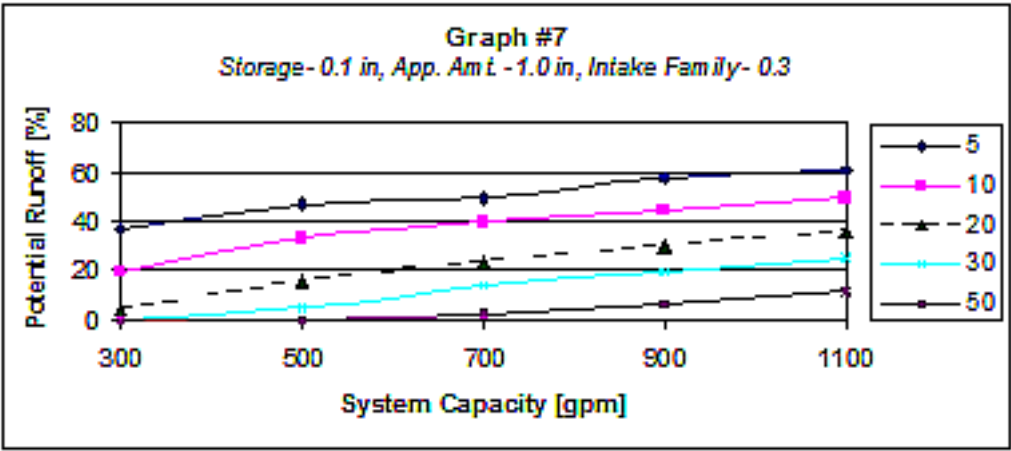
Table 1. Guide to CPNOZZLE graphs

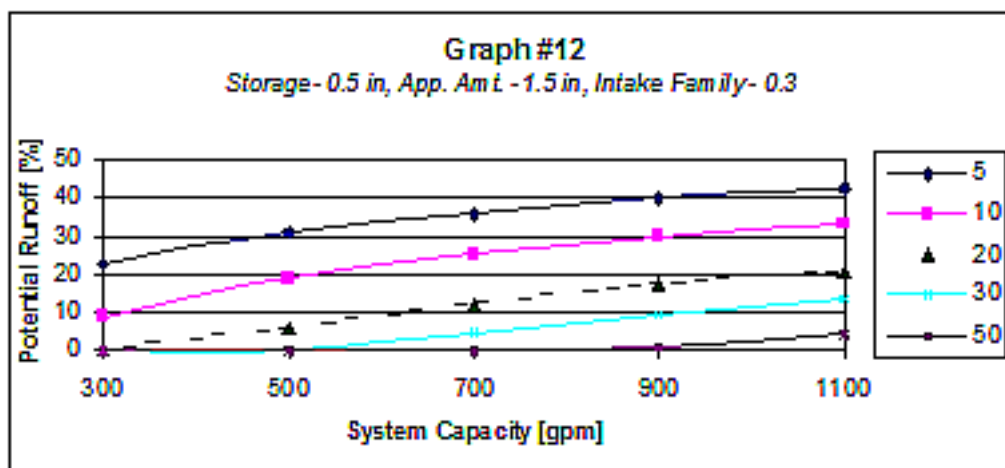
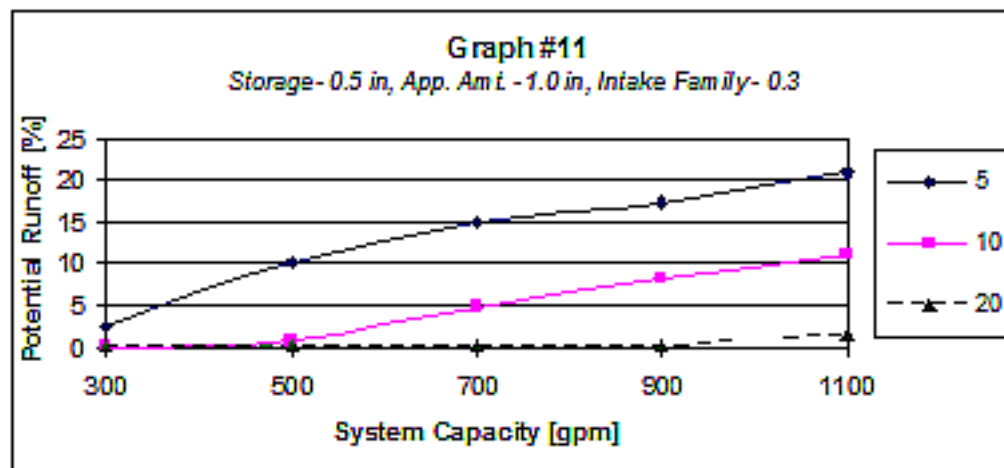
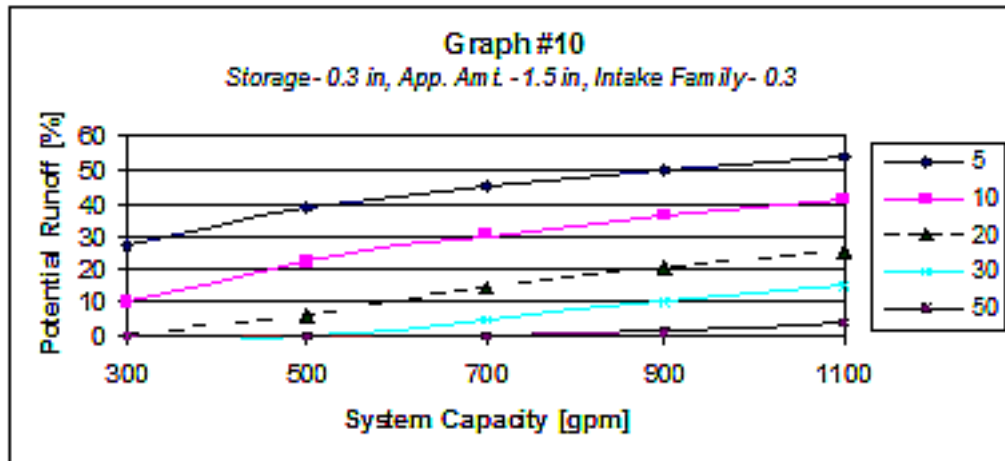
Length	Soil Storage	Application Amount	Soil Intake Family	Graph Number
<i>ft</i>	<i>in</i>	<i>in</i>		
1280	0.1	1.0	0.1	1
1280	0.1	0.75	0.1	2
1280	0.3	1.0	0.1	3
1280	0.3	0.75	0.1	4
1280	0.5	1.0	0.1	5
1280	0.5	1.5	0.1	6
1280	0.1	1.0	0.3	7
1280	0.1	0.75	0.3	8
1280	0.3	1.0	0.3	9
1280	0.3	1.5	0.3	10
1280	0.5	1.0	0.3	11
1280	0.5	1.5	0.3	12
1280	0.1	1.0	0.5	13
1280	0.1	1.5	0.5	14
1280	0.3	1.0	0.5	15
1280	0.3	1.5	0.5	16
1280	0.1	1.0	1.0	17
1280	0.3	1.0	1.0	18
2640	0.3	1.0	0.3	19
2640	0.5	1.0	0.3	20
2640	0.3	1.0	0.5	21
2640	0.5	1.0	0.5	22

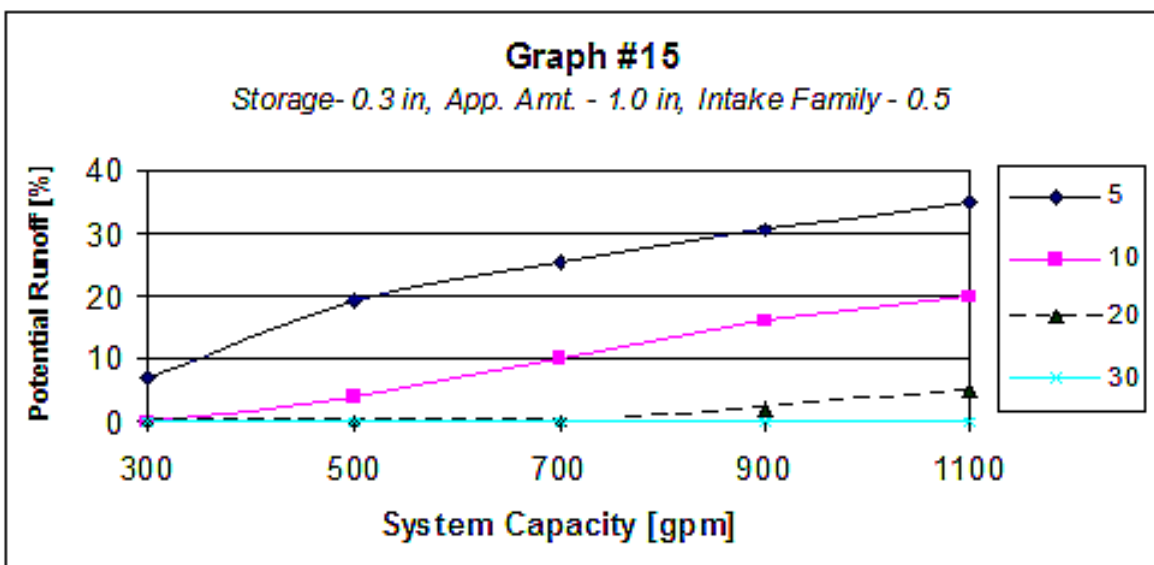
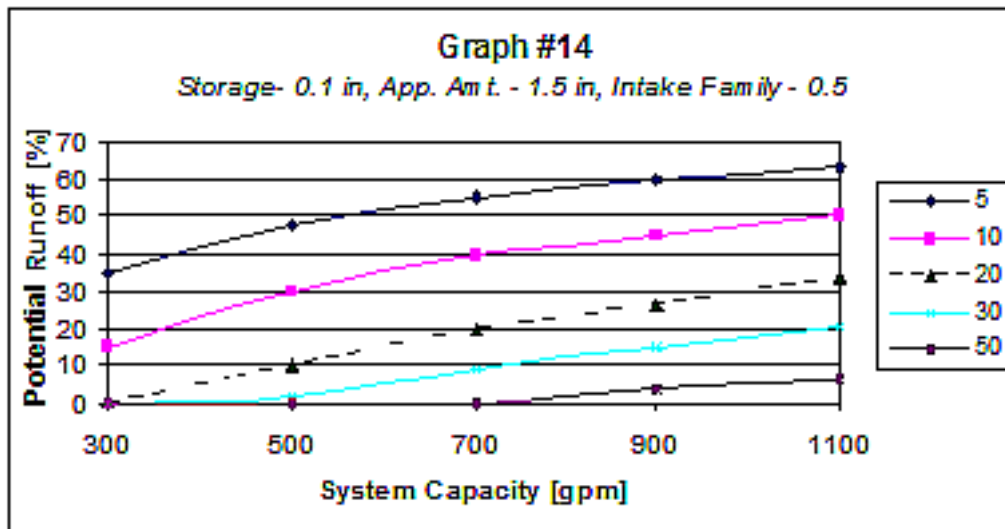
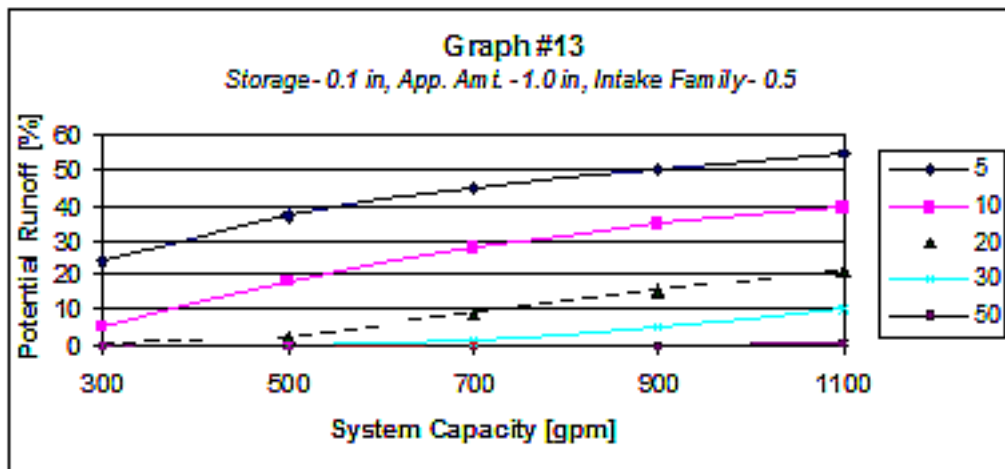
*Graphs were adapted with permission from Danny Rogers, Kansas State cooperative Extension, 2003.

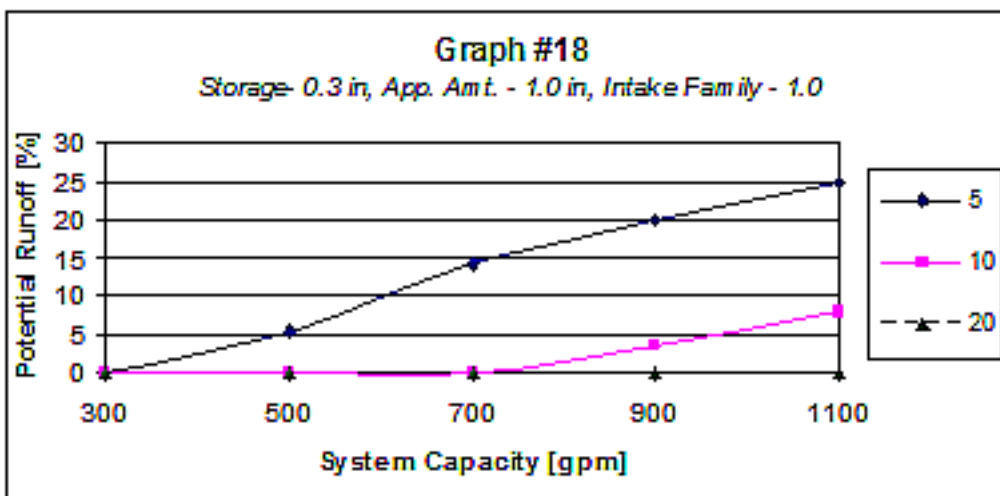
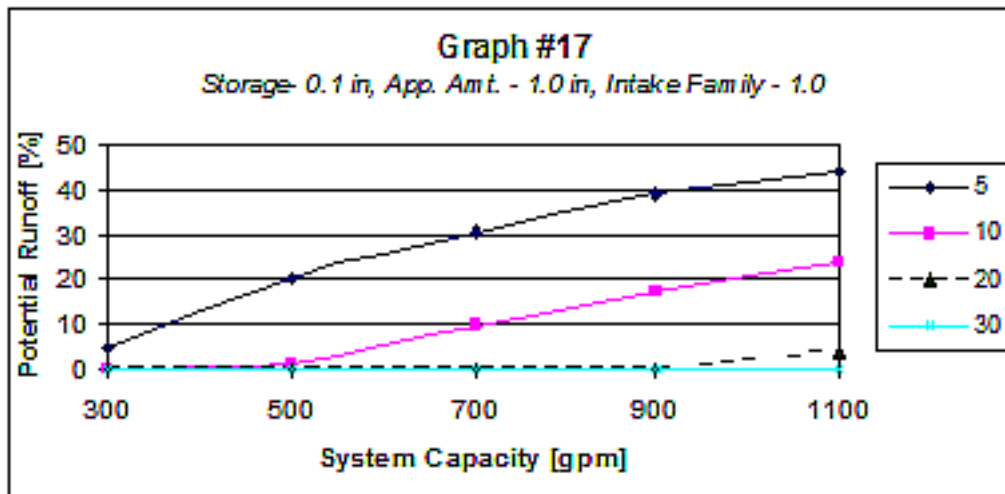
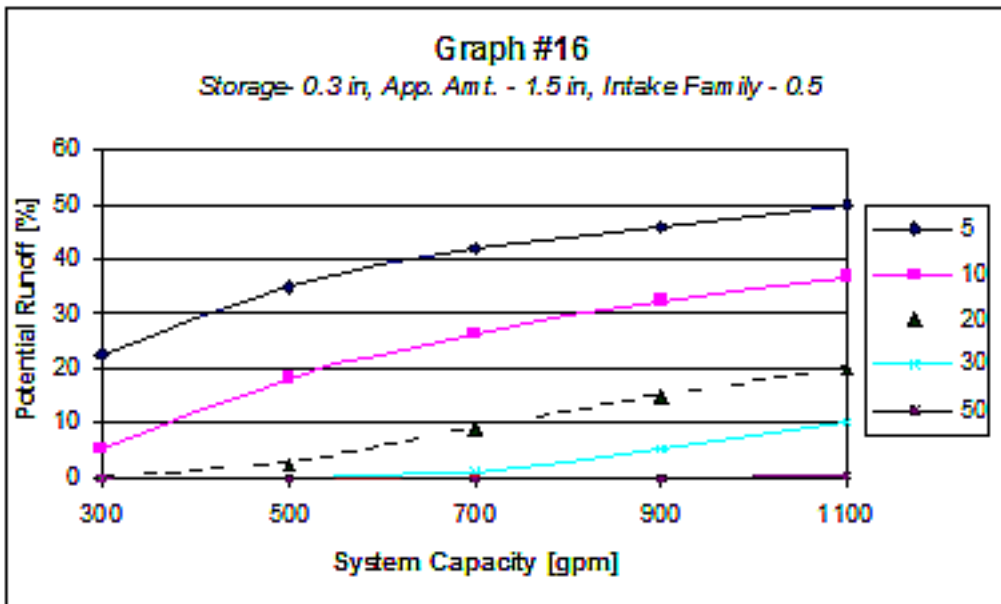


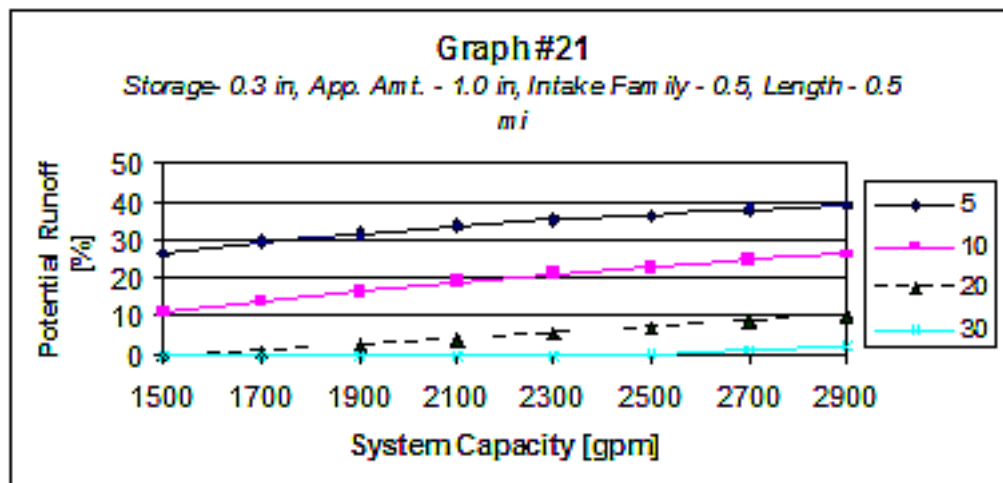
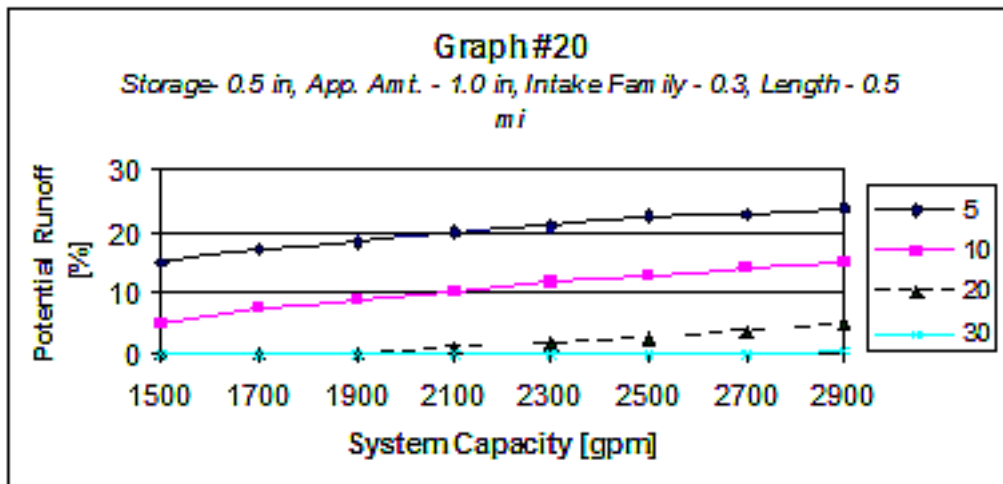
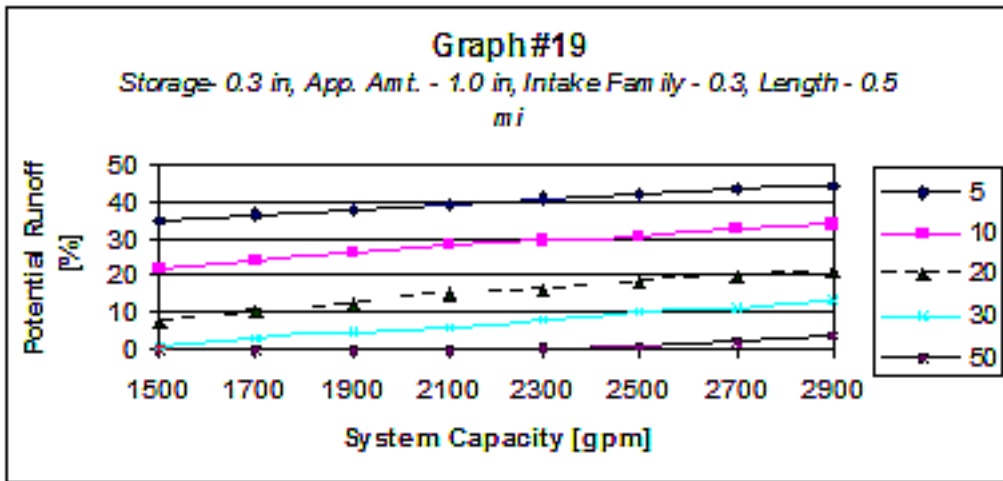


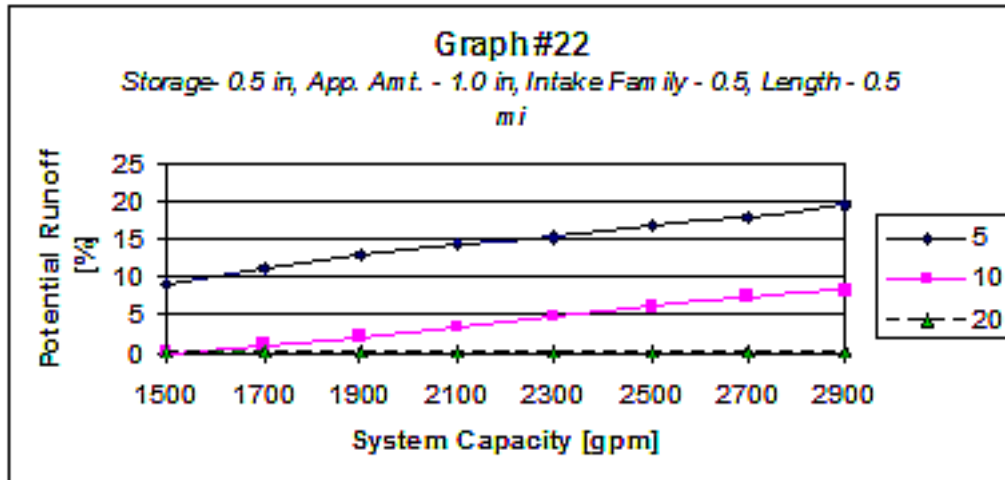












References

- Bordovsky, J.P., W.M. Lyle, R.J. Lascano, D.R. Upchurch. 1992. Cotton Irrigation Management with LEPA Systems. Transactions of the ASAE. Vol. 35(3): 879-884. American Society of Agricultural Engineers.
- Howell, T.A. 2003. Water Loss Comparisons of Sprinkler Packages. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.54-69.
- Kranz, B. 2000. Determining Runoff Potential. Proceedings of Central Plains Irrigation Short Course and Exposition. February 9-10, 2000, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.128-134.
- Lyle, W.M., J.P. Bordovsky. 1995. LEPA Corn Irrigation with Limited Water Supplies. Transactions of the ASAE. Vol. 38(2): 455-462. American Society of Agricultural Engineers.
- Rogers, D.H., W. Spurgeon, W. Sothers. 1994. Sprinkler Package Effects on Runoff: general guidelines. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1903.pdf>.

Furrow Irrigation Systems

Furrow irrigation is surface irrigation that avoids flooding the entire field surface by channeling water flow along the primary direction of the field slope using furrows. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir (Walker, 1989).

Making the right operational decisions for efficient furrow irrigation requires a good understanding of field conditions. Choosing set times and stream sizes are the most important management decision a producer will make in furrow irrigation systems. Set time and stream size should be selected according to the furrow length of run, soil type, and slope of field. This information sheet discusses some general guidelines for furrow irrigation systems.

Irrigation efficiencies of surface irrigation methods are inherently low. Proper furrow irrigation practices can increase the inherently low efficiencies of surface methods and reduce water application, irrigation costs, chemical leaching, and can result in higher crop yields (Rogers, 1995). Furrow irrigation, especially on moderately permeable soils is characterized by relatively large water applications and substantial losses to profile drainage and field runoff (Musick and Stewart, 1992). Several irrigation management practices have been developed to limit losses to profile drainage and field runoff. To conserve water, producers that use furrow irrigation systems should consider the following operational practices:

- Efficient distribution methods
- Cutback method
- Tailwater recovery
- Surge irrigation
- Every other row irrigation
- Polyacrylamide (PAM) application
- Land leveling

Set Time-Stream Size

To insure the most efficient use of water in furrow irrigation systems, set time and stream size should be selected according to the conditions present in the field. While producers do not have the ability to change soil type and cannot change field slope without land leveling, they do have the ability to manage set time and stream size for the most uniform and efficient application of irrigation water. Set time and stream size are the only two management variables that a producer has direct control over and are not accompanied by capital purchases or difficult changes in the physical irrigation system (Broner et al., 1992).

The stream size in an individual furrow is calculated by dividing the total water supply at the field, less water losses from seepage and evaporation, by the number of gates or siphon tubes in operation. Water measurement is crucial for determining the furrow stream size (Information Sheet No. 7). The stream size controls the rate at which water advances down the furrow, where the larger the stream size the faster the advance. In addition to faster advance, larger stream sizes also increase the uniformity along the length of the furrow because less water is allowed to deep percolate at the top of the furrow due to quick advance. Large stream sizes also have the potential to increase runoff at the end of the furrow. Options for reducing losses associated with runoff include: installing a tailwater reuse system, reducing the set time at which water is applied according to a cutoff ratio, and cutting back flow after a given time period. These are discussed in the following sections.

Figure 1 shows how the infiltration profile is affected by changing stream sizes for one set time. Figure 2 shows how the infiltration profile is affected by changing set times for one stream size. Set times and stream sizes should be adjusted to the point that the soil moisture deficit (SMD) is just satisfied, not over irrigated or under-irrigated.

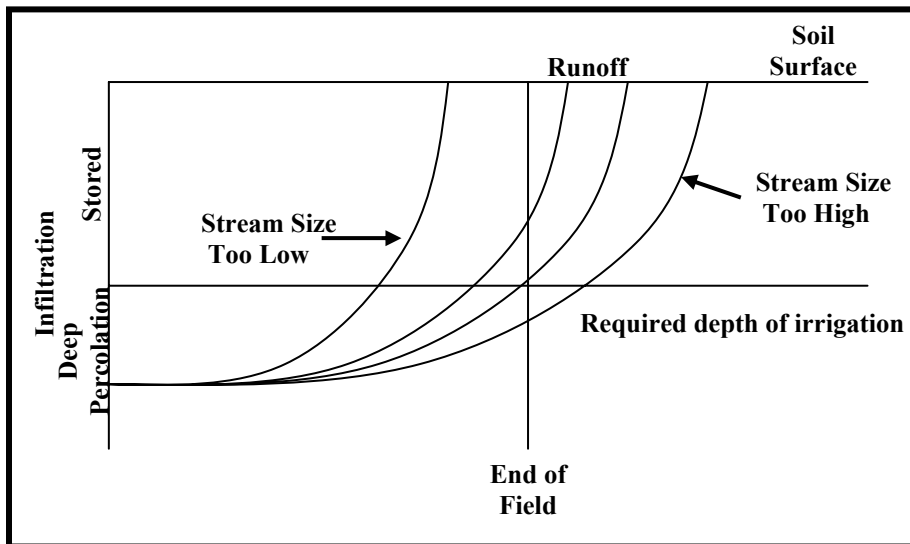


Figure 1. Effect of changing stream sizes for one set time

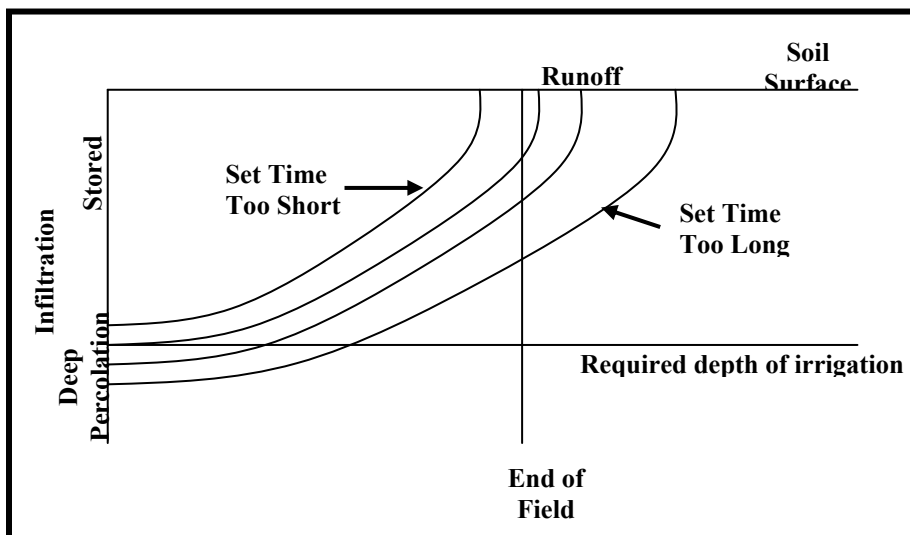


Figure 2. Effect of changing set times for one stream size

The field slope, the soil intake rate, and length of run in a furrow irrigation system are important to stream size and set time selection.

The more simple way to determine set time is to use a soil probe at the top of the furrow (Broner et al., 1992). At the end of an irrigation event, probing several locations along the width of the furrow can provide an estimate of the depth of water infiltration. The average depth of infiltration at the top of the furrow should be greater than the root zone by no more than 30%. The goal is to fill the root zone at the top of the furrow without excessive deep percolation.

The probing technique can also be used at the bottom of the furrow to determine the proper stream size (Broner et al., 1992). The bottom of the furrow should be fully irrigated, with a little deficit allowed. Stream sizes should be large enough to achieve a quick advance, but not too large that soil erosion results. Table 1 provides guidelines for stream sizes on a variety of slopes and soil conditions.

Slope

The slope of a furrow irrigation system will influence stream size selection. Furrows with steeper slopes will have quicker advance times and will therefore require smaller stream sizes than flatter slopes. Although quicker advance times are desirable for efficient and uniform water application, too quick of an advance and too large of a stream size can erode soils. In general, the maximum non-erosive stream size decreases as furrow slope increases. Maximum allowable stream sizes should be selected according to the equations presented in Table 1 (NRCS, 1997).

Soil Type

The rate at which water infiltrates into the soil varies with the steepness of slope, soil texture, spacing of furrows, and soil compaction (Rogers, 1995). Stream sizes should be selected according to the soil conditions in Table 1 to insure that soil erosion does not occur. Set times should also be selected according to the soil conditions (see Table 2). When water first infiltrates into the soil, the infiltration rate is high but decreases to a relatively constant rate after some time. This constant rate is called the basic infiltration rate. If the basic infiltration rate is 0.5 inches per hour or less, the length of furrow run can be at least 1300 feet (Rogers, 1995). Higher intake rates require shorter runs.

Table 1. Stream size guidelines

Equation	Soil Characteristic
$Q = 15/S$	Erosion resistant soils
$Q = 12.5/S$	Average soils
$Q = 10/S$	Moderately erodable soils
$Q = 5/S$	Highly erodable soils

Q = gpm per furrow
S = field slope in percent

Length of Run

Furrow advance time also depends on the length of run in a furrow irrigation system. Furrow runs that are too long have large advance times that result in water losses in the form of deep percolation at the top of the furrow. The length of run should not exceed 600 ft on sandy soils. Soils with extremely low infiltration rates can have longer run lengths if water is distributed uniformly between the top and bottom of the furrow.

Distribution Methods

Once water reaches a field there are a variety of methods both simple and complex that can be used in furrow irrigation systems to distribute water including: siphon tubes, gated pipe, and open or piped outlets. Open outlets are the simplest method of distribution, but also the most inefficient (Walker, 1989). Open outlets are small openings in the ditch bank that allow water to flow into each furrow (Figure 3). These open channels are also often used in border and basin irrigation systems. Siphon tubes are portable pipes placed in the lateral ditch to deliver water to each furrow (see Information Sheet No. 2 for picture). Gated pipe is PVC or aluminum pipe, which is typically connected to the main

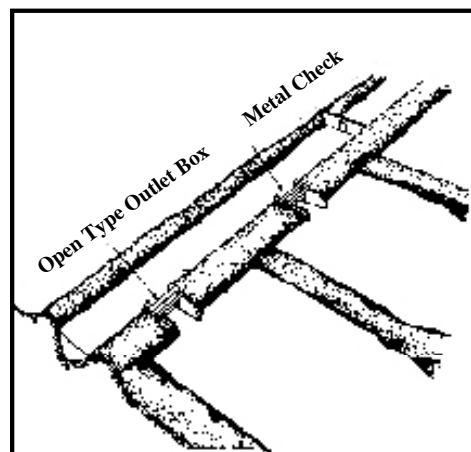


Figure 3. Open outlet distribution
Source: Walker (1989)

water supply through a pipe network (Figure 4). Gated pipe is more efficient than siphon tubes and open outlets because most losses associated with seepage and evaporation are reduced when water is conveyed in closed pipes as opposed to open channels.



Figure 4. Gated pipe for furrow irrigation

Water Savings Potential

- Average efficiency of furrow system using:
- o Siphon tubes or open outlets
 - o No land leveling
 - o No drainage system, reuse or surge 30-50%

Increase efficiency by 20% or more for furrow systems if:

- o Land is leveled
- o Gated pipe or delivery pipe is used
- o Drainage system is built to design standards

Cutback Method

Surface irrigation systems have two main sources of inefficiency, deep percolation and surface runoff (Walker, 1989). To minimize deep percolation, the advance phase should be completed as quickly as possible so that the intake opportunity time over the field as uniform as possible. This is typically achieved by applying a large, non-erosive stream size (Table 1). To minimize runoff, the inflow should be turned off or cutback when advance is complete. Although higher inflow rates are advantageous because they reach the end of the field sooner, they can also increase the duration and the magnitude of runoff at the bottom of the furrow. The practice of applying a large stream size and cutting back the stream size reduces the opportunity time at the upper end of the furrow, minimizes differences in application depths between the upper and lower ends of the furrow, and decreases tailwater at the bottom end. Therefore, under the cutback method, deep percolation is minimized at the upper end of the furrow and runoff is reduced at the lower end of the furrow.

Different soil types pose different challenges to the producer. Because light soils have a high rate of water intake, a large stream size is needed to speed the advance. In heavier soils that have a low rate of water intake, a smaller stream size is needed during the soaking phase to reduce tailwater. Proper practice in furrow irrigation is to start with a large stream size until advance is complete and cut it back for the soaking phase. Although this practice is labor intensive and difficult to implement, it can be automated through surge irrigation methods.

Because the use of the cutback method is dependent on the field conditions, stream size and the set time should be selected for a particular irrigation system. When the water has reached the end of the field, the size of the furrow stream should be cutback to one-third to one-half the original stream size.

Use of the cutoff ratio is another method that can be used to determine the time at which water should be turned off or cutback. The cutoff ratio is the ratio of advance time to the end of the field to the set time (Benham, 1998). Table 2 includes recommended cutoff ratios for achieving maximum efficiencies for various field conditions. The best combination of set time and stream size is the one which moves water to the end of the furrow within the requirements of the cutoff ratio, is less than the maximum erosive furrow stream size, and results in gross applications that are not excessive (Rogers, 1995).

Table 2. Recommended cutoff ratios

Method	Soil Type		
	Clayey	Silty or Loamy	Sandy
No Reuse	0.9	0.7	0.5
Open Reuse	0.7	0.5	0.35
Closed Reuse	0.5	0.4	0.2

Source: Benham (1998)

Tailwater Recovery

Recirculating irrigation runoff is a method of making more effective use of irrigation water and labor (Rogers, 1995). Tailwater recovery systems: (1) can offer substantial savings in irrigation power consumption if the water supply is groundwater, (2) increase yields because of higher irrigation efficiencies, and (3) increase irrigation efficiency by 25% to 30%.

Although tailwater recovery systems cannot save all tailwater, they can significantly increase efficiency and uniformity. The primary disadvantages of tailwater reuse systems are the loss of the area required for a reuse pit and the periodic maintenance of the pump, storage, and return facilities.

There are two types of tailwater recovery systems in use. The most common is a sequential use system that collects tailwater for use on lands at lower elevations. The second type is a return-water system that collects water that will be reused on lands at higher elevations. Both systems consist of tailwater ditches to collect the runoff; drainage ways to convey the water to a central collection point; sump or reservoir; a pump and power unit; and a pipeline or ditch to convey the water to a point of redistribution. If gravity can be used to convey water to where it is reused, a pump and power unit are not necessary. The size, capacity, selection and location of equipment and facilities for these systems depends on the type of irrigation system, topography, and a producer's practices and goals. For more information on the design and operation of tailwater reuse systems see Broner (1994).

Reuse systems are essential for efficient furrow irrigation. Producers who don't have reuse systems often reduce the stream size in the furrow to minimize runoff and subsequently reduce the uniformity of application (Eisenhauer et al., 1991).

Water Savings Potential

Expect a water savings of 25% to 30% if a furrow irrigation system incorporates a tailwater reuse system (savings refers to gross irrigation requirement).

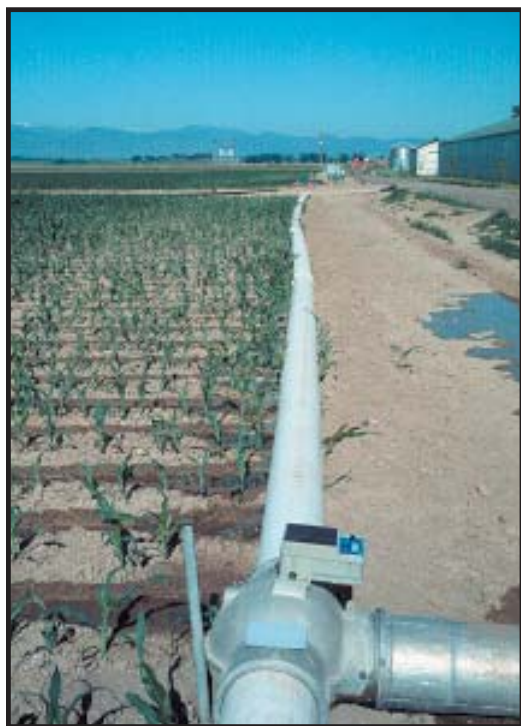


Figure 5. Surge valve and gated pipe

Surge Irrigation

Surge irrigation is the intermittent application of water to furrows in a series of surges of constant or variable time spans (Broner et al., 1992). In surge irrigation, water application is alternated between two sets of furrows until irrigation is completed rather than continuously irrigating all furrows. The process of applying water intermittently allows the furrow to seal over, decreasing infiltration and speeding up the advance time.

Usual operation includes the use of an automatic surge valve located between two sets of gated pipes (Figure 5). Water is alternated between the left side and right side of the surge valve. For example, a furrow on one side of the surge valve receives water for 40 min. and then water is shut off for 40 min. The second surge duration again can be 40 min or longer according to the particular program used. This process continues until the advance is completed for both sides.

To properly apply furrow irrigation, some cutback method is needed. Surge irrigation automates the cutback method. Cutback for the soaking phase in surge irrigation can be done in two ways. The first way is to divide the flow between the two sets, which reduces the stream size by 50%. The second way is to continue to alternate the water between

the two sets of furrows on a shorter time interval, which cuts back time and the average stream size, while still irrigating the entire furrow.

In addition to automating the cutback and subsequently reducing runoff at the end of the field, surge irrigation reduces the infiltration rate due to sealing, which reduces advance times and deep percolation at the upper end of the furrow. When water first contacts the soil, infiltration rates are high but continue to decrease to a constant rate. At this point, if water is shut off and delivered to another set of furrows, the soil is allowed to dry for a short period of time. This period of drying allows surface soil particles to consolidate and form a seal in the furrow (Yonts et al., 1991). When water is reintroduced into the soil, the sealing effect is believed to reduce the infiltration rate of the furrow, allowing faster advance times, reduced deep percolation, and more uniform application (Figure 6).

The time and frequency of irrigation with surge systems is determined from soil characteristics, slope, and length of run.

The University of Nebraska has evaluated surge irrigation in a series of trials from 1983 to 1989 (Yonts et al., 1991; Yonts et al., 1994a). The tests compared advance times for surge irrigation to continuous flow irrigation on a variety of different soils and field conditions. Of the 26 trials conducted, surge irrigation was never less effective than continuous flow. For 12 of the 26 trials, there was no significant difference in advance times for surge and continuous flow irrigation. The average reduction in advance time for the 14 remaining trials was 17% with a range of 0% to 52%. These trials showed that soil texture and structure play an important role in the ability of surge irrigation to reduce advance times. Soils having acceptable advance times

under conventional irrigation practices may not show a decrease in advance times under surge irrigation. Surge irrigation is most effective in soils with high intake rates.

Surge Irrigation methods have been compared to continuous flow irrigation in northeast Colorado for purposes of conserving water (Broner and Leibrock, 1993; Israeli, 1988). Table 3 shows the results from this research, which was conducted on an experimental farm south of Fort Collins. Surge irrigation has a higher efficiency value than continuous flow irrigation methods. The low efficiency value for the continuous method

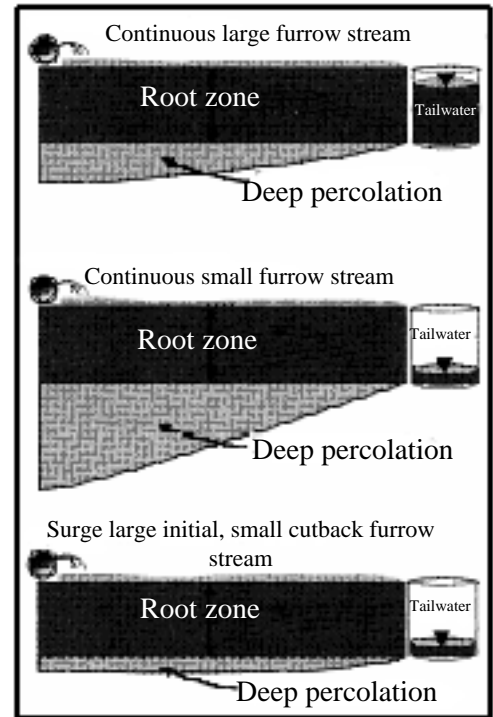


Figure 6. Comparison of continuous irrigation to surge irrigation
Source: Rogers and Sothers (1995)

Table 3. Irrigation water applied at Thompson Valley Young Farmers Farm

Method	No. of Irrigations	Water Applied in	Rain in	Average Application Efficiency %
Surge	9	30	6	85
Continuous North Field	6	61	6	55
Continuous South Field	6	44	6	45

Source: Broner and Leibrock (1993)

Water Savings Potential

- Expect a water savings of 10% to 30% if continuous flow irrigation is replaced with surge irrigation on high intake soils.
- Expect minimal water savings of 5% to 10% if continuous flow irrigation is replaced with surge irrigation on low intake soils where advance times are acceptable.

Surge Advantages

- Faster water advance to the end of the field reduces deep percolation at the upper end of the field.
- Automatic cutback reduces tail water.
- Allows lighter applications of water.
- More uniform water distribution along the furrow.
- More opportunities to save water and energy.

Surge Disadvantages

- Requires a higher level of management.
- Surge equipment must be maintained properly.
- Additional cost of the surge valve and gated pipe if not already in use.
- May not always reduce the advance time down a furrow (low intake soils).
- If infiltration rates are reduced, less water may be stored in the rootzone and irrigation may need to be more frequent.

on the south field is a result of steep slopes on this field. Similar research has been conducted in other areas in Colorado showing a water savings of 20% to 40% for surge irrigation (Broner and Leibrock, 1993).

For more information on how to design, install and operate surge irrigation systems see Broner (1988), Yonts et al. (1991), Yonts et al. (1994b), Wertz et al. (1994), Broner et al. (1992), and Rogers and Sothers (1995).

Every Other Row Irrigation

Every other row or alternate furrow irrigation is practiced to a limited degree in Colorado. Several field experiments indicate that this practice can conserve water without a reduction in crop yield. Irrigating every other furrow allows water to be applied to more acres than irrigating every furrow from a given water source for a given time period (Rogers et al., 1995). Under alternate row irrigation, losses associated with deep percolation, tailwater runoff, and evaporation from surface soil wetting are decreased (Musick and Stewart, 1992). In addition, irrigating every other furrow and applying less water per irrigation may provide more storage space within the root zone for rainfall (Rogers et al., 1995).

In a study (Graterol et al., 1989) in Nebraska, every other row irrigation was compared to conventional furrow irrigation of soybeans. The results showed that the same yields were obtained under both practices with significantly less water (46%) applied under every other row irrigation.

Another study (Fischbach and Mulliner, 1974) showed that every other row irrigation required 40% less gross water than conventional furrow irrigation of corn with no significant difference in yield between the two methods.

A recent study in Kansas (Rogers et al., 1995) showed that corn yields for a variety of soil types (clay loam to loamy sand) were not affected by every other row irrigation. Although water savings for this study were not specifically reported, the author suggests that water application can be reduced by 20% to 30% by implementing every other row irrigation. The distance between watered furrows in every other row irrigation should not exceed 6 feet (Rogers et al., 1995).

Water Savings Potential

- Expect a 20% to 30% water savings when converting from conventional irrigation (every furrow) to every other row irrigation for the following conditions:
 - o Medium textured soil
 - o Moderate to zero slope
 - o Row spacing less than 6 feet

Every Other Row Advantages

- Conserves water by reducing water input, which results in reduced deep percolation and reduced tailwater runoff.
- Reduces evaporation because of reduced wetted soil surface.
- Increases storage within the root zone for rainfall (every other row is dry).
- Requires less equipment and labor (fewer open gates in gated pipe and fewer siphons).
- With saline irrigation water, salts accumulate in the middle of the dry furrow away from the plant's root system.

Every Other Row Disadvantages

- Obtaining adequate lateral water movement that will wet enough soil volume before deep percolation starts can be problematic in coarse textured soils.
- The use of every other row irrigation becomes less successful on: coarse textured soils, soil with low intake rates, steep slopes, wide furrow spacing and small furrow wetted perimeter.

Polyacrylamide (PAM)

Polyacrylamide (PAM) is a long-chain, high molecular weight polymer that when mixed with irrigation water stabilizes near surface soil particles by forming polymer “nets” around existing soil aggregates (Yonts et al., 2000). These aggregates are less likely to disintegrated during irrigation, decreasing the potential for soil erosion.

PAM is well known for its ability to reduce soil erosion from 30% to 90%. PAM can also increase the lateral movement of water in furrows and improves infiltration on fine textured soils (Bauder et al., 2003). In some cases, PAM has been shown to increase infiltration rates by up to 50%.

A study in Idaho (Lentz and Sojka, 1994) showed that PAM applied at a rate of 0.6 lb/ac on a silt loam soil reduced erosion by 99% and increased infiltration by 15%. PAM has also been shown to decrease seepage in unlined ditches. (See Information Sheet No. 1). Because PAM increases infiltration, irrigators should increase stream size to maintain uniformity and advance times (Bauder et al., 2003). Research in Idaho has shown that inflow rates can be doubled with PAM, while still achieving greater overall uniformity and reducing soil loss (Valliant, 1999). Common practice of PAM application in Colorado is to make 2 or 3 applications at 1 lb/ac during the growing season (usually one during initial irrigation and one after the final cultivation).

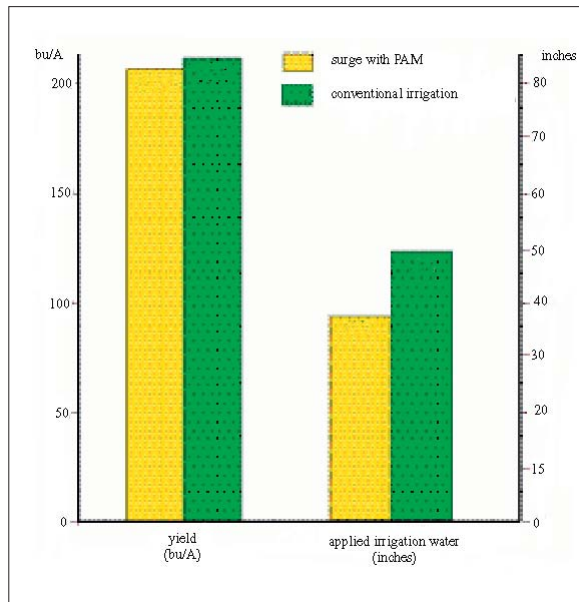


Figure 7. PAM application to furrows

Water Savings Potential

- Expect a 10% to 20% water savings when properly applying PAM to a surge furrow irrigation system when stream size is adjusted appropriately.
- Expect a 5% to 10% water savings when properly applying PAM to a conventional furrow system when stream size is adjusted appropriately.

Water savings potential is not attributed to PAM itself; rather the savings is a result of soils tolerating higher furrow flow rates. Using higher furrow flow rates that are appropriate for furrow conditions, will result in better uniformity and water savings.

Anionic (negatively charged) PAM formulations should be used for irrigation purposes because it is water soluble and non-toxic if used properly. Cationic (positively charged) PAM should never be used for irrigation purposes because it is highly toxic to aquatic organisms, even at low concentrations.

Land Leveling

The preparation of the field surface for conveyance and distribution of irrigation water is as important to efficient surface irrigation as any other single management practice that a producer employs (Walker, 1989). Land leveling is used to ensure that water depth is relatively uniform over the field surface and within the soil profile. The uniformity of water applied significantly affects the efficiency of an irrigation system (Howell, 2002). Although water distribution depends on many factors including the method of irrigation, soil topography, soil infiltration characteristics and the hydraulic characteristics of the irrigation system, land leveling provides one of the best methods for increasing uniformity in surface irrigation systems.



Figure 8. Land leveling

Establishment of a uniform slope is more important for surface irrigation systems, but can also be beneficial in sprinkler irrigation systems (Schwab et al., 1993). More uniform application means that less water is needed to irrigate the areas that were under-irrigated under non-uniform conditions. Land leveling not only improves efficiency and uniformity, but it also improves the utilization of labor and energy inputs by allowing irrigation events to be completed more quickly.

Laser leveling refers to (1) a one time leveling procedure that significantly modifies the topography of land and (2) to an occasional or seasonal land smoothing procedure called “floating.” Significant alterations to the topography of a field in favor of more level conditions can

greatly increase the uniformity of water application. Floating is typically performed as maintenance to previously leveled lands for purposes of filling the high and low spots that result from traffic and tillage operations and erosion. Floating is recommended occasionally for leveled lands to insure the most uniform water application.

New equipment is continually being introduced which provides the capability for more precise land leveling operations. One of the most significant advances has been the adaptation of laser control in land leveling equipment (Walker, 1989). While these methods are highly precise, they are also expensive. Leveling in surface irrigation systems is required nearly every season and therefore adds significant cost to a producers operation. However, the benefit of leveling in most cases out weighs the associated costs. The major problem with land leveling is the removal of fertile topsoil and its influence on crop growth and productivity. If significant soil removal is required, it may take several years before the soil can achieve normal fertility. Therefore, land leveling is not advised on slopes greater than 3%. Addition of organic amendments such as manure or compost on cut areas can help reclaim productivity. Another concern is the soil compaction caused by leveling machinery. Soil compaction will decrease the infiltration rate of the soil. To avoid unnecessary compaction, land should be leveled when soils are relatively dry and subsoiling and chiseling should be practiced after construction.

References

- Alam, M. 1997. Irrigation Efficiencies of Surface Systems. Proceedings of Central Plains Irrigation Short Course and Exposition, February 4, 1997, Colby, Kansas. Central Plains Irrigation Association, Colby Kansas. pp.45-48.
- Bauder, T., R. Waskom, J. Schneekloth, J. Alldredge. 2003. Best Management Practices for Colorado Corn. Colorado State University Cooperative Extension. Colorado State University, Fort Collins, Colorado.
- Benham, B. 1998. Computing Field Losses for Furrow Irrigation. Proceedings of Central Plains Irrigation Short Course and Exposition. February 17-19, 1998, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.1-5.
- Broner, I. 1994. Tailwater Recovery for Surface Irrigation. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.709. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04709.html .
- Broner, I. 1988. Surge Irrigation Guide. Colorado State University Cooperative Extension. Colorado State University, Fort Collins, Colorado.
- Broner, I., J. Cahoon, H. Manges. 1992. Furrow Irrigation Management. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.26-48.
- Broner, I. And J. Cahoon. 1991. Furrow Irrigation Management. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.1-22.
- Broner, I., F.R. Leibrock. 1993. Water Conservation Practices in Surface Irrigation. ICID Bulletin. Vol. 42 No. 1.
- Eisenhauer, D.E., D.L. Varner, C.D. Yonts, W. Liesemeyer. 1991. Managing Furrow Irrigation Systems. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.23-33.
- Fischbach, P.E., H.R. Mulliner. 1974. Every-Other Furrow Irrigation of Corn. Transactions of the ASAE. Vol. 17 (3):426-428.
- Graterol, Y.E., R.W. Elmore, D.E. Eisenhauer. 1989. The Use of Alternate-Irrigated Furrow Spacing for Soybean Production. UNL Clay Center, Nebraska.
- Israeli, I. 1988. Comparison of Surge and Cablegation to Continuous Furrow Irrigation. American Society of Agricultural Engineers, International Summer Meeting, St. Joseph, MI. Paper #88-2014.
- Lentz, R.D., R.E. Sojka. 1994. Field Results Using Polyacrylamide to Manage Furrow Erosion and Infiltration. Soil Science. Volume 158: 274-282.
- Musick, J.T., and B.A. Stewart. 1992. Irrigation Technologies. In: Groundwater Exploitation in the High Plains. Kromm, D.E. and S.E. White (eds.). University of Kansas Press. Lawrence, Kansas.
- Natural Resources Conservation Service (NRCS). 1997. National Engineering Handbook 210-VI: Irrigation Guide. Part 652. United States Department of Agriculture.
- Rogers, D.H. 1995. Managing Furrow Irrigation Systems. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/L913.PDF>.
- Rogers, D.H., W.M. Sothers. 1995. Surge Irrigation. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/AGENG2/1912.PDF> .

- Rogers, D.H., F.R. Lamm, M. Alam, T.P. Trooien, G.A. Clark, P.L. Barnes, K. Mankin. 1997. Efficiencies and Water Losses of Irrigation Systems. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/mf2243.pdf> .
- Schwab, G.O., D.D. Fangmeier, W.J. Elliot, R.K. Frevert. 1993. Soil and Water Conservation Engineering Fourth Edition. John Wiley & Sons, inc. New York.
- Valliant, J. 1999. PAM: A cost effective tool for improving irrigation and protecting soil and water Resources. Colorado State University, Soil and Crop Sciences, Drought Newsletter 1999. www.colostate.edu/Depts/SoilCrop/extension/Newsletters/1999/gujune99.htm .
- Walker, W.R. 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drainage Paper No. 45. Food and Agriculture Organization of the United Nations. Rome, Italy. <http://www.fao.org/docrep/t0231e/t0231e00.htm#Contents> .
- Wertz, K., J. Cahoon, C.D. Yonts. 1994. Surge Irrigation Management. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/nf179.htm.
- Yonts, C.D., B.L. Benham, J. Blumenthal and R.B. Ferguson. 2000. Polyacrylamide (PAM) Effect on Irrigation and Sediment Yield. Proceedings of the 4th Decennial National Irrigation Symposium. pp 523-528. Phoenix, AZ.
- Yonts, C.D., J.E. Cahoon, D.E. Eisenhauer, K. Wertz. 1994a. Nebraska Surge Irrigation Trials. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/nf177.htm .
- Yonts, C.D., J.E. Cahoon, D.E. Eisenhauer, K. Wertz. 1994b. Surge Irrigation. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/nf176.htm .
- Yonts, C.D., D.E. Eisenhauer, J.E. Cahoon. 1991. Fundamentals of SURGE Irrigation. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.34-51.

INFORMATION SHEET No. 6

Subsurface Drip Irrigation Systems

Subsurface drip irrigation (SDI) is a low-pressure, low-volume irrigation system that uses buried drip tubes below the soil surface.

Water application in SDI systems can be highly uniform and efficient when properly designed. A subsurface drip system is flexible and provides frequent but light irrigations. This is especially suitable for arid, hot and windy areas with limited water supply. Subsurface application of water to the root zone also has the potential to improve yields by reducing the incidence of disease and weeds. The applied water moves by soil matric potential, eliminating the effect of surface infiltration characteristics and the saturated condition of ponding water during irrigation. Although SDI systems have some of the highest field efficiency values, there are several specific issues for these systems that should be considered for the most efficient operation such as:

- The physical system
- Crop, soil, and field characteristics
- Water quality
- Hydraulic characteristics
- Filtration
- Operation and maintenance
- Cost

The Physical System

A typical layout and schematic of SDI system is shown in Figures 1 and 2. An SDI system may include some or all of the following components: settling pond if surface water supply is used; pumping unit; filtration unit; chemical injection and injection unit; pressure regulators; air vent at the manifold; and a PVC delivery system to carry water to the field. The delivery system is composed of mainline and submain pipes, to which drip tubes (laterals) are attached. Flow meters and pressure gages are needed to monitor the performance of the system and schedule efficient irrigation applications.

Although many varieties of drip tubes are available, polyethylene tubes are the most common and have built-in emitters through which water flows into the soil. The spacing and flow rate through emitters is dependent on the product, which comes in a variety of tube wall thickness and costs. The use of pressure compensating emitters allows for longer laterals and the installation on sleep slopes. Porous tubes that drip water from the entire length of the pipe can also be used in SDI systems, but are not recommended because of low distribution

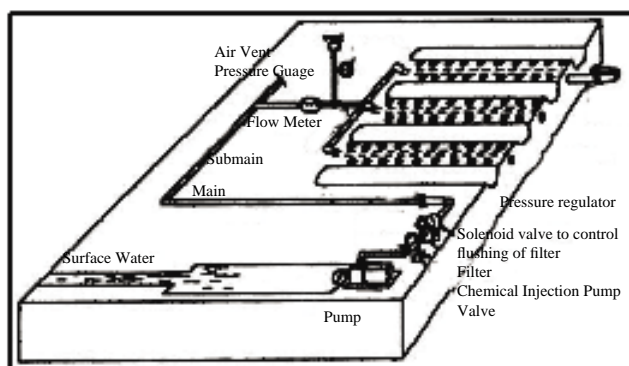


Figure 1. A typical SDI system field layout
Source: Alam (2001)

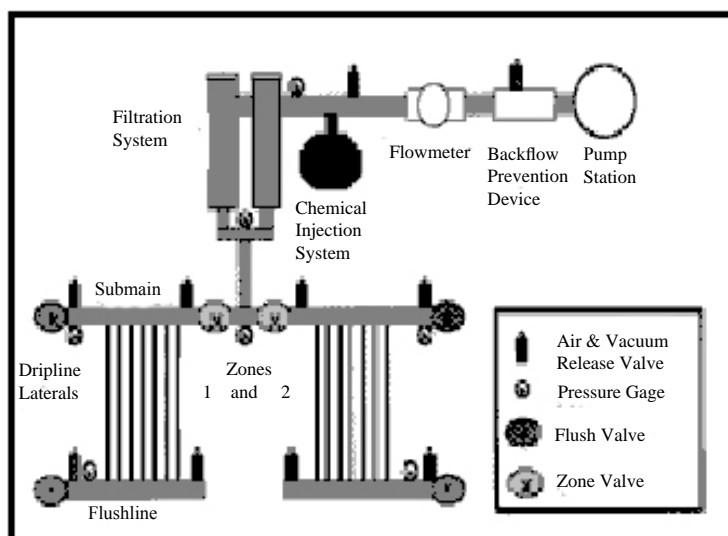


Figure 2. Schematic of SDI system
Source: Alam et al. (2002)

uniformity and clogging issues. The hydraulic design of the system should satisfy constraints dictated by crop, soil type, field size, shape and topography, water source, and water supply (Lamm et al., 2003a).

Crop, Soil, and Field Characteristics

The crop and soil type will dictate SDI system capacity, dripline spacing, emitter spacing, and installation depth (Lamm et al., 2003a). SDI is suitable for almost all crops, particularly for high-value vegetable crops, but is also feasible for forage crops such as alfalfa. Because there is concern that irrigation for emergence is difficult in SDI systems, Lamm et al. (2003a) should be consulted.

The system capacity of SDI systems must satisfy the peak crop water requirements of the crop being grown to achieve optimum yields. The capacity will dictate the emitter flow rate and the area over which submain sections of dripline are placed.

Dripline spacing is both an economic and agronomic decision. The wider the dripline spacing, the less the cost required to install dripline over the field. However, if spacing is too wide, water supply may not adequately meet crop needs or will lead to excessive deep percolation on some areas of the field. Research in western Kansas has shown that dripline spacing of 60 in is optimal for corn row spacing of 30 in for a silt loam soil (Lamm et al., 2003a). Another study on sandy loam soil in Kansas has shown that spacing of 60 in for alfalfa negatively impacts emergence, while spacing of 30 in has no advantage over 40 in spacing (Alam and Dumler, 2003). In areas with a restrictive layer below the dripline, wider spacing may be feasible.

While dripline spacing is dictated by crop row spacing, emitter spacing should be dictated by crop plant spacing. One advantage of SDI systems is the ability to apply water to only a fraction of the root zone, therefore careful attention to dripline and emitter spacing is crucial to water conservation (Lamm et al., 2003a).

Dripline placement depths vary from 6 to 24 in, depending on the soil and crop type. Deep installation of dripline is desirable because it reduces water losses associated with evaporation and allows for a wider range of tillage practices (Lamm et al., 2003a). In light soils, placement should be shallower because capillary water movement is limited in these soils. Because water moves upward more readily in heavier soils, driplines may be placed deeper. Research in western Kansas has shown success in placing driplines at 16 to 18 in depths in medium textured (silt loam soils) (Lamm et al., 2003a). Alam and Dumler (2003) have shown that alfalfa yields in light (sandy loam) soil in Kansas are not significantly different for depths of 12 and 18 in. During installation it is essential to place emitters upward and dripline should be placed at a uniform depth. Orientation of driplines with respect to crop rows, parallel or perpendicular, is not a critical issue in SDI systems.

The field size and shape are dictated by the available water supply at the field. The ability to economically adjust the size of the irrigated field to the available water is a distinct advantage that SDI systems have to center pivots (Lamm et al., 2003a). SDI systems are most efficient when installed downslope on slopes less than 2%. On steeper slopes, driplines should be installed along the contour and pressure regulators should be used (Lamm et al., 2003a).

Dripline Hydraulic Characteristics

Velocity, pipe diameter, roughness, and pipe length cause friction when water flows through pipes, which creates pressure loss and a variable flow rate. Similar to pipelines used in sprinkler systems, flow rates in SDI systems should not vary more than 10% to 20% along the length of the dripline. Excessive flow variation leads to non-uniform water application through drip emitters. Flow rate variation greater than 20% can lead to distribution uniformity as low as 50% (ASAE, 2002). The degree of uniformity in an SDI system is dependent on the field characteristics including slope, length of run, dripline capacity, and diameter (Lamm et al., 2003a). In some instances, larger diameter dripline can be used to overcome uniformity issues, but it is generally more expensive and has issues with applying timely irrigations. Reducing the length is another option when flow rate varies greatly, but this is usually expensive because it involves installing more header and flush lines. When slope variation is significant enough to cause a large variation in pressure, pressure emitters are recommended.

Filtration

The filtration system is one of the most important components of an efficient SDI system. Clogging of emitters is the biggest reason for SDI failure. Consult Lamm et al. (2003), Alam et al. (2003), and Alam et al. (2002) for proper operation and maintenance of SDI systems. Failure occurs when emitters become clogged with physical, biological, or chemical constituents. Prior to SDI installation, chemical and biological analyses of irrigation water should be performed to aid in filter selection, emitter opening size, and pressure and flow measurement devices. Periodic flushing is also required for the successful operation of SDI systems.

Groundwater pumping through wells may introduce small particles that can clog emitters. Screen filters can remove physical clogging hazards. A 200-mesh screen filter will remove fine sand and larger particles and is usually adequate for SDI systems in the Great Plains (Alam et al., 2002). Sand filters should be periodically cleaned or backflushed (Alam et al., 2002; Alam et al., 2003).

Biological clogging hazards are primarily fine organic materials. Sand media filters or disk filters are recommended for removing organic materials, but require occasional backflushing for proper operation. For discussion on backflushing these filters, see Alam et al. (2002) and Alam et al. (2003).

Two chemical constituents of concern in the Great Plains are calcium carbonate (lime) and iron ochre (slime). These constituents precipitate or become solid and can clog emitters when water is evaporated and salts are left behind, or when the solubility of the chemical in water changes due to temperature or pH. Evaporation and high temperatures are usually not issues in subsurface systems as driplines are below the soil surface. Occasional injection of acid, acid-forming chemicals or chlorine may help to stop precipitation and scum formation. N-phuric, a commercial mixture of acid and N-fertilizer, can be used to lower the pH as well as provide nitrogen fertilizer for the crop. Wells that tend to have problems with iron bacteria slime should be chlorinated regularly.

In addition to a well functioning filtration system, driplines should be completely flushed at least once a season to remove sediment that has collected in driplines. Flushing more than once a season may be beneficial if sediments or other contaminants are of concern. This practice will provide greater uniformity and will increase the longevity of the system. For a more detailed discussion on this practice see Lamm et al. (2003a). It is also essential to winterize the system at the end of the season by thoroughly draining all pipes and appurtenances.

Operation and Management

Because improper management of SDI systems can result in complete system failure and a loss in investment, day-to-day operation and management are particularly important. The producer must evaluate system performance, crop water needs, and adjust system operation on a daily basis (Lamm et al., 2003a). For this reason, pressure and flow rate gages are essential in SDI systems. Comparison between two pressure and flow rate gages can indicate problems such as water leaks or filtration clogging.

Clogging by root intrusion is another problem encountered with SDI. This problem can be managed by injecting small amounts of herbicides or acids, which suppress the roots around the drip lines. Flow rate gages are also essential to successful irrigation scheduling. One of the reasons SDI systems are so efficient is the below ground placement eliminates evaporation and runoff. Small, frequent water application also reduces deep percolation losses. Because indicators of over-irrigation, such as runoff, are not as visible in these systems as other irrigation systems, it is more important to properly schedule irrigation and to monitor soil moisture in SDI systems (Lamm et al., 2003).

SDI Advantages

- High irrigation efficiency if operated properly.
- Deep percolation losses can be eliminated.
- Underground placement is not in the way of cultivation and field operations.
- Can potentially increase crop yield.
- Amenable to various crop and soil types.

SDI Disadvantages

- High initial installation cost.
- Susceptible to damage from machinery and rodents.
- Difficult to repair because placement is underground
- Requires more monitoring since system is not visible above ground (clogging is typically detected after crops show stress).

The low volume and high frequency of water required by SDI systems requires a dependable source of irrigation water. Since the SDI is operating to meet virtually instantaneous crop requirements, there is not much cushion for an interruption in water supply. However, studies have shown that irrigation frequencies can be quite high without significantly affecting crop yield. A study by Caldwell et al. (1994) shows that for corn irrigated under SDI, there is no significant difference in yield for irrigation frequencies of 1, 3, 5, and 7 days. In addition, longer irrigation frequencies tend to have higher irrigation water use efficiencies because rainfall is used more effectively.

Cost

A recent economic analysis performed by Kansas State University has shown that the return on investment for SDI for corn is dependent on the system life (O'Brien et al., 1997). SDI with a 15-year life expectancy is comparable to a center pivot irrigation system on a quarter section (160 acres). Life expectancies of SDI systems are highly dependent on proper design, management, operation, and maintenance. See also Lamm et al. (2003b) for a more detailed economic comparison of SDI and center pivot irrigation systems.

Water Savings Potential

Significant potential for water savings exists when SDI systems are used in place of surface or sprinkler irrigation methods. By converting to SDI, water savings can be expected in the form of reduced evaporation, runoff, and deep percolation, or otherwise an increase in irrigation efficiency. Although some proponents claim that SDI reduces evaporation, it is not recommended to plan for reduced evapotranspiration for design and irrigation management purposes. The gross irrigation requirement for SDI will be quite lower than surface and many sprinkler systems because of the high efficiency of SDI. See Information Sheet No. 2 to determine the water savings that can be expected by converting to SDI systems.

In addition to high irrigation system efficiencies, SDI systems have also been shown to increase yields when compared to LEPA and spray irrigation methods under limited water conditions. Colaizzi et al. (2003) conducted a three-year study in Bushland, Texas to compare SDI, LEPA, and spray irrigation under various irrigation conditions and the effect on grain sorghum yields. The results show that at 25% and 50% of full irrigation, grain sorghum yields, water use efficiency, and irrigation water use efficiency, were higher for SDI systems than LEPA and spray irrigation methods. At 75% and full irrigation, grain yield, water use efficiency, and irrigation water use efficiency for spray irrigation were greater than LEPA and SDI. In general, SDI and LEPA systems appear to partition more water to transpiration and less to soil evaporation, which enhances grain yield with limited amounts of water. But when system capacity is adequate to meet ET demands, yield increases are unlikely with conversion to SDI.

References

- Alam, M., I. Broner. 2001. Subsurface Microirrigation. Colorado State University Cooperative Extension Crop Series, Irrigation, No. 4.716. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04716.html .
- Alam, M., T.P. Trooien, F.R. Lamm, D.H. Rogers. 2002. Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/mf2361.pdf> .
- Alam, M., T.J. Dumler. 2002. Using Subsurface Drip Irrigation for Alfalfa. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 102-109.
- Alam, M., T.P. Trooien, F.R. Lamm, D.H. Rogers. 2002. Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 110-121.
- American Society for Agricultural Engineers (ASAE). 2002. Design and Installation of Microirrigation Systems. ASAE EP405.1, Dec. 01, pp. 903-907.

- Colaizzi, P.D., A.D. Schneider, T.A. Howell, S.R. Evett. 2003. Comparison of SDI, LEPA, and Spray Efficiency for Grain Sorghum. ASAE Annual International Meeting. July 27-30, 2003, Las Vegas, Nevada. American Society of Agricultural Engineers.
- Lamm, F.R., D.H. Rogers, W.E. Spurgeon. 2003a. Design and Management Considerations for Subsurface Drip Irrigation Systems. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.189-198.
- Lamm, F.R., D.M. O'Brien, D.H. Rogers, T.J. Dumler. 2003b. Center Pivot Sprinkler and SDI Economic Comparisons. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.199-211.
- Lamm, F.R., D.H. Rogers, W.E. Spurgeon. 2002. Design and Management Considerations for Subsurface Drip Irrigation Systems. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 93-101.
- O'Brien, D., D.H. Rogers, F. Lamm, G. Clark. 1997. Economic Comparisons of SDI and Center Pivots for Various Field Sizes. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/MF2471.pdf> .

On-Farm Water Measurement and Control

On-farm water measurement and control are needed to achieve the most efficient use of water.

Implementation of best management practices for irrigated agriculture is facilitated by proper on-farm water measurement and control. Water measurement can provide the basis for evaluations to optimize irrigation efficiency (Rogers et al., 2002). Proper water measurement is used to:

- Accurately measure water to determine efficiency
- Apply proper amounts of water to minimize energy cost and water use
- Facilitate on-farm management
- Monitor system performance
- Detect well or delivery system problems
- Monitor pumping plant performance

Better on-farm management through irrigation scheduling requires knowledge of the amount of water applied to a field. Through irrigation scheduling, soil moisture monitoring, and on-farm water measurement and control, a producer can expect significant water savings. Measurement and control of water can be achieved through many different methods and differs according to the type of irrigation method used. Flow control devices and pressure regulators can be used in sprinkler systems to better control non-uniform water flow through sprinklers. This information sheet discusses several methods for water measurement including:

- Open channel flow devices
- Closed pipe measurement devices

Open Channel Measurement Devices

Numerous methods are available to measure and control open channel flow in surface irrigation systems. Some of the more common methods are orifices, weirs, and flumes. An orifice is an opening with a closed perimeter through which water flows. The velocity of water through an orifice is a function of head and can be calculated using standard orifice equations and coefficients that have been determined experimentally (NRCS, 1997).

Weirs consist of a barrier placed in a stream to constrict the flow and cause it to fall over a crest (Schwab et al., 1993). Weir openings can be rectangular, trapezoidal, or triangular and include sharp crested, V-notch, Cipolletti, and trapezoidal weirs. Standard weir equations and experimentally determined coefficients are used to calculate water flow through these control structures (NRCS, 1997).



Figure 1. Flow meter for closed pipe.

Flumes are geometrically specified horizontal channel sections that constrict flow. Some of the more common flume types are Parshall, Cutthroat, and broad-crested weirs. Water flow through flumes is determined from empirically derived formulas that are specific to the geometric features of the flume (NRCS, 1997; Walker, 1989).

The use of long-throated flumes is increasing because these have several advantages over other, more standard flume measuring devices. Long-throated flumes are often preferred because they can fit in simple and complex channel shapes, are more accurate, cost less, have better technical performance, and can be computer designed and calibrated. A comprehensive discussion of these water measurement devices and methods can be found in the Bureau of Reclamation Water Measurement Manual, see USBR (1997).

Closed Pipe Measurement Devices

Several methods are available to measure flow in closed pipes. Methods include those that measure the difference in head distribution in a pipe (orifice, venturi, and convergence meters), those that measure the difference in velocity head (pitot tubes), electromagnetic and ultrasonic flow devices and propeller meters that measure actual flow velocity. For more discussion on these methods see NRCS (1997), Rogers and Black (1993) and Schwab et al. (1993).

Propeller Meters

The most common closed pipe measurement method used in Colorado is the propeller meter (Evans, 1998). Propeller meters are in-line devices that relate the average velocity (revolutions per second) and pipe cross sectional area to achieve a flow rate and volume of water (Rogers and Black, 1993) (Figure 2). Propeller meters can provide accurate measurements of flow rate and volume if properly selected, installed, and maintained. These measurement devices can attain an accuracy of +/-2%.

Each meter is strictly calibrated for the specific diameter of the pipe and projected flow rate. Flow through the pipe should be uniform, should be within flow rate guidelines, should not be excessively turbulent or spiraling, and should be flowing completely full (Table 1).

Table 1. Common flow rate ranges for propeller

Meter size	Minimum flow (gpm)	Maximum flow (gpm)
4 in	50	400
6 in	90	900
8 in	100	1200
10 in	125	1500
12 in	150	2000

from the meter (Figure 3). See Eisenhauer (1984), Rogers and Black (1992), Rogers et al. (2002), and Evans (1998) for in-depth discussion on these aspects of using a propeller meter for irrigation water measurement.

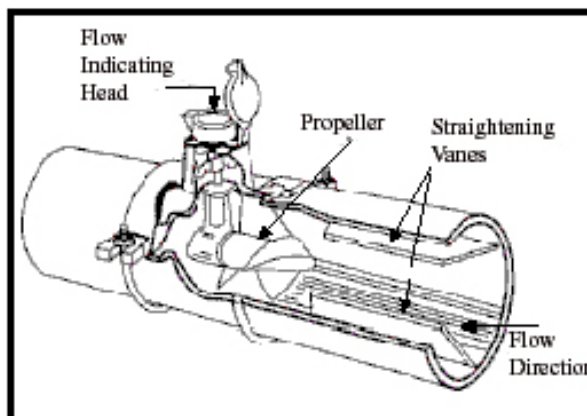


Figure 2. Irrigation propeller meter

Source: Rogers et al. (2002)

Selecting the appropriate propeller meter, installing the meter, maintaining the meter, and understanding the meter reading is crucial to the success of using propeller meters for efficient water measurement. Proper installation of flow meters is one of the most important criteria for accurate flow measurement. Although propeller meters can be installed in any position, it is very important that the pipe is flowing full at the meter section. A valve downstream of the propeller or blocking the pipeline up higher than the meter section may be required to guarantee full pipe flow (Eisenhauer, 1984). Another method is to install a “U-shaped” fitting downstream

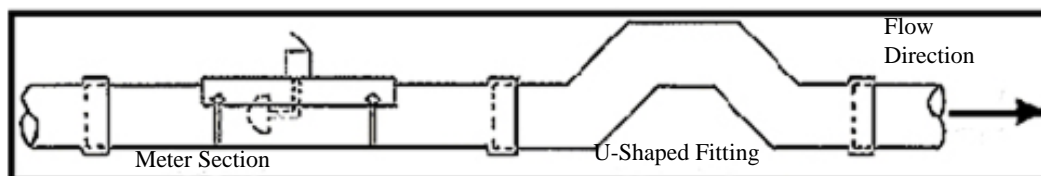


Figure 3. U-shaped fitting installed to guarantee full pipe flow in the meter section

Source: Eisenhauer (1984)

List of equivalent units for water measurement

Volume units

1 gallon	=	8.33 pounds
1 cubic foot	=	7.48 gallons
1 acre-inch	=	3.630 cubic feet
1 acre-foot	=	43,560 cubic feet
1 acre-inch	=	27,154 gallons
1 acre-foot	=	325,851 gallons

Rate-of-flow units

1 cubic foot per second	=	449 gallons per minute (use 450 gpm for most cases)
1 cubic foot per second for 1 hour	=	1 acre-inch
452 gallons per minute for 1 hour	=	1 acre-inch
1 gallon per minute	=	0.00223 cubic feet per second
1 gallon per minute	=	0.00221 acre-inches per hour

References

Eisenhauer, D.E. 1984. Selecting and Using Irrigation Propeller Meters. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g392.htm

Evans, R.G. 1998. Propeller Meters for Irrigation. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.710. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04710.html .

Measurement Advantages

- Easier to achieve accurate irrigation scheduling.
- Has the potential to reduce applied water.
- Has the potential to save energy.
- Allows for more efficient water application.
- Can be used to monitor system performance and problems.

Measurement Disadvantages

- Requires a higher level of management.
- High cost of measurement devices.
- Regular maintenance is required.

Natural Resources Conservation Service (NRCS). 1997. National Engineering Handbook 210-VI: Irrigation Guide. Part 652. United States Department of Agriculture.

Rogers, D.H., R.D. Black. 1993. Irrigation Water Measurement. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1877.pdf> .

Rogers, D.H., R.D. Black. 1992. Guidelines for Use of Propeller-type Irrigation Water Meters. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/AGENG2/1869.PDF> .

Rogers, D.H., G. Clark, M. Alam. 2002. Irrigation Water Measurement as a Management Tool. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1878.pdf> .

Schwab, G.O., D.D. Fangmeier, W.J. Elliot, R.K. Frevert. 1993. Soil and Water Conservation Engineering Fourth Edition. John Wiley & Sons, inc. New York.

United State Bureau of Reclamation (USBR). 1997. Water Measurement Manual. A Water Resource Technical Publication. Third Edition. www.usbr.gov/pmts/hydraulics_lab/pubs/wmm.index.htm .

Walker, W.R. 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drainage Paper No. 45. Food and Agriculture Organization of the United Nations. Rome, Italy. <http://www.fao.org/docrep/t0231e/t0231e00.htm#Contents>.

INFORMATION SHEET No. 8

Tillage and Crop Residue Management in Sprinkler Irrigation Systems

Management practices that better capture, store, and utilize available water in an irrigation system can result in the reduction of irrigation water requirements.

Conservation tillage practices and crop residue management have traditionally been used in dryland agriculture to utilize precipitation during the growing season and maintain stored soil water in the non-growing season. Such practices should also be used to conserve water resources in irrigated agriculture. Because these practices serve a largely positive role in sprinkler irrigation systems, selecting a tillage system that is best suited for a particular field is an important decision when attempting to capture the amount of irrigation water applied, at the point of application.

In the past, conventional tillage practices were used to till the soil and bury weeds, thereby eliminating surface residue (Vigil et al., 1995). More recently, there has been a significant shift to conservation tillage primarily because of the benefits associated with this management practice. As tillage practices become less intense (conventional to no tillage) farmers experience less soil erosion, less soil compaction, increases in infiltration, less runoff, lower fuel and labor costs, and lower soil moisture loss. This information sheet emphasizes:

- Water conservation benefits associated with reduced tillage practices
- The benefits of proper crop residue management
- The more common tillage practices used in the High Plains of Colorado

Water Conservation Benefits of Reduced Tillage Practices

Tillage practices affect the way that water moves into the soil (infiltration) and off of the soil surface (runoff) (Cahoon et al., 1993). For purposes of water conservation, tillage practices are used to: (1) alter the soil surface to provide additional water storage, (2) modify the soil structure to increase water infiltration, and (3) allow surface and subsurface soil pores to remain connected, thus improving water transmission through the soil (Kranz et al., 1991).

Reduced tillage operations increase the roughness of the soil surface, allowing for greater surface storage and a subsequent increase in the time available for water to infiltrate. To minimize the differences between water application and infiltration rates for runoff control, one option aside from changing the water application rate is to reduce the degree of tillage.

Under reduced tillage practices, crop residue remains close to the soil surface, which increases infiltration rates during the growing and non-growing season as well as reduces evaporation from the soil surface (Broner et al., 1992). In addition, surface residue reduces the impact of water droplets on the soil surface structure and allows the soil surface to remain intact.

Reduced tillage practices also decrease the amount of water that is lost through evaporation immediately following a tillage event. Good and Smika (1978) report on the effects of tillage on residue reduction and soil water loss 4 days after a tillage event. A one-way disk tillage method, which reduces crop residue by 50% results in evaporation of 0.51 in after 4 days. A less intense tillage practice, sweep plow, reduces crop residue by only 10% and has evaporation of 0.14 in after four days.

Crop Residue Management

Crop residue management is a function of the tillage practice used and can increase the availability of water in the soil profile during the growing and non-growing season. When crop residue is left on the soil surface, water is conserved during the non-growing season in the form of snow catch and during the growing season in the form of reduced soil evaporation and retention of precipitation and irrigation water (Schneekloth, 2003). Crop residue tends to increase soil infiltration rates, which is desirable when using sprinklers to irrigate (Yonts et al., 1991). Water savings associated with crop residue management results

from three processes: non-growing season snow catchment, soil surface evaporation, and precipitation and irrigation water absorption and retention.

Non-Growing Season Snow Catchment

Northeast Colorado and other parts of the central Great Plains are in a unique position to take advantage of the snow catchment capabilities of crop residue to augment the available water content of the soil (Greb, 1980).

Nielsen (1998) found that standing sunflower residue accounted for significant snow catchment during the non-growing season near Akron, Colorado. In this study, standing residue accounted for an increase in soil moisture of 5.0 in as compared to flat sunflower residue (for 80/1600 sq in silhouette factor). Silhouette factor equals stalk height x diameter x population. In Nielsen (1998) stalks were left standing at 18 and 28 inches. Although the degree to which standing crop residue can catch and effectively use snow is highly dependent on the weather conditions present and the type, density, and height of crop residue left in the field, several studies have shown that standing residue for most crop types is more effective in harvesting snow and increasing soil moisture than is flat residue or bare ground. Bauer and Tanaka (1986) found that as wheat stubble is increased from 2 to 14 in, snow catchment accounted for an increase in soil moisture of 1.3 in over the non-growing season in North Dakota. Smika et al. (1986) in Colorado showed an increase in overwinter average soil moisture of 0.8 in for no-till wheat stubble (unspecified height) over 11 winters.

Soil Surface Evaporation

Crop residue suppresses evaporation from the soil surface during the growing and non-growing season (Klocke, 2003). Most soil evaporation occurs when the soil surface is wet, within one to three days after precipitation or irrigation (Cahoon et al., 1993). Research has demonstrated that evaporation from the soil surface is a substantial portion (30% for corn grown in bare sandy soil) of total crop consumptive use (Klocke, 2003). Residue insulates the wet soil surface from solar energy and reduces evaporation, similar to crop canopy shading.

Todd et al. (1991) conducted a study on the effect of flat wheat residue (3 tons per ac) on water savings potential in sprinkler irrigated corn. The results from this study indicate a reduction in soil evaporation losses by up to 40% throughout the season when compared to a bare soil surface (Figure 2). Only soil evaporation was measured in this study, not evapotranspiration or transpiration. The study indicates that flat wheat residue can reduce evaporation beneath an irrigated crop canopy.



Figure 1. Ripper post-harvest in a sprinkler irrigation system
Source: Irrigation Research Foundation, Yuma, CO

Water Savings Potential

- Allow 1 in of water savings (gross irrigation requirement) for changing from conventional tillage (minimum surface residue) to wheat standing residue (at least 14 in stalk height).
- Increase water savings (gross irrigation requirement) up to 3 in for larger diameter crop residue and for stalk height greater than 14 in.

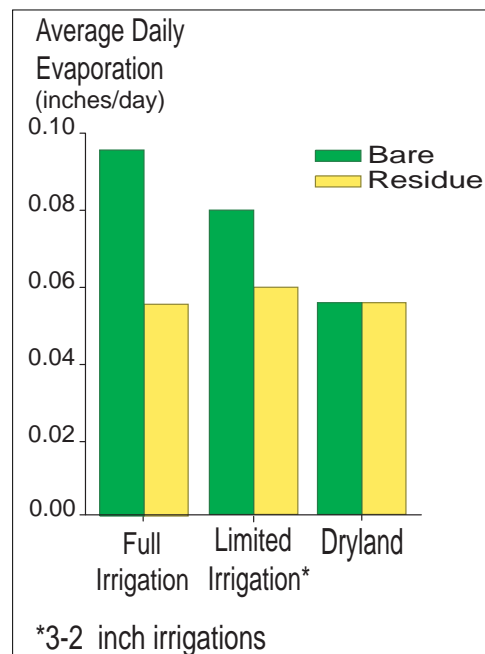


Figure 2. Average daily evaporation rates impacted by wheat straw mulch (3 tons/ac)
Source: Todd et al. (1991)

Evaporation savings have also been quantified for a dryland system with wheat stubble in west central Nebraska. This particular practice indicates a savings of 2 in of water during the non-growing season from wheat harvest in July until row crop planting the following May (Cahoon et al., 1993). Less evaporation savings is expected from corn and other crop residues since they do not cover the surface as much as wheat residue (Cahoon et al., 1993).

Acceptable quantities of residue depend on many factors including the crop harvested, the crop planted, climate, planting equipment, age of residue, and the amount of residue remaining directly over the emerging plant (Smith, 1986). Tillage practices that leave at least 30% residue coverage on the soil surface are considered conservation or reduced tillage practices. In general, a minimum of 30% residue cover is needed for erosion control and 50% cover is required to significantly reduce evaporation losses during the growing and non-growing season (Bauder et al., 2003) (See Figures 3 to 8). A general rule is to avoid residue amounts in excess of 2.5 tons per acre directly over the emerging plant (Smith, 1986).

Water Savings Potential

- Allow up to 2 in of water savings (gross irrigation requirement) for at least 50% crop residue cover as compared to bare soil during the non-growing season.
- Allow up to 2.5 in of water savings (gross irrigation requirement) for at least 50% crop residue cover as compared to bare soil during the growing season.



Figure 3. Corn Residue 25%



Figure 4. Corn Residue 50%

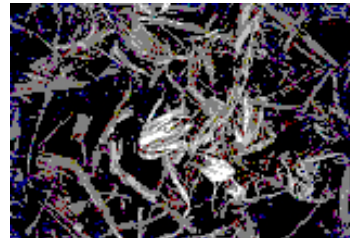


Figure 5. Corn Residue 75%



Figure 6. Sorghum Residue 25%



Figure 7. Wheat Residue 90%



Figure 8. Soybean Residue 50%

Precipitation and Irrigation Water Absorption and Retention

The soil texture, soil structure, and tillage practice can influence the rate at which water infiltrates into the soil. When water is applied to a soil surface, droplets create a hardened surface crust, reducing infiltration rates up to 75% (Cahoon et al., 1993). Kranz et al. (1991) state that although surface crust can be less than 0.1 in, it can still reduce infiltration rates by 50%. When crop residue is distributed evenly over the soil surface, the energy of falling water droplets is absorbed, decreasing crust formation, increasing infiltration rates and decreasing the potential for runoff.

Crop residues also serve as small dams for the temporary storage of excess water (Cahoon et al., 1993; Schneekloth, 2003; Kranz et al., 1991). Nielsen and Anderson (1993) show that during fallow periods in dryland agriculture near Akron Colorado, the amount of precipitation that is effectively stored in the soil profile increases after harvest, over the winter, and during the summer as practices go from stubble mulch to reduced tillage to no tillage. The amount of crop residue increases as practices go from stubble mulch to no tillage. In irrigated agriculture, similar relationships are expected during the growing and non-growing season.

Residue increases both the time available for water to infiltrate and the amount of water stored on the soil surface. In addition to increasing total infiltration, the rough surface associated with crop residue can reduce soil erosion caused by water runoff. Crop residues have the potential to decrease the amount of runoff particularly for water applications of one in or less (Kranz et al., 1991). The water savings potential associated with reduced runoff is discussed in Information Sheet No. 4.

Choice of Tillage Practice

The choice of tillage practice depends on a wide variety of factors including: soil erodibility (soil texture, slope, organic matter content), irrigation system used, equipment available, and rotation with other crops (Bauder et al., 2003). Selecting a tillage system that is best suited for a particular field condition is a very important decision. For water conservation purposes, the tillage system selected should be one that eliminates all or most runoff from irrigation and precipitation. Table 1 provides a guideline for selecting proper tillage practices according to the irrigation system or sprinkler package used. This table is meant to provide only a general guideline and does not address other factors that should be considered when selecting a tillage practice.

Common Tillage Practices

In general, tillage practices are classified into three categories: conventional tillage, conservation or reduced tillage, and no tillage.

Conventional tillage usually consists of moldboard plowing, followed by secondary tillage operations such as disking or harrowing before planting. Conventional tillage leaves little crop residue on the soil surface.

Conservation tillage represents a broad spectrum of farming methods, provided at least 30% of the soil surface remains covered with crop residue following planting (Jasa et al., 1991).

No till is similar to conservation tillage, but where the majority of crop residue is left undisturbed on the surface to maximize conservation.

Conventional (clean) Tillage

Moldboard plowing is a common conventional tillage practice for sprinkler irrigation systems. Conventional tillage typically consists of a plow or disk twice in fall or spring, followed by disk and/or mulch, plant and cultivate.

Table 1. Tillage for sprinkler irrigation systems

Sprinkler Package	Tillage System
ABOVE CANOPY	
Impact, Rotators, Spinners	Any
MESA* or Spray	Basin tillage w/ ridge till, reservoir tillage, no-till, ridge till, or conservation tillage
WITHIN CANOPY	
LPIC*	
360o Spray head Low drift head Spinner Oscillating plate	Basin tillage w/ ridge till, reservoir tillage, no-till, ridge till, or conservation tillage
LESA*	
360o Spray head Low drift head Spinner	Basin tillage w/ ridge till, reservoir tillage, no-till, ridge till, or conservation tillage
LEPA* (bubble)	Basin tillage w/ ridge till, reservoir tillage
LEPA* (drag socks)	Basin tillage w/ ridge till, reservoir tillage (basin more effective)
<small>*MESA=mid elevation spray application (5-8 ft above ground) LPIC=low pressure in canopy (1-6 ft above ground within mature crop canopy) LESA=low elevation spray application (near the ground surface 1-2 ft) LEPA=low energy precision application (near ground with bubblers or drag socks) Source: Howell (2003)</small>	

Reduced or Conservation Tillage

Any tillage practice that leaves at least 30% residue cover on the soil surface prior to planting is considered a conservation practice. There are a variety of conservation tillage methods available including basin, reservoir and furrow diking as well as chisel plow, ripping and disk and field cultivate. All reduced tillage practices have some common advantages and disadvantages.

Basin, Reservoir and Furrow Diking Tillage Practices

Various basin, reservoir, and furrow diking tillage practices exist. In general, these practices are used to increase the soil surface storage by creating small basins, reservoirs, or dikes on the surface. This is achieved by mounding loose soil on the surface to create small dams between rows or by creating small depressions below the soil surface (Figure 9). This tillage practice is especially important when farmers select in-canopy sprinkler systems to increase water savings and reduce energy costs.

Lower pressure sprinkler methods such as LEPA, LPIC, and LESA have a high potential for runoff because the practice is to apply water at a greater rate than water can infiltrate into the soil. In LEPA systems, the reservoirs and dikes created under basin tillage pond water for infiltration, rather than allowing water to runoff. Without proper tillage under LEPA, the potential for runoff can easily decrease the high application efficiencies associated with this system (Buchleiter, 1991; Yonts, 2000). LEPA systems should be designed and managed such that the application volume per irrigation does not exceed the surface storage volume of the soil (Lyle, 1992). Lyle and Bordovsky (1981) describe the concepts of furrow diking for successful operation of LEPA systems.

Hackwell et al. (1990) compared application efficiencies for LEPA systems with and without reservoir tillage for two different levels of soil compaction on a sandy loam soil with 0.2% slope. At the low compaction level, there was little difference in application



Figure 9. Irrigated field with furrow diking, every other row
Source: www.wtamu.edu

Each sprinkler system was used to irrigate land under conventional tillage and furrow diking. In almost every sprinkler device, under two different application depths (1.0 in and 0.7 in), runoff was reduced under furrow diking (Yonts, 2000; Yonts et al., 1999).

efficiency between the two tillage systems with 97% and 99% for no reservoir tillage and reservoir tillage respectively. For the high compaction level, there was significant water savings associated with reservoir tillage with 56% and 81% application efficiencies for no reservoir tillage and reservoir tillage respectively. The decrease in efficiency is the result of an increase in runoff due to a lack of soil surface storage in the conventional tillage practice.

In a Nebraska study, runoff was measured for three different sprinkler devices: a LEPA system, spinners located at 42 in above the ground, and spinners located above the crop canopy on slopes ranging from 1% to 3%.

Conventional Tillage Advantages

- Suited for most soils
- Well-tilled seedbed

Conventional Tillage Disadvantages

- High erosion potential
- High compaction potential
- High fuel and labor costs
- High soil moisture loss
- No remaining residue cover
- Increased runoff potential

Conservation Tillage Advantages

- Less erosion potential than conventional tillage practices
- Chisel plow adapted to poorly drained soils
- Lower fuel costs than conventional tillage
- Saves soil moisture

Conservation Tillage Disadvantages

- Stalk chopping necessary for chiseling (corn)
- Potential for compaction with disking under wet conditions

Chisel Plow, Ripping, and Disk and Field Cultivate

Chisel plow, ripping, and disk and field cultivation refer to a variety of tillage implements and practices but in general leave between 40% to 70% of corn, sorghum, and wheat residue on the soil surface after a single plow or disk (Jasa et al., 1991). These practices are typically not considered conservation tillage practices for soybeans as not enough residue is left on the surface under such practices. A second disking or cultivation for corn, sorghum, and wheat does not generally leave enough residue on the surface to be considered a conservation tillage practice.

Tillage done before furrow diking, such as ripping or chiseling, can enhance the effectiveness of furrow dikes (Rogers et al., 1994). However, for some field conditions, this practice can actually increase runoff and should therefore be exercised with caution. Chisel shanks can also be used to increase infiltration rates on fields that have too steep a slope for LEPA systems. The slot of soil disturbed by the chisel shank can act as a collection point and serve as a channel for water (Rogers et al., 1994).

Ridge Tillage

Ridge tillage is best suited for poorly drained soils. The practice is to plant the crop on the top of ridges that are formed during cultivation. Typical operations include chopping stalks, planting on ridges, and cultivating to rebuild ridges. Ridge tillage is illustrated in Figure 10, while advantages and disadvantages are listed.



Figure 10. Ridge tillage

No Tillage

No-till is similar to conservation tillage where the majority of crop residue is left on the surface. This practice allows for the maximum water conservation under any tillage system. Strip tillage is a variation of no tillage where narrow strips are cleared of crop residue to increase soil

warming and drying either before or during planting operations. Advantages and disadvantages of no tillage practices are given.

Ridge Tillage Advantages

- Reduces wind and water erosion by leaving most of residue on surface
- Saves water
- Lowers fuel costs
- Minimizes soil compaction
- Maintains or improves yields

Ridge Tillage Disadvantages

- Fine textured soils may crust
- Not well suited to all rotations (alfalfa, root crops or small grains)
- Must have equal wheel spacing on all equipment, including harvesting and narrower tires

No Tillage Advantages

- Conserves moisture
- Greatly reduces erosion
- Increases organic matter
- Lowers overall fuel costs
- Requires less overall equipment

No Tillage Disadvantages

- Special equipment needed
- Greater reliance on herbicides
- Requires a larger horsepower tractor (strip tillage)

References

- Bauder, T., R. Waskom, J. Schneekloth, J. Alldredge. 2003. Best Management Practices for Colorado Corn. Colorado State University Cooperative Extension. Colorado State University, Fort Collins, Colorado.
- Broner, I., J. Cahoon, H. Manges. 1992. Furrow Irrigation Management. Proceedings of the Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.26-48.
- Buchleiter, G.W. 1991. Irrigation with LEPA. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.64-68.
- Cahoon, J., N. Klocke, W. Kranz. 1993. Crop Residue and Irrigation Water Management. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1154.htm .
- Good, L.G., D.E. Smika. 1978. Chemical Fallow for Soil and Water Conservation in the Great Plains. *Journal of Soil and Water Conservation*. Vol 5:6-11.
- Greb, B.W. 1980. Snowfall and its Potential Management in the Semiarid Central Great Plains. Agricultural Research (Western Region) Science and Education Administration, USDA, Central Great Plains Research Station, Akron, Colorado.
- Hackwell, S.G., E.W. Rochester, K.H. Yoo. 1990. Reservoir-Tillage and Controlled-Traffic Practices on Irrigated Crops in Humid Regions. Proceedings of Third National Irrigation Symposium. 47-53.
- Howell, T.A. 2003. Water Loss Comparisons of Sprinkler Packages. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.54-69.
- Jasa, P.J., D.P. Shelton, A.J. Jones, E.C. Dickey. 1991. Conservation Tillage and Planting Systems. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs.fieldcrops/g1046.htm.
- Klocke, N.L. 2003. Water savings from crop residue in irrigated corn. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp 134-142.
- Kranz, W.L., D.P. Shelton, E.C. Dickey, J.A. Smith. 1991. Water Runoff Control Practices for Sprinkler Irrigation Systems. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1043.htm .
- Lyle, W.M. 1992. LEPA, Concept and System. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.14-16.
- Lyle, W.M., J.P. Bordovsky. 1981. Low Energy Precision Application (LEPA) Irrigation System. *Trans. ASAE*, Vol. 9(5):776-781.
- Nielsen, D.C., R.L. Anderson. 1993. Managing Residue and Storing Precipitation. USDA-ARS, Akron, Colorado. www.akron.ars.usda.gov/fs_managing.html .
- Nielsen, D.C. 1998. Snow catch and soil water recharge in standing sunflower residue. *J. Prod. Agric.* 11:476-480.
- Rogers, D.H. 1996. Sprinkler Application and Effects on Corn Yield Tillage Practices. Proceedings of Central Plains Irrigation Short Course and Exposition. February 6-7, 1996, Burlington, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp.1-12.
- Rogers, D.H., F.R. Lamm, W. Spurgeon. 1994. LEPA Irrigation Management for Center Pivots. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. <http://www.oznet.ksu.edu/library/ageng2/1907.pdf> .
- Schneekloth, J.P. 2003. Management strategies for a limited water supply. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp 109-118.
- Smika, D.E., A.B. Page, R.H. Mickelson. 1986. Snow Water Management for Crop Production In the Central Great Plains. 335-344. In H. Steppuhn and W. Nicholaichuk (eds.) *Proc. Of the Symp. on Snow Management for Agric.*, Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. No. 120, University of Nebraska, Lincoln.
- Smith, J.A. 1986. Distribution of Crop Residue: A requirement for conservation tillage. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/fieldcrops/g782.htm .

- Todd, R.W., N.L. Klocke, G.W. Hergert and A.M. Parkhurst. 1991. Evaporation From Soil influenced by crop shading, crop residue, and wetting regime. *Trans. of the ASAE* 34(2):461-466.
- Vigil, M.F., D. Nielsen, R. Anderson, R. Bowman. 1995. Taking Advantage of the Benefits of No-Till with Rainfall Probability Distributions. USDA-ARS, Akron, Colorado. www.akron.ars.usda.gov/fs_taking.html .
- Yonts, C.D., W.L. Kranz, D.L. Martin. 1999. Application Uniformity of In-Canopy Sprinklers. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1337.htm .
- Yonts, C.D., J.A. Smith, J.E. Bailie. 1991. Furrow Irrigation Performance in Reduced- Tillage Systems. *Transactions of the ASAE*, Volume 34(1):91-96.
- Yonts, C.D. 2000. Performance of In-Canopy Sprinklers. *Proceedings of Central Plains Irrigation Short Course and Exposition*. February 9-10, 2000, Garden City, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.107-112.

Tillage and Crop Residue Management in Furrow Irrigation Systems

Tillage and crop residue management can be used to conserve water in most furrow irrigation systems.

Conventional tillage for furrow irrigation systems is used to clean the soil surface of all crop residues in preparation for the next crop cycle. These field operations include shredding, offset disking, chiseling, tandem disking, bedding, rod weeding, planting, and two cultivations (Amosson, 2003). These conventional methods tend to over till the soil, which promotes moisture loss from the soil surface. Reduced tillage is recommended in furrow irrigation systems because it increases water infiltration into the soil, decreases the amount of water that evaporates from the soil surface, and traps snow during winter months, leaving more water available for plant use (Pearson et al., 1998). Tillage practices that leave at least 30% residue coverage on the soil surface are considered conservation or reduced tillage practices.

Reduced tillage in furrow irrigation systems has not been widely accepted by farmers because there are general concerns associated with tilling, planting, irrigating, and harvesting furrow irrigated fields with crop residue (Pearson et al., 2002). Of concern is the uncertainty of being able to irrigate in a timely and uniform manner when crop residue tends to slow water movement down the furrow (Eisenhauer et al., 1984). Although these issues should be considered, tillage and crop residue management can be used to conserve water in most furrow systems (Sojka and Carter, 1994). This information sheet will examine crop residue and tillage management practices needed to conserve water in furrow irrigation systems. In particular this information sheet will examine:

- The benefits of reduced tillage
- Reduced tillage effects on infiltration rates
- The importance of understanding the soil conditions
- Proper reduced tillage practices for water conservation



Figure 1. Furrow irrigation conventional tillage



Figure 2. Furrow irrigation conservation tillage

Benefits of Reduced Tillage

Benefits of reduced tillage in furrow irrigation systems include: reduced runoff, increased soil moisture, trapped snow during winter months, and reduced evaporation during the growing and non-growing season. A majority of water savings associated with reduced tillage practices are due to reduced evaporation from the soil surface and increases in infiltration. Crop residues not only partially cover the surface, preventing some evaporation, they also increase the infiltration of irrigation water, natural precipitation, and snowfall.

In a study in western Colorado (Pearson et al., 2002), the soil water content at an experiment site averaged 17% higher for corn, 17% higher for soybean, and 27% higher for dry bean over the irrigation season for conservation tillage than for conventional tillage (Pearson et al., 2002). The increase in soil moisture associated with reduced tillage practices indicates that it may be possible to irrigate less often under conservation tillage practices.

A computer simulation was used to compare water use (gross irrigation minus return flow) differences between a furrow system under ridge tillage and conventional tillage in the Central Platte Valley of Nebraska (Boldt et al., 1996). The results of this computer simulation showed that ridge tillage practices used 25% less water than conventional tillage. The water savings under ridge tillage was attributed to a combination of less rainfall runoff and less soil water evaporation, which resulted in one less irrigation event during the simulated irrigation season.

Reduced Tillage Effects on Infiltration Rates

As tillage practices become less intense (from conventional tillage to no tillage), infiltration rates increase. By some estimates, infiltration rates can increase by 24% to 50% in the shift from conventional tillage to conservation tillage (Pearson et al., 2002). Numerous studies have shown that reduced tillage practices increase infiltration rates (Eisenhauer et al., 1984; Cahoon et al., 1993; Eisenhauer et al., 1982).

Longer advance times or the time it takes water to move down the furrow are associated with increasing infiltration rates (Eisenhauer et al., 1982; Eisenhauer et al., 1984; Cahoon et al., 1993). Pearson et al. (2002) state that for a study in western Colorado, advance times can be 25% to 37% longer with conservation tillage than with conventional tillage. The primary reason for increases in infiltration and advance times is the increase in furrow roughness. Crop residues in a furrow: increase surface roughness, increase the wetted perimeter of the furrow, decrease the rate of flow, and therefore, increase infiltration and slow advance time (Pearson et al., 1998). Longer advance times will usually lower irrigation application efficiency, requiring more water per irrigation event to cover the entire field. Stream size should be increased and the opportunity time should be reduced to offset the higher infiltration rates.

Understanding the Soil Conditions

Management practices and the success of reduced tillage practices in furrow irrigation systems will depend on the soil conditions in the field. The degree to which increases in infiltration help to conserve water is highly dependent on the soil conditions at the time of irrigation. Before selecting a crop residue and tillage system, there should be a concerted effort to understand field soil conditions.

Conservation tillage practices should be exercised with caution in soils with high intake rates, as they may not benefit from additional increases in infiltration. In such soils it may be necessary to firm and enlarge the furrow surface to achieve acceptable advance times under increased infiltration. Although crop residue may decrease runoff in these situations, this savings may be negated by over irrigation at the top of the field (Pearson et al., 1998).

Soils with medium to low intake rates usually benefit from higher infiltration rates in the form of less frequent irrigations. Such soil conditions may also require changes in management such as an increase in furrow stream size and decrease in advance time to ensure greatest water conservation.

Proper Reduced Tillage Practices for Water Conservation

Because reduced or conservation tillage in furrow systems leaves some residue in the bottom of the furrow, it is important to properly manage crop residue, select appropriate stream sizes and set times, length of run, manage surface conditions in the furrow bottom, and adjust furrow size if necessary. These management practices are crucial to the success of conventional tillage in furrow irrigation systems. It may also be advantageous to decrease the furrow length if possible for a particular field formation. Because increases in crop residue tend to increase infiltration rates and can in some cases decrease the efficiency of an irrigation system, the following management practices must be followed to save water.

Amount of Crop Residue

Too much crop residue in the furrow can negate the benefits of conservation tillage by slowing advance time and increasing total infiltration to the point of excessive deep percolation losses. Yonts et al. (1991) found that when crop residue covers 48% or more of the soil surface prior to the first irrigation, inadequate furrow irrigation results unless furrow length is reduced. When crop residue is in excess, a common practice is to move excessive crop residue to alternate rows or between rows using roller cultivator tools (Pearson et al., 2002). A common practice for corn is to move residue to alternate furrows during seedbed preparation and apply the first irrigation after planting to the furrows with less crop residue. Once plants are big enough, residue can be mulched around plants and irrigation for the remainder of the season can occur in all furrows (Pearson et al., 2002). Crop residue cover greater than 30% but not greater than approximately 50% has been shown to increase advance times but be acceptable in well designed furrow systems (Yonts et al., 1991).

Stream Size and Set Time

Selecting proper stream sizes and set times are important to the success of conservation tillage in furrow systems. Stream size and set time depend on a variety of factors including crop type, field slope, length of run, soil type, soil conditions, and crop residue characteristics. The objective of selecting proper stream size and set time is to achieve uniform distribution and minimize deep percolation and runoff. As crop residue tends to increase infiltration and slow advance times, it may be necessary to increase stream size and decrease set time to decrease losses from excessive infiltration (Cahoon et al., 1993).

Under reduced tillage, increasing the furrow stream size too much may create an erosive energy that causes water to transport crop residue, erode soil, and overtop furrows in some extreme cases (Pearson et al., 1998; Pearson et al., 2002). Maintaining the size of the residue as large as possible and using an appropriate stream size will reduce the likelihood of residue movement. Farmers must find a balance between advance time and infiltration that is suitable to the soil and field conditions under reduced tillage, just as many have done under conventional tillage systems. If infiltration rates are too severe to overcome with management factors alone, it may be necessary to make physical changes to the system including field slope, length of run, furrow packing, or surge irrigation flow (Cahoon et al., 1993).

Furrow Residue and Tillage Advantages

- Increases infiltration and reduces runoff.
- Decreases evaporation during the growing and non-growing season.
- Traps snow.
- Has the potential to conserve water.

Furrow Residue and Tillage Disadvantages

- General concerns with tilling, planting, irrigating, and harvesting with crop residues in furrows.
- Concerns regarding the timely and uniform irrigation because crop residues tend to slow advance times.
- Not recommended for high intake soils without furrow firming and furrow enlarging.
- Requires a change in furrow irrigation operation and management (set time and stream size).
- May require a decrease in the length of furrow run.

Furrow Characteristics

Some soils may have infiltration rates that are too high under conservation tillage. Managing the surface conditions in the bottom of the furrow is one way of controlling excessive infiltration rates associated with furrow roughness (Pearson et al., 1998). A common tillage practice in furrow systems with high infiltration rates is furrow firming (Yonts and Eisenhauer, 1999). Furrow firming is a process of using an implement to firm the top 3 to 4 in of soil in the furrow without compacting to a depth that might hinder root development.

Yonts and Eisenhauer (1999) used 13 test locations in Nebraska to compare advance times for furrow irrigation in conventional tillage and in firmed furrows. Advance times were reduced by 18% and 27% when conventional tillage was compared to firmed furrows for continuous and surge irrigation practices respectively. Furrow firming results in faster advance time to the end of

the field, improved water distribution uniformity, and decreased potential for deep percolation at the top of the field. Furrow firming practices should be used in conjunction with proper set times and stream sizes so as to minimize runoff (Broner et al., 1992).

Under conservation tillage in furrow systems it may be necessary to increase the wetted perimeter of the furrows to promote the partitioning of infiltration more to lateral water movement and less to vertical movement (Pearson et al., 1998; Pearson et al., 2002). In the furrow, crop residue tends to increase soil lateral wetting while at the same time increasing infiltration to the point of excessive soil vertical wetting (deep percolation). In order to maximize the benefits associated with the lateral movement of water in the vicinity of crop residue, it may be necessary to increase the size of the furrow so that crop residue can promote lateral movement as opposed to vertical movement.

References

- Amosson, S. 2003. ROI Are you getting the most from your irrigation water? Irrigation Business And Technology. Irrigation Association, April 2003.
- Boldt, A.L., D.E. Eisenhauer, D.L. Martin, G.J. Wilmes. 1996. Irrigation Water Conservation Practices for the Central Platte Valley, Nebraska. Proceedings from 1996 Platte River Basin Ecosystem Symposium. www.ianr.unl.edu/ianr/pwp/products/96papers/irrigate.htm .
- Broner, I., J. Cahoon, H. Manges. 1992. Furrow Irrigation Management. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.26-48.
- Cahoon, J., N. Klocke, W. Kranz. 1993. Crop Residue and Irrigation Water Management. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1154.htm .
- Eisenhauer, D.E., K. Frank, E. Dickey, P. Fischbach, W. Wilhelm. 1984. Tillage Practice effects on water conservation and the efficiency and management of surface irrigation systems. UNL, Project Completion Report. B-057-NEB.
- Eisenhauer, D.E., E.C. Dickey, P.E. Fischbach, K.D. Frank. 1982. Influence of Reduced Tillage on Furrow Irrigation Infiltration. ASAE Paper No. 82-2587. ASAE, St. Joseph, MI.
- Pearson, C.H., C.A. Holcomb, A.W. Cooley, J.E. Murray. 2002. Guidelines for Using Conservation Tillage Under Furrow Irrigation. Colorado State University: Agricultural Experiment Station Cooperative Extension. Technical Report TR02-6.
- Pearson, C.H., K.E. White, A.L. Brinkworth. 1998. Surface Residue and Soil Clods During Furrow Irrigation Under Simulated Conditions. *Journal of Sustainable Agriculture*, Volume 12(1):5-21.
- Sojka, R.A. and D.L. Carter. 1994. Constraints on conservation tillage under dryland and Irrigated agriculture in the United States Pacific Northwest. In: Carter, M.R. (ed.), *Conservation Tillage in Temperate Agroecosystems*. Lewis Publishers. Ann Arbor, MI. 285-304.
- Yonts, C.D., J.A. Smith, J.E. Bailie. 1991. Furrow Irrigation Performance in Reduced-Tillage Systems. *Transactions of the ASAE*, Volume 34(1):91-96.
- Yonts, C.D., D.E. Eisenhauer. 1999. Firming Irrigation Furrow to Improve Irrigation Performance. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g1340.htm .

Irrigation Scheduling

Irrigation scheduling is a planning and decision-making tool used for determining the amount and timing of irrigation application for maximizing efficient water use and crop yield.

Important concepts of irrigation scheduling include the following (Broner, 2001):

- Irrigation scheduling is the decision of when and how much water to apply to a field.
- Its purpose is to maximize irrigation efficiencies by applying the correct amount of water needed to replenish the soil moisture to a desired level.
- Irrigation scheduling saves water and energy.
- All irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation.

Irrigation scheduling offers a variety of benefits including energy and water savings, minimized crop stress, maximized crop yield, reduced cost and labor through fewer irrigations, lower fertilizer costs through decreased runoff and deep percolation, and increased net returns through increases in crop yields. Irrigation scheduling also limits underirrigation, which stresses crops, and causes yield reduction.

This information sheet emphasizes the water savings associated with irrigation scheduling and briefly describes some of the more common methods used to properly schedule irrigation.

Associated Water Savings

Irrigation scheduling can reduce irrigation water use by: (1) reducing runoff from either irrigation or rainfall, (2) by decreasing percolation of water beneath the root zone in excess of any required leaching for salinity management, (3) by reducing soil water evaporation after an irrigation, and (4) by controlling soil water depletion in a manner that reduces ET during known non-sensitive crop growth stages (Howell, 1996).

Better management of the soil water profile through irrigation scheduling can be used to determine the exact quantity and timing of irrigation application throughout the season. Proper timing and amount saves water by: (1) avoiding overirrigation during a single irrigation event, (2) determining the first and last irrigation dates, and (3) determining the proper number of irrigation events throughout the season.

It is well known that irrigation scheduling can increase water savings while maintaining or increasing crop yields. Many farmers and irrigation systems have long made use of these practices to stretch limited water supplies. Research in Nebraska shows that irrigation scheduling provides an average of 35% savings in water and energy (Broner, 2001). An irrigation management demonstration project in the Republican River Basin has also shown significant water savings associated with irrigation scheduling in west central Nebraska. Since 1996, several sites in the basin were selected to demonstrate that best management practices (BMP) for irrigation management can be used to reduce irrigation

Table 1. Four-year average of corn yields and water use by management strategy and site

Management Strategy			
Average Yields (bu/ac)			
	Soil WHC	FARM*	BMP
	(in/ft)		
Site			
Arapahoe	2.1	188	189
Elsie	1.5	193	193
Dickens	1.1	200	201
Benkelman	1.8	191	199
All Sites		193	194
Applied Water (ac-in/ac)			
	Soil WHC	FARM*	BMP
	(in/ft)		
Site			
Arapahoe	2.1	8.1	7.4
Elsie	1.5	9.5	9.2
Dickens	1.1	13	13
Benkelman	1.8	7.9	7.2
All Sites		9.8	9.4

*FARM=irrigation water applied according to farmer's current management strategy

Source: Schneekloth, J.P. and N.A. Norton (2001)

water with little or no decrease in crop yields (Table 1). BMPs in this study include bi-weekly soil water monitoring, use of predicted crop water use (ET), and maintaining plant available soil water (in the active root zone) in the range of 50% depletion and field capacity. Table 1 compares these BMPs to water applied according to a farmer's current management strategy. The results show that less water is applied under the BMP practice with an increase in crop yields in most cases.

The water savings associated with irrigation scheduling are highly variable. The degree of complexity with which irrigation scheduling is practiced is quite large. Irrigation scheduling can be as simple as physically observing the crop and soil appearance to operating a computer model that predicts crop use from real-time data of weather conditions. A critical element to proper irrigations scheduling is accurate measurement of the volume of water applied or the depth of application. If adequate measurement and control devices are not available, the success of irrigation scheduling practices will be limited. See Information Sheet No. 7 for a discussion on water measurement and control devices for efficient irrigation.

Another crucial factor to the success of irrigation scheduling is the reliability and availability of water supply. The importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal of optimal crop yields. If water supply is not reliable or available for reasons such as limited well capacity or restrictions on pumping allocation, the success of scheduling will be minimal. These issues should be considered before adopting irrigation scheduling practices for water conservation purposes.

Methods of Irrigation Scheduling

To determine the timing and amount of water application through irrigation scheduling, the soil moisture status should be measured or estimated. Table 2 compares different methods of irrigation scheduling by monitoring or estimating the soil moisture content or tension. Recommended methods are described briefly.

Atmometers

An atmometer (ETgage®) measures the amount of water evaporated to the atmosphere from a wet, porous ceramic surface. The primary purpose of these instruments is to provide reference ET at any field location they are installed. This information is visually displayed on a site tube mounted in front of a ruler on the instrument (Figure 1). Reading the site tube is as easy as reading a rain gauge. Therefore, a grower or consultant can use an atmometer to quantitatively gauge how crop water use varies with changing weather conditions.

The modified atmometer can be used for irrigation scheduling in Colorado by providing daily estimates of alfalfa reference ET. Reference ET is used in the water-balance method (see Table 3 for references on how to use this method) as an estimation of the potential water loss from a reference crop. ET estimation is the difficult portion of the water-balance method and usually is done by calculating ET from measured weather parameters. The modified atmometer facilitates the ET estimation by supplying a direct reading of reference ET. Consequently, no cumbersome weather measurements and calculations are required. In some areas of Colorado, daily ET values based on climatological data are published by Colorado State University (CoAgMet). However, these values represent conditions of the weather station area and not local conditions at each farm.

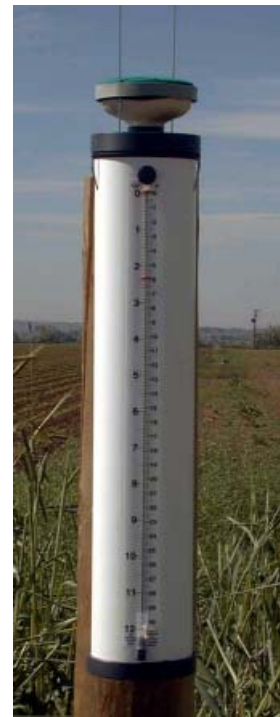


Figure 1. Atmometer

CoAgMet

Colorado Agricultural Meteorological Network (CoAgMet) is a local weather data collection management system available on the Internet at: <http://ccc.atmos.colostate.edu/~coagment/>. CoAgMet was developed by several groups at Colorado State University for purposes of providing local weather data and evapotranspiration estimates in real time. Figure 2 shows a map of CoAgMet weather stations, most of which are in eastern Colorado. CoAgMet uses a standardized set of instruments and standard data logger program to convey accurate and real time data over the Internet so that producers can download ET reports on their personal computers for a weather station near their farm. CoAgMet can be used in conjunction with a water balance approach to schedule irrigations. For more information on ET based approaches to irrigation scheduling, see references listed in Table 3.

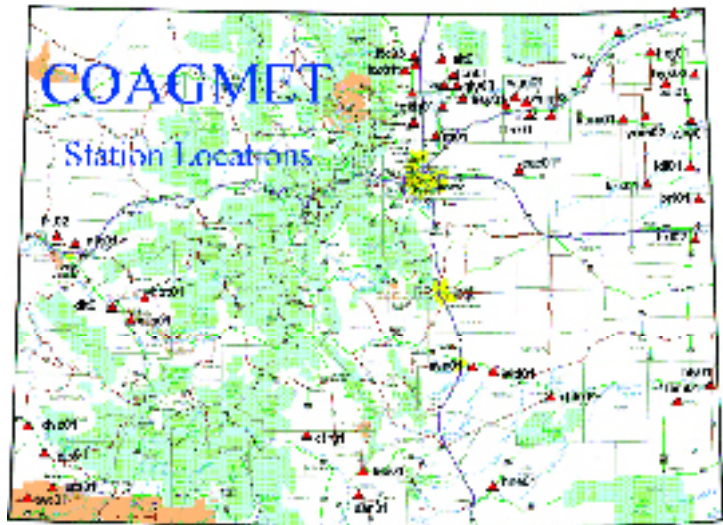


Figure 2. CoAgMet weather station network

Cropflex

Many irrigation scheduling programs that use the water balance approach have been developed during the last two decades. Recently a new approach to developing irrigation management programs, based on expert systems, was developed at Colorado State University. This approach integrates water and nitrogen management. The result is a flexible crop management computer program called *Cropflex*. This easy to use tool provides irrigation scheduling and fertility management advice to help producers maintain or increase yields while minimizing the potential of leaching nitrates into the groundwater. Studies have shown that fertilizer and water applications can be substantially reduced without reducing yield by the proper timing of irrigation and nitrogen applications. *Cropflex* is a decision support system designed to help the producer apply water and fertilizer more accurately.

Cropflex handles a variety of Colorado crops. Basic crop information has been developed for corn, alfalfa, sorghum, onions, potatoes, and barley. Entering new or additional crops to the database is simple and straightforward. All databases of the program can be accessed by the user, and crop, soil, and weather station information can be edited or new information can be entered. The program was developed for use by a producer with minimal computer experience and has self-explanatory and easy to understand pull down menus. The program can be downloaded from the Internet at: <http://ccc.atmos.colostate.edu/~crop>.

The irrigation scheduling techniques that offer the most reliable information and highest degree of management flexibility are the ET based method and soil moisture monitoring. The use of both methods simultaneously is recommended for greatest water conservation.

Table 3 lists a variety of literature sources that can be consulted for each of the methods provided in Table 2. The literature sources provide a more comprehensive explanation of how to properly use each of the methods for water conservation purposes.

Water Savings Potential

- Allow at least 20% water savings (gross irrigation requirement) during the irrigation season if at least one of the methods in Table 2 is used compared to no irrigation scheduling methods.

Table 2. Different methods of irrigation scheduling

Method	Measured parameter		Soil Moisture	Advantages	Disadvantages
Hand feel and appearance of soil	Soil moisture content by feel.	Hand probe.	Soil moisture content.	Easy to use; simple; can improve accuracy with experience.	Low accuracies; field work involved to take samples.
	Soil moisture content by taking samples.	Auger, caps, oven.	Soil moisture content.	High accuracy.	Labor intensive including field work; time gap between sampling and results.
	Soil moisture tension.		Soil moisture tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labor to read; needs maintenance; can't be used at tensions above 0.7 atm.
Electrical resistance blocks	Electric resistance of soil moisture.	Resistance blocks AC bridge (meter).	Soil moisture tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading. Gypsum blocks (silt loam-clay soils only). Granular Matrix (sand-silt loam soils only).
Water budget approach	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall, depending on model used to predict ET.	Weather station or available weather	Estimation of moisture content.	No field work required; flexible; can forecast irrigation needs in the future; with same equipment can schedule many fields.	Needs calibration and periodic adjustments, since it is only an estimate; calculations cumbersome without computer.
Modified atmometer	Reference ET.		Estimate of moisture content.	Easy to use, direct reading of reference ET.	Needs calibration; it is only an estimation.

Table 3. Literature sources for irrigation scheduling methods	
Method	Literature Sources
Hand feel and appearance of soil	Miles, 1998 Klocke and Fischbach, 1984 Black and Rogers, 1989
Gravimetric soil moisture sample	Black and Rogers, 1989
Tensiometers	Black and Rogers, 1989 Alam and Rogers, 1987
Electrical resistance blocks	Alam and Rogers, 2001 Lorenz, 1997 Black and Rogers, 1989
Water budget approach	Broner, 1993a CoAgMet, 2003 CropFlex, 2000 Yonts and Klocke, 1985 Rogers, 1995a and 1995b Broner and Law, 1992
Modified atmometer	Broner, 1993b Broner and Law, 1991
Misc. Scheduling Sources	Klocke et al., 1991 Rogers and Sothers, 1996 Duke, 1991

References

- Alam, M., D.H. Rogers. 2002. Effect of Irrigation Ending Date on Corn Yield and Irrigation Scheduling for Water Conservation. 2002 ASAE Annual International Meeting, Chicago, IL. July 28-31, 2002. American Society for Agricultural Engineers. Paper No. 022062.
- Alam, M., D.H. Rogers. 2001. Scheduling Irrigations by Electrical Resistance Blocks. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.oznet.ksu.edu/library/ageng2/1901.pdf .
- Alam, M., D.H. Rogers. 1987. Tensiometer Use in Scheduling Irrigation. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.ozanet.ksu.edu/library/ageng2/1796.pdf .
- Black, R.D., D.H. Rogers. 1989. Soil Water Measurements: an aid to irrigation water management. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.oznet.ksu.edu/library/AGENG2/1795.PDF
- Broner, I. 2001. Irrigation Scheduling. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.708. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04708.html .
- Broner, I. 1993a. Irrigation Scheduling: The Water Balance Approach. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.707. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04707.html .
- Broner, I. 1993b. Irrigation Scheduling with Atmometers. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.706. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04706.html .
- Broner, I., R.A.P. Law. 1992. Water Balance for Irrigation Using ET Input. ICID Bulletin. Vol. 41, No.2.
- Broner, I., R.A.P. Law. 1991. Evaluation of a Modified Atmometer for Estimating Reference ET. Irrigation Science, 12:12-26. Springer-Verlag.

- Broner, I., K. Thompson, M. Dillon. 1997. Validation of a Malting Barley Water and Nutrient Management Expert System. *Agricultural Water Management* (33): 159-168. Elsevier Science B.V.
- CoAgMet. 2003. CoAgMet Homepage. Colorado State University. <http://ccc.atmos.colostate.edu/~coagmet/>
- CropFlex. 2000. Crop Management Decision Support Systems: Download CropFlex2001. <http://ccc.atmos.colostate.edu/~crop/>
- Duke, H.R. (eds). 1991. Scheduling Irrigations: A guide for improved irrigation water management through proper timing and amount of water application. USDA, Soil Conservation Service, Agricultural Research Service, Cooperative Extension Colorado State University, Fort Collins, CO.
- Howell, T.A. 1996. Irrigation Scheduling Research and Its Impact on Water Use. In: C.R. Camp, E.J. Sadler, and R.E. Yoder (eds.). *Evapotranspiration and Irrigation Scheduling, Proceedings of the International Conference, Nov. 3-6, 1996, San Antonio, TX, American Society of Agricultural Engineers, St. Joseph, MI.*
- Idaho Department of Water Resources. 2000-2002. Scientific Irrigation Scheduling Program. www.udwr.state.id.us .
- Klocke, N.L., D.E. Eisenhauer, T.L. Bockstadter. 1991. Predicting the Last Irrigation for Corn, Grain, Sorghum and Soybeans. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g602.htm .
- Klocke, N.L., P.E. Fischbach. 1984. Estimating Soil Moisture by Appearance and Feel. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g690.htm .
- Lamm, F.R., D.H. Rogers, H.L. Manges. 1994. Irrigation Scheduling with Planned Soil Water Depletion. *Transactions of the ASAE, Vol. 37(5): 1491-1497.* American Society of Agricultural Engineers.
- Lorenz, J.W. 1997. Upgrades and Testing of CropFlex-A Knowledge Based Expert System In Agriculture. Colorado State University, Unpublished Master's Thesis. Colorado State University, Fort Collins, Colorado.
- Miles, D.L. 1998. Estimating Soil Moisture. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.700. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04700.html .
- Musick, J.T., and B.A. Stewart. 1992. Irrigation Technologies. In: *Groundwater Exploitation in the High Plains.* Kromm, D.E. and S.E. White (eds.). University of Kansas Press. Lawrence, Kansas.
- Pima Natural Resource Conservation District. 2002. Irrigation Conservation Assistance Program. www.pimanrcd.org .
- Rogers, D.H. 1995a. Using Evapotranspiration Reports for Center Pivot Irrigation Scheduling. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.oznet.ksu.edu/library/ageneg2/1915.pdf .
- Rogers, D.H. 1995b. Using Evapotranspiration Reports for Furrow Irrigation Scheduling. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.oznet.ksu.edu/library/ageng2/1914.pdf .
- Rogers, D.H., W.M. Sothers. 1996. Predicting the Last Irrigation for Corn, Grain, Sorghum and Soybeans. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State University, Manhattan, Kansas. www.oznet.ksu.edu/library/AGENG2/mf2174.PDF .
- Schneekloth, J.P. and N.A. Norton. 2001. Living with limited water in southwest Nebraska. *Proceedings of the 2001 Central Plains Irrigation and shortcourse and Exposition, Kearney, Nebraska. Febr. 5-6, 2001.* pg. 18-28.
- Schneider, A.D., T.A. Howell. 2001. Scheduling Deficit Wheat Irrigation with Data From an Evapotranspiration Network. *Transactions of the ASAE, Vol. 44(6): 1617-1623.* American Society of Agricultural Engineers.
- Yonts, C.D., N.L. Klocke. 1985. Irrigation Scheduling Using Crop Water Use Data. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/irrigation/g753.htm .

Limited Irrigation and Crop Rotation Options

Limited irrigation occurs when water supplies are restricted in some way to the point that full evapotranspiration demands cannot be met (Schneekloth, 2003).

Full irrigation is the amount of water minus rainfall and stored soil moisture needed to achieve maximum crop yield. However, when irrigation water is insufficient to meet crop demand, limited irrigation management strategies should be considered (Schneekloth et al., 2001). Because different crops in different locations have different water requirements, the choice of crop mixes and the decisions that producers make about using available water is crucial when irrigation water is in limited supply. Reasons that producers may be limited on the amount of available water include: (1) limited capacity of irrigation wells (in regions with limited saturated depth of the aquifer, well yields can be marginal and not sufficient to meet the needs of the crop), and (2) reduced water supplies due to droughts, seasonal water fluctuations, or restricted pumping allocation.

When irrigation water is limited, the goal is to manage crops and water use for the greatest possible return for the crop grown. Management opportunities for achieving this goal include (Schneekloth and Kaan, 2003; CSU, 2003):

- Reduce total acreage of irrigated crops
- Reduce the amount of irrigation water applied over the entire field
- Grow crops that require less water (either shorter growing season or rotation with crops that require less water)
- Switch from irrigated to dryland crop production
- Delay irrigation until critical water requirement stages of the crop
- Manage the soil water reservoir to capture precipitation

If producers cannot apply full irrigation to meet crop requirements, crop yields and returns will be reduced. To properly manage the water for the greatest return, producers should consider the following topics discussed in this information sheet:

- Crop water requirements
- How crops respond to water
- Options for allocated limited water in low capacity systems
- How cropping mixes can be adjusted to better match water availability

Crop Water Requirements

Knowing seasonal crop water requirements is crucial in limited irrigation situations. Water requirements for crops depend mainly on environmental conditions. However, different crops have different water requirements under the same environmental conditions. For example, in the Burlington area, the seasonal water use of sugar beets is 30 in while corn for silage requires only 23 in of water. That means sugar beets require 23% more water than corn to fully irrigate. These water requirements are net crop water use or the amount a crop will use (not counting water losses such as deep percolation and runoff) in an average year, given soil moisture levels don't fall below critical levels. Under ideal conditions, this net water requirement is reduced by the effective precipitation, which for Burlington is 11.3 in during the growing season of an average year.

Table 1 provides a summary of net water requirements by crop and location for the High Plains of Colorado. With such a wide range of water requirements among different crop types, one option for increasing returns under limited irrigation is to select crop types that use less water on a seasonal basis. In addition to selecting crops with lower seasonal requirements, producers can also select a crop that has a shorter growing season or can plant several crops that have different peak water requirements, spreading

irrigation over a greater time period. Table 2 provides a summary of potential field crops for limited irrigation and dryland in northeast Colorado.

Understanding critical growth stages of crops is also important under limited irrigation because too much stress during critical growth periods reduces the yield and quality of crops (Al-Kaisi and Broner, 1992). However, some water stress during vegetative growth stages helps to save

Table 1. Estimated seasonal crop water requirements for eastern Colorado (in/season)

	Burlington	Cheyenne Wells	Lamar	Springfield	Wray
Alfalfa	35.64	36.1	39.1	37.4	35.2
Grass hay/ pasture	31.1	31.7	34.2	32.6	30.9
Dry beans	19.2				18.7
Corn, grain	26	25.8	26.8	26.7	25.4
Corn, silage	22.8	22.1			
Melons			15.8		
Small vegetables			18.8		
Sorghum, grain	21.5		22.6	22.6	21
Spring grains			11.8	10.4	15.2
Sugar beets	30	30.4	34.3	32.3	30
Wheat, winter	19	18.6	19.3	18.6	

Table 2. Summary of potential field crops for limited irrigation or dryland in northeast Colorado

Crop	Seeding rate lbs/ac	Usual planting date	Seeding soil cover in	Planting to harvest days	Yield potential grain unit/ac	Yield potential forage tons/ac	Potential residue/ cover	Drought tolerance	Comments
Barley --spring	60 to 90	2/20 - 3/31	1 to 2	100-120	20-80 bu	3 to 5	med-high	Fair	grain, forage, cover, grazing
Beans -- pinto	60 to 70	5/25 - 6/25	1 to 3	90-110	15-40 bu		unacceptable	Little	limited irrigation only
Corn -- grain	8 to 18	4/15 - 5/20	1 to 3	100-140	20-200 bu		low	Poor	dryland must be no-till
Corn -- forage	8 to 18	4/15 - 5/20	1 to 3	85-110		5 to 35	unacceptable	Poor	
Millet -- proso	6 to 20	5/15 - 6/30	0.5 to .75	70-90	5-40 bu		med-high	Good	grain or cover
Millet -- foxtail	4 to 12	5/15 - 6/30	0.5 to .75	50-60		1 to 4	low- forage	Fair	forage, cover, grazing
Millet -- pearl forage	5 to 15	5/25 - 6/15	0.5	40 to 45 for forage	may not mature	1 to 3	low- forage	Good	forage, cover, grazing
Oats -- spring	50 to 90	2/20 - 3/30	1 to 2	100-120		1 to 5	med	Poor	forage, cover, grazing
Safflower	15 to 20	4/15 - 5/20	0.75 to 1.5	120-150	400 - 1,500 lbs		low	Good	grain
Sorghum									
Grain	2 to 8	5/5 - 6/10	0.75 to 1	90-130	30-80 bu		med-high	Good	grain or cover
Forage	4 to 8	5/15-6/10	0.75 to 1	90-100		5-20			
Soybeans	60	5/15 - 5/30	1 to 1.5	90-120			low	Good	
Sorghum/Sudangrass	8 to 20	5/15 - 7/1	0.75 to 1	40 to 45 for forage		3 to 10	high	Good	forage, cover, grazing; moderate prussic acid potential
Sunflower									
Oil	3 to 7	5/10 - 7/1	1 to 2	90-120	600 - 2,500 lbs		very low	Good	No-till preferred
Confectionary	3 to 6	5/10-6/20	1 to 2	90-120					
Triticale --winter	50 to 80	8/30 - 9/30	1 to 2			3 to 5	high	Fair	grain, forage, cover, grazing
Wheat -- spring	50 to 70	2/20 - 3/30	1 to 2	110-120		3 to 5	high	Fair	forage, cover, grazing
Wheat -- winter	35 to 45	9/10 - 9/25	1 to 2		15-80	3 to 5	high	Fair	grain, forage, cover, grazing

Table 3. Critical growth stages for major crops

Crop	Critical period	Symptoms of water stress	Other considerations
Alfalfa	Early spring and immediately after cuttings	Darkening color, then wilting	Adequate water is needed between cuttings
Corn	Tasseling, silk stage until grain is fully formed	Curling of leaves by mid-morning, darkening color	Needs adequate water from germination to dent stage for maximum production
Sorghum	Boot, bloom and dough stages	Curling of leaves by mid-morning, darkening color	Yields are reduced if water is short at bloom during seed development
Sugar beets	Post-thinning	Leaves wilting during heat of the day	Excessive full irrigation lowers sugar content
Beans	Bloom and fruit set	Wilting	Yields are reduced if water short at bloom or fruit set stages
Small grain	Boot and bloom stages	Dull green color, then firing of lower leaves	Last irrigation at milk stage
Potatoes	Tuber formation to harvest	Wilting during heat of the day	Water stress during critical period may cause cracking of tubers
Onions	Bulb formation	Wilting	Keep soil wet during bulb formation and dry near harvest
Cool season grass	Early spring, early fall	Dull green color, then wilting	Critical period for seed production is boot to head formation

soil water without significantly reducing yields (Bauder et al., 2003). Table 3 provides critical growth stages for some of the major crops in the High Plains. The proper timing and amount of water application throughout the irrigation season and during critical periods can increase crop yields and can make more efficient use of the water applied in limited irrigation situations.

Yield vs. ET and Irrigation

Management of limited water supplies requires understanding of how limited water will affect crop yields. Schneekloth et al. (1991) have shown that crop yields increase linearly with the water that is used by the crop (Figure 1). Crops such as corn, respond with more yield for every inch of water that the crop consumes, as compared to winter wheat or sunflower. High water use crops such as corn also require more ET for plant development or maintenance before yields are produced. Corn requires approximately 10 in of ET as compared to 4.5 and 7.5 in of ET for wheat and sunflower before any yield is produced (Schneekloth, 2003). These crops also require less ET for maximum production compared to corn.

In Colorado's semi-arid climate, irrigation supplements rainfall in periods when ET is greater than precipitation. However, not all of the water applied by irrigation is used for ET. Inefficiencies in applications by the system result in losses. As crop yield is maximized, more water losses occur since the soil is closer to field capacity and more prone to losses, such as deep percolation, which cause the deviation from the straight line (Hergert et al., 1991; Schneekloth et al., 1991; Stone, 2003).

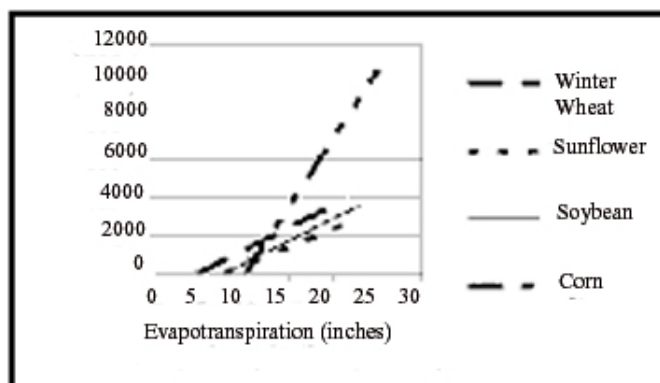


Figure 1. Yield vs. ET relationship for several irrigated crops

Water can be saved by applying less water than is needed for maximum yield. As seen in Figure 2, a reduction in water applied from point A to point B can save water with little or no yield reduction. Therefore, the area between the curved and straight-line represent the inefficiencies caused by the irrigation system and/or inappropriate irrigation timing and amount (Lamm, 1997).

Allocating Limited Water Supplies in Low Capacity Systems

When managing for maximum production, irrigation systems must have minimum capacities to meet crop water requirements during peak water use periods (Howell, 1992; Broner, 1991). If irrigation system capacities are below normal requirements, reduced yields are expected. Producers have several management options to allocate limited water supplies. Two of these options include reducing the amount of land irrigated and reducing the water allocated to the entire field.

The purpose of reducing irrigated acreage is to better match the irrigation water available with the full irrigation requirements and the corresponding crop yields on a smaller area of land. For maximum return, the land that is not irrigated under this option is reverted to dryland production or is planted in a low water use crop. 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 increase in dryland production (Schneekloth and Kaan, 2003).

Reducing the amount of irrigation per acre applied to the entire field creates the possibility for near normal crop yields if above normal precipitation occurs. In normal to below normal rainfall years, yields per acre would be less than those achieved with full irrigation (Schneekloth et al., 2001).

If the entire pivot or field is planted to a single crop, the producer should maintain soil moisture at or near field capacity when ET is less than the system can apply. When the ET for the crop is greater than the capacity of the system, plants will use stored soil moisture to maintain ET. This type of management is necessary to insure that moisture will be available for plants when they reach the reproductive growth stage, which is also the peak water demand. Pre-irrigation and beginning irrigation at higher soil moisture contents are also strategies that may maintain yields in above normal precipitation years but do not help as much in below normal precipitation years.

Crop Options

Some crops can be effectively grown under limited irrigation in northeast Colorado, some can be grown dryland, and some are not economically feasible without a full supply of irrigation water (Table 1 and 2). One option for irrigating with limited water supplies incorporates the use of crops with lower water requirements. Soybean, edible bean, winter wheat, and sunflower are some crops that can be grown to save water. Cropping strategies for limited irrigation include growing a single crop that has a lower water requirement, splitting fields into two or more crops that have different peak water needs, switching to dryland forage production, and implementing crop rotations.

Crops such as corn, soybean, and wheat have different timings for peak water use (Figure 3). With low capacity wells, planting multiple crops with smaller area allows for water to be applied at amounts and

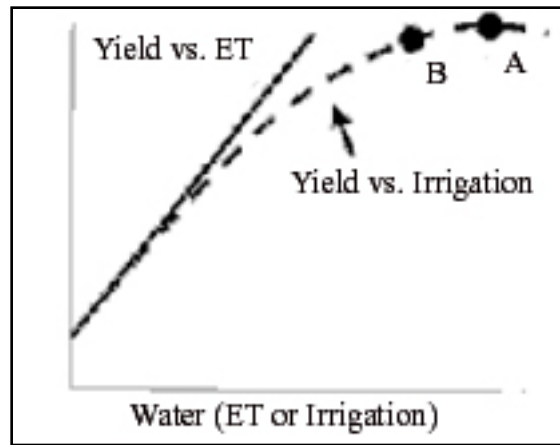


Figure 2. Generalized Yield vs. ET and Yield vs. irrigation production functions

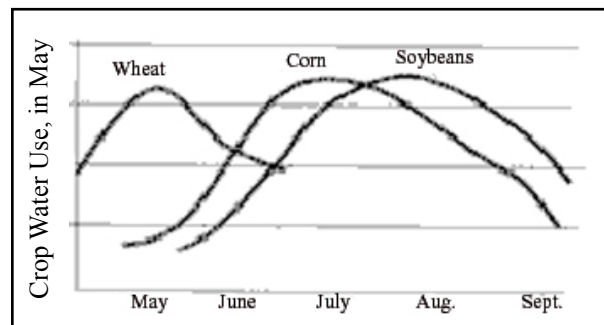


Figure 3. Example of daily ET during the growing season

times when the crop needs the water. The net effect of irrigating less area at any one point in time is that ET demand of that crop can be better met. If capacities are increased by splitting acres into crops with different water timing needs, management can be done to replace stored soil moisture rather than maintaining soil moisture near field capacity in anticipation of peak crop ET, since the system will not meet ET. This strategy allows the user to take better advantage of natural precipitation.

Another option is crop rotations, which spread the irrigation season over a greater period as compared to a single crop. When planting multiple crops such as corn and winter wheat

under irrigation, the irrigation season is extended from May to early October as compared to continuous corn, which is predominantly irrigated from June to early September. This practice allows less water to be spread throughout the season, while maintaining full irrigation to both crops. Schneekloth et al. (1991) found that when limited to 6 in of water, corn following wheat, yielded 13 bu/acre (8%) more than continuous corn. The increase grain yield following wheat was due to an increase in stored soil moisture during the non-growing season. This stored soil moisture provided an increase in the water available for ET during the growing season.

Several rotations for dryland production have been shown to decrease irrigation water requirements in northeast Colorado (Peterson et al., 2002). Some common crop rotations used in dryland agriculture for water conservation are shown in Table 4. Because irrigation is essentially dryland agriculture with an additional source of water supply, it is possible to use dryland rotations for water conservation purposes, even in irrigated agriculture.

Under limited irrigation, switching to dryland production may be one option for salvaging a

marketable commodity and maintaining soil cover (CSU, 2003). Dryland production should be such that it is a profitable enterprise. If dryland production is unprofitable, producers should consider planting a cover crop such as oats, wheat, triticale or millet the first year and then follow up with a dormant season planting of perennial grasses during the period from March to mid-May. Alternatively, a no-till dryland annual forage crop such as hay millet or sorghum-sudangrass may be a better fit if harvested forage is more important in the long term than permanent pasture (CSU, 2003).

Other options for irrigating under limited water supply include delaying irrigation until critical growth stages (Al-Kaisi and Broner, 1992), managing

Examples: Limited Irrigation Options in Burlington

Assume an irrigation well in Burlington is limited to 14 in of water in a given year. A producer can irrigate all corn or irrigate some corn and plant a lower water use crop such as dry beans. Corn requires 17.3 in of gross irrigation (85% efficiency) and dry beans require 9.3 in.

Here are several options a producer can consider under limited water supplies:

Option 1: If the well capacity is limited, a producer can raise 80% of their area to irrigated corn and the remainder in dryland production or leave idle.

Option 2: The producer can also plant 100% of their area to corn and apply only 80% of the irrigation required for maximum production.

Option 3: Another option is to split the field into corn and bean production. This means that 50% of the area is dry bean and 50% is corn and the maximum water requirement is applied to the entire area within the limited water supply.

Option 4: Revert all land to a lower water use crop such as dry beans.

Option 5: Revert all land to dryland production of crops such as sorghum.

Table 4. Crop rotations for water conservation

Common Dryland Crop Rotations

Wheat-Fallow
 Wheat-Hay Millet-Fallow
 Wheat-Wheat-Corn-Soybean-Sunflower-Pea
 Wheat-Corn-Fallow
 Wheat-Corn-Proso-Fallow
 Wheat-Corn-Proso
 Wheat-Sorghum-Fallow
 Wheat-Corn-Soybean
 Wheat-Wheat-Corn-Soybean
 Wheat-Wheat-Sorghum-Soybean

the soil profile to capture natural precipitation through proper tillage and crop residue management (see Information Sheets No. 8 and 9), and through proper timing and amount of water application through irrigation scheduling (see Information Sheet No. 10).

Producers must determine what the economic tradeoffs are for different limited irrigation options. The advantages and disadvantages of any particular option will depend on a producer's situation and their goals. Schneekloth and Norton (2001) report on a variety of water management practices for limited irrigation that were conducted on six irrigation sites in southwestern Nebraska over a five year period.

References

- Al-Kaisi, M.M. and I. Broner. 1992. Crop Water Use and Growth Stages. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.715. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04715.html
- Bauder, T., R. Waskom, J. Schneekloth, J. Alldredge. 2003. Best Management Practices for Colorado Corn. Colorado State University Cooperative Extension. Colorado State University, Fort Collins, Colorado.
- Broner, I., J. Schneekloth. 2003. Seasonal Water Needs and Opportunities for Limited Irrigation for Colorado Crops. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.718. Colorado State University, Fort Collins, CO. www.ext.colostate.edu/pubs/crops/04718.html .
- Broner, I. 1991. Center-Pivot Irrigation Systems. Colorado State University Cooperative Extension Crop Series Irrigation No. 4.704. Colorado State University, Fort Collins, CO. <http://www.ext.colostate.edu/pubs/crops/04704.html> .
- Colorado State University. 2003. Cropping Options for Limited Water Supplies in Northeast Colorado, 2003. Colorado State University, Soil and Crop Sciences, Fort Collins, CO. www.colostate.edu/Depts/SoilCrop/drought.htm .
- Croissant, R.L., J.W. Echols. 2003. Planting Guide for Field Crops. Colorado State University Cooperative Extension Crop Series Irrigation No. 0.103. Colorado State University, Fort Collins, CO. <http://www.ext.colostate.edu/pubs/crops/00103.html> .
- Hergert, G.W., J.P. Schneekloth, and N.L. Klocke. 1991. Stretching Limited Water Supplies. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991, North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.117-121.
- Howell, T.A. 1992. Evapotranspiration and Irrigation Capacity. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.9-13.
- Lamm, F. 2003. Corn Production in the Central Great Plains as Related to Irrigation Capacity. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.151-165.
- Lamm, F. 1997. Improvements in Irrigation Efficiency. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4, 1997, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.49-52.
- Martin, D., N. Klocke, G. Hergert. 1992. Planning for Deficit Irrigation. Proceedings of Central Plains Irrigation Short Course and Exposition. February 4-5, 1992, Goodland, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.49-64.
- Peterson, G.A., D.G. Westfall, F.B. Peairs. 2002. Sustainable Dryland Agroecosystem Management. Colorado State University, Fort Collins, CO. www.colostate.edu/Depts/SoilCrop/dryland/dryland.htm .
- Rogers, D.H. 2002. Cropping Strategies with Water Resource Constraints. Proceedings of Central Plains Irrigation Short Course and Exposition. February 5-6, 2002, Lamar, Colorado. Central Plains Irrigation Association, Colby, Kansas. pp. 74-79.
- Schneekloth, J.P. 2003. Management Strategies for a Limited Water Supply. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.109-118.
- Schneekloth, J.P. and D.A. Kaan. 2003. Determining Crop Mixes for Limited Irrigation. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.143-150.
- Schneekloth, J.P., N.A. Norton, R.T. Clark, N.L. Klocke. 2001. Irrigating for Maximum Economic Return with Limited Water. University of Nebraska Lincoln Cooperative Extension. Institute of Agriculture and Natural Resources. www.ianr.unl.edu/pubs/water/g1422.htm .

Schneekloth, J.P. and N.A. Norton. 2001. Living with limited water in southwest Nebraska. Proceedings of the 2001 Central Plains Irrigation Shortcourse and Exposition, Kearney, Nebraska. Febr. 5-6, 2001. pg 18-28.

Schneekloth, J.P., N.L. Klocke, G.W. Hergert, D.L. Martin and R.T. Clark. 1991. Crop Rotations With Full and Limited Irrigation and Dryland Management. Trans. of the ASAE. Vol. 34(6):2372-2380.

Stone, L.R. 2003. Crop Water Use Requirements and Water Use Efficiency. Central Plains Irrigation Short Course and Exposition. February 4-5, 2003, Colby, Kansas. Central Plains Irrigation Association, Colby, Kansas. pp.127-133.